LBS 2016

13th Conference on Location-Based Services

Vienna, 14–16 November 2016

Proceedings of the

13th International Conference on Location-Based Services

Georg Gartner and Haosheng Huang (Editors)

Vienna, Austria

November 14–16, 2016

ICA ACI

ICA Commission on Location Based Services

TU WIEN

cartography

Editors

Georg Gartner, georg.gartner@tuwien.ac.at

Research Group Cartography

Vienna University of Technology

Haosheng Huang, haosheng.huang@geo.uzh.ch

Department of Geography

University of Zurich

This document contains the online proceedings of the 13th International Conference on Location-Based Services (LBS 2016), held on November 14–16, 2016 in Vienna, Austria.

The conference was organized by the ICA Commission on Location-Based Services, and the Research Group Cartography at the Vienna University of Technology, with the endorsement of the following organizations: International Cartographic Association (ICA), Association of Geographic Information Laboratories for Europe (AGILE), International Association of Geodesy (IAG), International Federation of Surveyors (FIG), and Deutsche Gesellschaft für Kartographie (DGfK).

Additional papers from this conference were published in:

– Progress in Location-Based Services 2016, Lecture Notes in Geoinformation and Cartography, Georg Gartner and Haosheng Huang (eds.) (2017), Springer-Verlag, Berlin/Heidelberg.

Type setting of the chapters by the authors,
processed by Haosheng Huang.

Think before you print!

ISBN 978-1-907075-02-5

Table of Contents

Section I: Outdoor and Indoor Navigation

Section II: Positioning

Section III: Mobility Analysis

Section IV: VGI, Social Media, and Spatial-Temporal Analysis

Section V: LBS Applications

Recent Advances and Challenges in the Development of Landmark-based Pedestrian Navigation Systems using OSM

Anita Graser

AIT Austrian Institute of Technology, Vienna, Austria

Extended Abstract

Literature shows that pedestrian navigation systems profit from including landmarks into navigation instructions (Ross et al. 2004). Landmarks serve as reference points supporting navigation decisions (Millonig & Schechtner 2007). Still, today's publicly available pedestrian navigation systems continue to use paradigms developed for car navigation, which use only street names and street network geometry to generate turn-by-turn instructions such as "In 500 meters, turn right into Main Street". In order to allow navigation by landmarks, it is necessary to provide more information (Elias 2003) and connect it to the pedestrian route in meaningful ways using a landmark navigation model (LNM). Current research aims to finally bring landmark-based navigation to the end user (Rousell et al. 2015, Graser 2016a) using data from OpenStreetMap (OSM). OSM is open and globally available and contains both information about the pedestrian network, as well as potential landmarks. Using OSM ensures that the LNM is widely applicable rather than restricted to a certain area with exceptional data sources.

This work summarizes recent advances, including our own (Graser 2016a, Graser 2016b, Naumann et al. 2016) and related publications, and discusses open challenges in the development of landmark-based pedestrian navigation systems using OSM. Landmark-based pedestrian navigation systems require the development of algorithms covering three main stages: 1) generating a suitable pedestrian routing graph, 2) extraction, weighting, and selection of landmarks based on their suitability and 3) generation of landmark-based navigation instructions. In the following we describe the advances and major challenges of the three stages.

Published in "Proceedings of the 13th International Conference on Location-Based Services", edited by Georg Gartner and Haosheng Huang, LBS 2016, 14-16 November 2016, Vienna, Austria.

A graph dedicated to pedestrian routing consists of sidewalks, road crossings, squares or plazas and – only in case no sidewalks are available – roads and paths themselves as they are used for vehicle routing. In order to construct such a graph from OSM, it is necessary to deal with different representations of pedestrian infrastructure. Most notably, sidewalks can be represented as either separate line features or as attributes of the corresponding road feature. A suitable algorithm therefore has to construct sidewalks from attributes (Naumann et al. 2016) and be able to merge both representations, which is still an open issue. Furthermore, a pedestrian routing graph should also enable realistic crossing of open spaces, such as squares and plazas. Different approaches, including visibility graphs (Graser 2016b) have been proposed to tackle this issue.

Using landmarks from OSM requires the automatic extraction of a set of potential landmarks, from which the most suitable landmark is subsequently selected. Potential landmark features can be points, lines, or polygons. Current landmark selection algorithms deal with points and polygons (Rousell et al. 2015, Graser 2016a), but so far ignore linear features such as rivers. Another open issue is how to determine the visibility of landmarks from a certain decision point. Current approaches using line of sight estimation (Rousell et al. 2015) are computationally expensive and have issues dealing with potential landmarks which are modeled as points within polygons, such as multiple shops within a big building. On a similar note, selecting the most suitable landmark is complicated by the fact that not all sides of a building have the same visual salience. For example, a hotel might stand out if approached from the front but less so if approached from a different side. To the best of our knowledge, this issue has not been solved in any of the OSM-based LNMs.

Experiments using basic "car navigation" methods to generate instructions, have shown that these tend to produce too many navigation instructions, often in short succession. It is therefore necessary to develop algorithms to identify unnecessary instructions (Graser 2016a) or otherwise reduce the number of navigation instructions. While computation of prepositions (typically "before", "at" and "after") is straightforward for point landmarks, it is less obvious for polygon landmarks. The polygon centroid can serve as a generalization (Graser 2016a) but this can lead to suboptimal results for bigger polygon landmarks.

References

Elias B (2003) Determination of landmarks and reliability criteria for landmarks, in 'Proceedings 5th Workshop on Progress in Automated Map Generalization'.

Graser A (2016a) Developing an Open Pedestrian Landmark Navigation Model. presentation at FOSS4G2016, Bonn, Germany.

Graser A (2016b) Integrating open spaces into OpenStreetMap routing graphs for realistic crossing behavior in pedestrian navigation. GI_Forum – Journal for Geographic Information Science, 1-2016, 217-230.

Millonig A, Schechtner K (2007) Developing landmark-based pedestrian–navigation systems, Intelligent Transportation Systems, IEEE Transactions on 8(1), 43-49.

Naumann S, Graser A, Straub M (2016). Converting OSM data into a routable graph for pedestrians. presentation at EURO2016, Poznan, Poland.

Ross T, May A, Thompson S (2004) The use of landmarks in pedestrian navigation instructions and the effects of context, in 'Mobile Human-Computer Interaction-MobileHCI 2004', Springer, pp. 300-304.

Rousell A, Hahmann S, Bakillah M, Mobasheri A (2015) Extraction of landmarks from OpenStreetMap for use in navigational instructions, in 'Proceedings of AGILE 2015', Lisbon.

A multidimensional model for personalized landmarks

Eva Nuhn*, Sabine Timpf*

*Geoinformatics Group, Institute for Geography, University of Augsburg, Alter Postweg 118, 86169 Augsburg, {eva.nuhn, sabine.timpf}@geo.uni-augsburg.de

Routing services for pedestrians play an important role in everyday life. Nowadays routing directions are provided mostly on smart phones to support various wayfinding tasks such as exploratory travel in an unknown environment (e.g., as a tourist) as well as travelling towards a novel destination (Wiener et al., 2012). Studies in cognitive psychology have shown that even the shortest routing direction given by humans refers to special objects, i.e. landmarks (Daniel and Denis, 1998; Lovelace et al., 1999). By contrast, today's routing services calculate some optimal route from any start to any destination and guide the user with the help of a sequence of instructions. A few Points of Interest (POIs) currently are included in navigation services (e.g. petrol stations or churches) to provide additional information. However, they are not used as an integral part of the routing instructions, nor do they influence the selection of the route.

In this research we explore the notion of landmarks being integrated into and influencing the computation of the route. Personalized routing instructions require an assessment of the objects in the database for usefulness for a specific person as well as an integration of personal information. Although research on the objective spatial characteristics (e.g. Sorrows and Hirtle, 1999; Raubal and Winter, 2002) of landmarks exists, it is still not clearly defined what exactly a landmark is for a specific person. Persons add salience to geographic objects due to their knowledge, background, interests and preferences. Current approaches and existing frameworks do not incorporate this fact. Although some researchers (Götze and Boye, 2016) propose a personalized salience model they do not incorporate personalization factors within their model, nor do they investigate the integration of personal information into route selection. Hence, the challenge of our research is twofold: the first concern is a formal or standardized model of landmarks taking into account a personalization factor. The second problem is in integrating personalized

LBS 2016
13th Conference on Location-Based Services
Vienna, 14–16 November 2016

Published in "Proceedings of the 13th International Conference on Location-Based Services", edited by Georg Gartner and Haosheng Huang, LBS 2016, 14-16 November 2016, Vienna, Austria.

landmark data for inclusion in the routing algorithm. This paper tackles these challenges by proposing a multidimensional model for landmarks.

In order to determine whether a geographic object is useful for a specific person four dimensions are considered within the model: the established ones proposed by Sorrows and Hirtle (1999), i.e. visual, semantic and structural dimensions and, in addition, a personal dimension of landmarks. For each dimension attributes are defined (e.g. color and façade area for the visual dimension), which determine the usefulness of an object as a landmark.

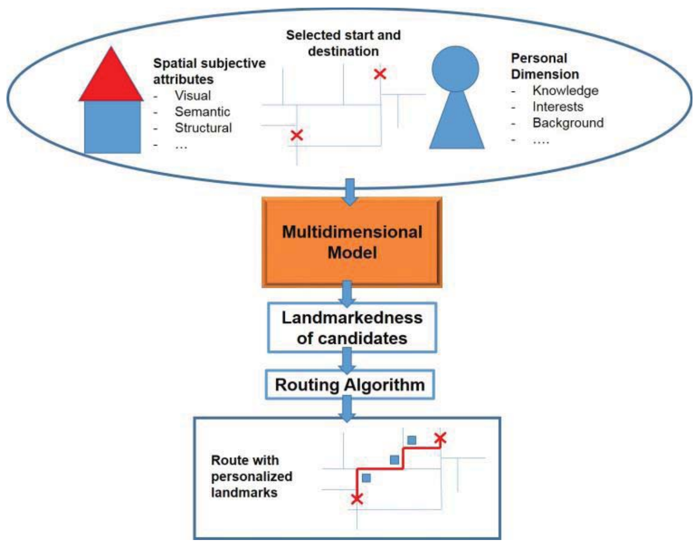


Figure 1. Model configuration.

We propose three different inputs to get the values for the model attributes (see fig. 1): spatial objective attributes of landmark candidates, start and destination of the route and a user profile. The user profile includes the inputs for the attributes of the personal dimension: the spatial knowledge of the user, her interests (e.g. interest in architecture) and her background (i.e., demographic data like gender, age, hometown and education). The model allows for the assessment of the inputs and the determination of their effect on the landmarkedness or salience (Caduff and Timpf 2008) of a landmark candidate. The result of the model is a measure of the personal salience of a landmark candidate for a specific person. The measure can then be integrated in the generation of a route between the defined start and destination, i.e. it can be introduced in a shortest path algorithm. The result of the routing algorithm is an optimal route in terms of personal landmarks.

References

Daniel, M.-P. and Denis, M. (1998): Spatial descriptions as navigational aids: A cognitive analysis of route directions. Kognitionswissenschaft 7(1): 45-52.

Caduff, D. and Timpf, S. (2008): In the assessment of landmark salience for human navigation. Cognitive Processing 9(4): 249-267.

Götze, J. and Boye, J. (2016): Learning Landmark Salience Models from Users' Route Instructions. Journal of Location Based Services 10(1): 47-63.

Lovelace, K. L., Hegarty, M. and Montello, D. R. (1999): Elements of good route directions in familiar and unfamiliar environments. In: Freksa, C. and Mark, D. M. (eds), Spatial information theory. Cognitive and computational foundations of Geographic Information Science. Springer, pp: 65-82.

Raubal, M. and Winter, S. (2002): Enriching wayfinding instructions with local landmarks. In: Egenhofer, M. J. and Mark, D. M. (ed), Geographic information science. Lecture Notes in Computer Science Springer, pp: 243 - 259.

Sorrows, M. E. and Hirtle, S. C. (1999): The nature of landmarks for real and electronic spaces. In: Freksa, C. and Mark, D. M. (eds), Spatial information theory. Cognitive and computational foundations of geographic information science. Springer, pp: 37-50.

Wiener, Jan M, Simon J Büchner, and Christoph Hölscher. 2009. "Taxonomy of Human Wayfinding Tasks: a Knowledge-Based Approach." Spatial Cognition & Computation 9 (2): 152–65.

Cognitive subdivisions in outdoor navigation

Mahsa Sadat Naseri, Farid karimipour

School of Surveying and Geospatial Engineering, College of Engineering, University of Tehran

Abstract. Navigation aids provide users with a route as a sequence of turn by turn instructions, each of which guides the user from one decision point to the next. Along the extensive research on enriching navigation aids with the elements of spatial cognition, this research provokes the idea of including cognitive subdivisions of space in outdoor navigation. As the first step, we present the results of a field study to investigate the influence of cognitive subdivisions on human navigation process.

Keywords. *Spatial cognition, Outdoor navigation, Spatial knowledge, Cognitive map, Navigation instruction*

1. Introduction

Navigation aids provide users with a route as a sequence of turn by turn instructions, each of which guides the user from one decision point to the next. Such geometric-based instructions result in a passive exploration of the environment, which has the least influence on improving spatial knowledge of the user. Instead, humans actively employ different forms and representations of spatial information in the navigation procedure. They depend on their cognitive representation of space (in the form of landmark, route, and survey knowledge) to perform navigational tasks in large scale environments (Dillon et al., 1993; Golledge, 1999).

There has been extensive research on enriching navigational aids with the elements of spatial cognition in order to improve their efficiency. However, as described in Section 2.2., they mostly consider landmark and route knowledge. Although survey knowledge is a key element of humans' spatial

Published in “Proceedings of the 13th International Conference on Location-Based Services”, edited by Georg Gartner and Haosheng Huang, LBS 2016, 14-16 November 2016, Vienna, Austria.

mental representation (Tversky, 1993), to the best of our knowledge, there has not been considerable research on including such knowledge in outdoor navigation.

This research provokes the idea of including cognitive subdivisions of space in outdoor navigation. As Kuipers (1978) stated, information in mind is hierarchical; and the sequences of containing districts about the desired places are checked from the "top down" to find the smallest district containing the origin and destination. As we have all experienced, such cognitive subdivisions can contribute in our navigational tasks.

As the first step of this idea, this paper presents the results of a field study to investigate the influence of cognitive subdivisions on human navigation process. For this, Section 2 reviews the existing related research on enriching navigational aids with the elements of human spatial cognition. Section 3 provides details about designing the field study and presents the statistical results. Finally, Section 4 concludes the paper and introduces the future steps of the research.

2. Enriching Navigational Aids with the Elements of Human Spatial Cognition: State-of-the-Art

Wayfinding is one of the substantial human activities in daily life, that concerns about how to reach from a current location to a desired place (Timpf et al., 1992). According to Lynch's definition of wayfinding as "a consistent use and organization of definite sensory cues from the external environment" (Lynch, 1960), wayfinding is a complex task in which people apply several skills such as various spatial, cognitive, and behavioral abilities (Raubal & Winter, 2002). Wayfinding involves organizing multiple behavioral and cognitive abilities that are spatially distributed. Therefore, it is influenced by humans' sensory abilities and environmental factors.

On the other hand, the mode of environment exploration influences wayfinding behaviors (Feldman & Acredolo, 1979). While exploring the environment, humans update their spatial knowledge and cognitive map, which support their future wayfinding behavior. Although active exploration of the environment improves spatial information, increasing use of navigation applications has led to a modern passive exploration of the environment.

There has been a significant body of research on considering cognitive representations of space —in the form of landmark, route, and survey knowledge (Siegel & White, 1975) in the navigation procedure. At the level of landmark knowledge, (Raubal & Winter, 2002) proposed an approach to enrich wayfinding instructions with local landmarks, which automatically extracts local landmarks from datasets and integrates them in wayfinding instructions. (Duckham et al., 2010) developed a weighting model for generating routing instructions that annotate simple routes with references to landmarks. (Klippel & Winter, 2005) proposed an approach to formalize the structural salience of objects along routes, upon which landmarks are automatically integrated into route directions. On the other hand, at the level of rout knowledge, (Tomko et al., 2008) introduced a criterion to rank streets in a network, which reflects the interaction of people with the streets.

There has not been considerable research on including survey knowledge in outdoor navigation. An exception is a line of research by Zelatanova and her colleagues (Zlatanova et al., 2013; Kruminaite, 2014; Krūminaitė & Zlatanova, 2014) to develop a conceptual model for determination of space subdivisions (as a form of survey knowledge) in indoor navigation.

3. Field Study: Design and Results

A field study was designed to investigate the influence of cognitive subdivisions on human navigation process. We paid particular attention to the role of landmarks and subdivisions mentioned in route directions and how often they were effective in acquiring spatial knowledge by comparing the searching time and area.

The participants were divided into two groups of familiar and unfamiliar with the area. For the unfamiliar group, the influence of cognitive subdivisions on navigation were investigated: They were provided information to navigate to certain destinations using (1) plain turn by turn instructions, (2) instructions enriched with local landmarks and (3) instructions enriched with subdivisions. For the familiar group, on the other hand, they were asked to provide instructions for navigating to certain destinations in order to see how often and what type of cognitive elements they use. In this case, should they include cognitive subdivisions in their instructions, they were asked to sketch the boundary of the subdivisions on the map. Note that although individual differences are critically significant to perception of environmental (Li & Klippel, 2014), this research is largely mute with respect to this.

In general, based on the results of the questionnaires, all participants ─no matter if they are familiar or unfamiliar with the environment─ reported that use of subdivisions in navigation instructions improves their wayfinding efficiency and helps them to remember mental representation and make it more accurate. In other words, this type of information develops a connection between the spatial experience and navigation instruction, which means that cognitive subdivision-based instructions lead to learning the environment and improving the navigation process.

Specifically, evaluating the results show that:

- Enriching the navigational instructions with cognitive subdivisions eases the navigation for the users with prior-knowledge of the subdivisions. In the case of unfamiliarity with the subdivisions, this information helps the users to acquire this knowledge and deploy it in future navigation systems. It means that cognitive subdivisions assist people to create a local cognitive representation which can support wayfinding and enrich their spatial mental representations.
- People often includes cognitive subdivisions in their instructions if they have prior-knowledge of the area. Interestingly, if they just got familiar with a subdivision in the former series of questions, they immediately used them in providing navigation instructions in the latter.
- Users provides different boundary for subdivisions, but this imprecision does not affect their navigation. This is along with what (Tversky, 1993) states that everyday spatial descriptions used by people are not very precise, but they are frequently produced and readily understood.

4. Conclusion

This study investigates the influence of subdivision on navigation instructions. The results of the field study indicate that enriching navigational instruction by cognitive subdivisions lead to active exploration of the environment and assist memory in spatial information acquisition. We are now working on an approach to generalize the navigational instructions based on the knowledge of the user from the cognitive subdivisions.

References

Dillon, A., J. Richardson, et al. (1993). Space-the final chapter or why physical representations are not semantic intentions. Hypertext: A psychological perspective.

Duckham, M., S. Winter, et al. (2010). Including landmarks in routing instructions. Journal of Location Based Services, 4(1): 28-52.

Feldman, A. and L. Acredolo (1979). The effect of active versus passive exploration on memory for spatial location in children. Child development: 698-704.

Golledge, R. G. (1999). Wayfinding behavior: Cognitive mapping and other spatial processes, JHU press.

Klippel, A. and S. Winter (2005). Structural salience of landmarks for route directions. Spatial information theory, Springer: 347-362.
Kruminaite, M. (2014). Space Subdivision for Indoor Navigation, TU Delft, Delft University of Technology.
Krūminaitė, M. and S. Zlatanova (2014). Indoor space subdivision for indoor navigation. Proceedings of the Sixth ACM SIGSPATIAL International Workshop on Indoor Spatial Awareness, ACM.
Kuipers, B. (1978). Modeling spatial knowledge*. Cognitive science, 2(2): 129-153.
Li, R. and A. Klippel (2014). Wayfinding Behaviors in Complex Buildings The Impact of Environmental Legibility and Familiarity. Environment and Behavior: 0013916514550243.
Lynch, K. (1960). The image of the city, MIT press.
Raubal, M. and S. Winter (2002). Enriching wayfinding instructions with local landmarks, Springer.
Siegel, A. W. and S. H. White (1975). The development of spatial representations of large-scale environments. Advances in child development and behavior, 10: 9.
Timpf, S., G. S. Volta, et al. (1992). A conceptual model of wayfinding using multiple levels of abstraction. Theories and methods of spatio-temporal reasoning in geographic space, Springer: 348-367.
Tomko, M., S. Winter, et al. (2008). Experiential hierarchies of streets. Computers, Environment and Urban Systems, 32(1): 41-52.
Tversky, B. (1993). Cognitive maps, cognitive collages, and spatial mental models. Spatial Information Theory A Theoretical Basis for GIS, Springer: 14-24.
Zlatanova, S., L. Liu, et al. (2013). A conceptual framework of space subdivision for indoor navigation. Proceedings of the Fifth ACM SIGSPATIAL International Workshop on Indoor Spatial Awareness, ACM.

Criteria for Selecting Small Sets of Alternative Routes in Constrained Free Space Scenarios

Sebastian Feld, Martin Werner, Claudia Linnhoff-Popien

Mobile and Distributed Systems Group, LMU Munich, Munich, Germany
sebastian.feld@ifi.lmu.de, martin.werner@ifi.lmu.de, linnhoff@ifi.lmu.de

Abstract. Recently, alternative routes have gained momentum in the creation of Location-Based Services. This paper gathers and sorts existing work regarding quality metrics of alternative routes and alternative graphs in road networks and discusses their commonalities. Based on this, the paper clarifies what challenges need to be tackled in order to create such metrics for constrained free space scenarios and discusses possible courses of action, opportunities, and limitations. The general goal of this paper is to stimulate the discussion on and the development of quality metrics for alternative routes and alternative graphs for constrained free spaces like pedestrian navigation, or even maritime or aviation scenarios.

Keywords. Alternative Routes, Alternative Graphs, Quality Metrics, Constrained Free Space, Indoor Navigation

1. Introduction

The technical progress in reducing the physical size of processing power, storage, and connectivity supports the enlarged spread of Location-Based Services (LBS) not only on powerful mobile devices like smartphones, but also on mobile robots or in distributed sensor networks. The importance of single computing devices vanishes and leads to an active construction of ubiquitous computing and the Internet of Things. Navigation is surely a central topic in LBS consisting, amongst others, of positioning, path finding, path representation, and (interactive) guidance. The calculation of a shortest path between two points in a street network is one of the most famous applications.

Routing in street networks is usually handled using a directed graph where edges represent streets and interconnections of streets represent nodes.

LBS 2016
13th Conference on Location-Based Services
Vienna, 14–16 November 2016

Published in "Proceedings of the 13th International Conference on Location-Based Services", edited by Georg Gartner and Haosheng Huang, LBS 2016, 14-16 November 2016, Vienna, Austria.

Another field of research and application is routing in constrained free space scenarios, i.e., wayfinding for subjects that can freely operate in a scenario like pedestrians in large buildings or characters in computer games. The main question is to find an appropriate map representation that handles the tradeoff between the map's simplicity and expressive power. Basically, the simpler the map the faster the algorithms can perform. On the other hand the scenario may suffer from missing details or imprecisions. There exist numerous considerations on how to create simple maps out of complex maps, consider topology-aware shape simplification, for example.

The calculation of shortest paths is widely investigated leading to speed-up techniques that enable continental-sized path finding in real-time applications. A further, much less examined, field of research is the question of how to calculate alternative routes and the subsequent creation of an alternative graph. An alternative graph is the aggregation of several alternative routes into one representation. Often, there are several highly different ways to traverse a map from a given start and to a goal that are nearly as optimal as the shortest path. Depending on the use case, the optimal path may not match the personal preferences of the concrete user, or the preferences may be hard to obtain or calculate. They may depend on local knowledge (Abraham et al., 2013), or contextual information like toll pricing, scenic value, fuel consumption, or the risk of traffic jams (Bader et al., 2011). Thus, true to the slogan “Human-in-the-loop”, we want to compute a set of good alternatives in order to let the user choose based on personal needs. Besides that, there are motivations for alternative routes for non-human users, i.e. robots, or as a background service: multiple mobile robots get different routes from start to goal to increase the chance that at least one robot will find the goal; proactive avoidance of bottlenecks; offline calculation of pathways for action forces like firefighters; non-player characters in computer games that tactically adapt their travel path. The task of calculating alternative routes and alternative graphs is quite difficult since there is no clear definition of what represents a good alternative; the topic is very subjective, almost philosophical.

Testing the quality of possible alternative routes and alternative graphs is not trivial and – at least for street network scenarios – in the focus of many researchers (Kobitzsch, 2013). There is much work on alternative routes and alternative graphs in streets networks, but not for constrained free space scenarios like navigation in buildings, maritime navigation in harbors, pedestrian navigation, or airplane navigation. With this paper we want to close the gap and discuss the reasons why the proposed solutions for outdoor scenarios cannot directly be transferred to constrained free space scenarios. Our goal is to stimulate research and discussion on measures and target functions for comparing sets of routes in said constrained free space scenarios.

The remainder of this paper is structured as follows: After introducing the motivation of this paper, Section 2 introduces needed background including map representations, algorithms for calculating alternative routes, and existing quality metrics for alternative routes and alternative graphs in street networks. Section 3 discusses the transferability of the measures to free space scenarios and their mutual interference. Section 4 concludes the paper.

2. Background

This Section deals with the presentation of different ways to represent constrained free space scenarios and algorithms for calculating alternative routes. Based on this, existing measures for calculating the quality of alternative routes and alternative graphs in street networks are discussed.

2.1. Map Representations

Street networks form a graph structure in a quite natural way: streets are modelled as sequences of linear segments and crossings of streets as well as turning points inside a street are usually becoming a vertex of the graph. Then, the graph is an embedded and high-quality abstraction of the real abilities of movement in a street network.

For constrained free space, the situation is different. First of all, movements in all directions are possible. However, we might have some constraints regarding the possible movements, e.g., a mobile robot may only change movement by steering leading to smooth trajectories with bounded curvature. Dealing with such complicated objects is computationally demanding and often intractable. Therefore, trajectories are often modelled as polylines, that is, by points connected by linear segments. In the sequel, we will always assume that routes are given as polygonal lines and not as some parametrized curves.

Still, dealing with polylines in free space is difficult. An example is the optimization over all possible polylines for finding the shortest connection between two points. At this point, map representations come into play, which effectively reduce the space of possible movements for more efficient planning. Map representations involve the tradeoff between the map representation's ability to describe any given path in the building and the computational complexity of algorithms performing choices in the environmental model.

Recently, relatively free movement is being planned in the field of continuous planning. More classically, however, synthetic graphs are being used such that the paths through the graph represent possibly large sets of movements through constrained free space.

A very simple form of map representation is given by constrained grids. In this map representation, one chooses an arbitrary length and a regular grid which is then put over the map. The points of the grid represent vertices and two adjacent points in the grid are connected if and only if they are connected by free space. In occupancy grids, for example, a two-dimensional bitmap is being used to represent walkable space in one color (e.g., white) and obstacles in another color (e.g., black). Then, each pixel creates a vertex and two pixels are connected in the graph if they are both white and direct neighbors. At a first glance, grids are large and inefficient; however, as computers are actually able to manipulate large bitmaps, they can be very efficient in practice. Additionally, the graphs have bounded degree of 4 when connecting vertical and horizontal neighbors, or 8 including diagonals. Finally, the algorithms' performance depends only on the amount of free space and not on the complexity of involved geometry.

A second form of creating a graph representation of constrained free space is given by polygonal maps. For polygonal maps, the constraints are modelled as polygons and a graph is created by using vertices and edges of the polygons. There are several constructions for maps given as sets of such obstructive polygons. If, for example, all vertices of these polygons are connected as long as the direct line between them does only cross free space, we call it visibility graph. This representation has some good properties: for example, it can be relatively small for few and simple polygons and it contains all shortest paths between vertices of the involved polygons. However, it is not obvious, how this graph can be used for motion planning starting in arbitrary locations in free space and shortest paths in this graph tend to scrape along walls or walk in diagonals.

Another approach called navigation mesh is given by using a polygonal tessellation of free space and adding edges to a graph for each edge shared by two polygons meaning that one could go from one polygon to the other. In such constructions, each polygon represents some space and simple polygons have the advantage of having low degree in the resulting graph. Therefore, navigation meshes are often built from very simple polygons such as triangles or rectangles. In a sense, the grid-based approach is also a navigation mesh in which small and regular squares are being used for the polygons. There are some choices of building a graph representation from a navigation mesh: one could just represent each polygon as a vertex and connect neighboring vertices. When the polygons are convex, one often uses centers of the polygons' edges as navigation points leading to slightly better paths as they become embeddable into free space. However, the resulting paths often have an unusual shape. A third way of extracting a navigation graph from a navigation mesh is by traversing edges of the involved polygons. This leads, again, to wall-scraping behavior, which can have positive impact (e.g., knowing which obstacles are being passed) or negative impact (e.g., not being able to directly visualize the path) depending on the application.

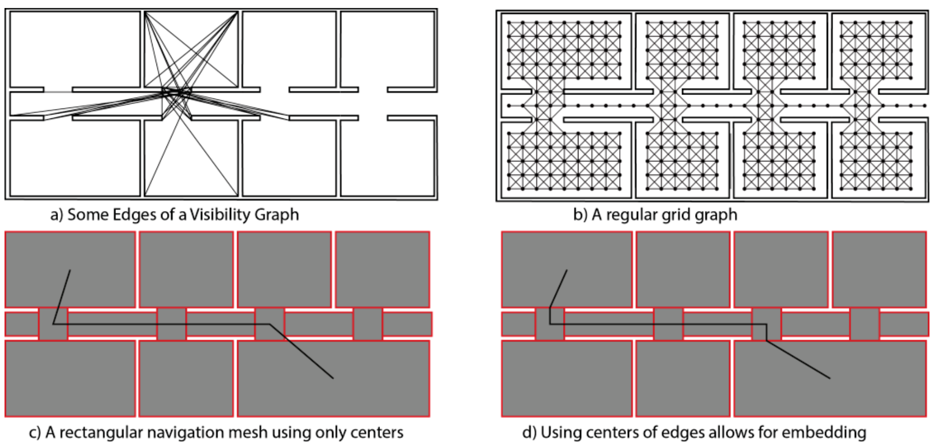


Figure 1. Examples of map representations, adapted from (Werner, 2014).

Figure 1 depicts examples for the three basic approaches in an indoor scenario. *Figure 1a* shows that the amount of edges in visibility graphs can get high very quick and that the average degree of vertices will be high, too. This effect is even worse, when GIS systems are being used in which round objects are tessellated into many line segments. A circular pillar can easily generate hundreds of additional lines. In contrast to that, a regular grid graph is depicted in *Figure 1b*. It has low-degree vertices, however, there are many of them. *Figure 1c* and *Figure 1d* depict a rectangular navigation mesh. In *Figure 1c* the shortest path is calculated only on the rectangles' center points leading to the situation that the lower-right line segment is not fully inside free space. In *Figure 1d*, however, the shortest path remains in free space due to the use of the middle points of the rectangle's edges and also the rectangles' convexity.

These basic approaches are being used to make path planning in constrained free space tractable and simple. However, they all have in common that their scale is limited. In this case, space subdivisions are commonly used to combine several “local” models in a general view. Usually, space is subdivided recursively (e.g., Binary Space Partitioning) or in a regular way (e.g., Grids) and local models can be combined to models that are small, but large enough to contain all relevant geometry.

Finally, reducing the combinatorial complexity of free space introduces inaccuracies as not all movements are being represented. From an observer perspective, one has to discuss, how a given trajectory is represented in the graph, and, from a planning perspective, one should consider post-processing to alleviate artifacts like diagonals, wall-scraping, and detours.

2.2. Algorithms for Calculating Alternative Routes

Finding alternative routes relies on the problem of calculating a single shortest path between two given points. Starting with Dijkstra’s algorithm from the year 1959 (Dijkstra, 1959), there are considerable extensions and speed-ups, see the survey (Bast et al., 2015), for example.

The next step is to calculate not a single shortest path, but multiple routes. The class of K-shortest-path algorithms (Eppstein, 1994, Yen, 1971) seem to solve the problem but they do not, since, in general, the resulting paths do not change significantly until a high value of k. An extension is to calculate k disjoint paths (Scott, 1997). That in turn introduces the notion of overlap, a very important term in the further course of this paper. Currently, there do not exist suitable implementations to efficiently enumerate the paths for continental sized road networks.

Another class of algorithms is based on multicriteria optimization, i.e the use of multiple edge weights like distance, travel time, or fuel cost. The idea is to calculate so-called Pareto-optimal paths, i.e. paths that have the lowest edge weights for at least one criterion (Martins, 1984, Delling & Wagner, 2009, Geisberger et al., 2010, Graf et al., 2010).

The penalty algorithm tries to compute alternative routes by iteratively calculating the shortest path and increasing certain edge weights (Chen et al., 2007). There are several improvements of the algorithm together with the use for generating alternative graphs (Bader et al., 2011).

Finally, there is a class of algorithms for creating alternative routes that uses via-nodes or plateaus (Abraham et al., 2010, Bader et al., 2011, Kobitzsch, 2013, Luxen & Schieferdecker, 2102, Werner & Feld, 2014). The basic idea is to concatenate a shortest path from a start to a supporting via-node with a shortest path from the said node to the goal. Additionally, there is a proprietary algorithm called choice routing by Camvit (Camvit, 2009).

2.3. Quality Metrics for Alternative Routes

The central reference for quality metrics for alternative routes is (Abraham et al., 2013), a paper that extends its predecessor (Abraham et al., 2010) by various extensions and an elaborate evaluation. The authors try to find good alternative routes and define an “admissible path” as a path that is substantially different to the reference path, not much longer than that, and that is natural without unnecessary detours. The just stated three properties have been defined formally and will be described successive:

1. **Limited Sharing**: The alternative path has to be significantly different to the reference path, i.e. the total length of the edges they share must be a small fraction of the reference route’s length.
2. **Local Optimality**: The alternative path must be reasonable, i.e. no unnecessary detours are allowed. Every local decision must make sense, so local optimality is given if every subpath up to a certain length is a shortest path.
3. **Uniformly Bounded Stretch**: The alternative path must not be much longer than the reference path, i.e. every subpath needs to have a good stretch. This condition also enhances local optimality, since there may be the case that a path has good high optimality, but a shortcut could skip an unnecessary part of the route.

Based on these prosaic descriptions, Abraham et al. formally define the class of paths to be found as “admissible alternative paths”. Let $G = (V, E)$ be a directed graph with nonnegative edge weights, with $|V| = n$ being the number of nodes and $|E| = m$ the number of edges. Given a path P in G, $|P|$ is the number of the path’s edges and $l(P)$ is the sum of the edge weights. Furthermore, $l(P \cap Q)$ is the sum of the edge weights shared by paths P and Q, and $l(P \setminus Q)$ is $l(P) - l(P \cap Q)$. Given two vertices, s and t, finding the shortest path − denoted by $Opt(s, t = Opt)$ − is called the point-to-point shortest path problem. Given three tuning parameters $0 < \alpha < 1$, $\epsilon \leq 0$, and $0 \leq \gamma \leq 1$, and a shortest path Opt between s and t, a s-t-path P is an admissible alternative if the following criteria are fulfilled:

1. **Limited Sharing**: $l(Opt \cap P) \leq \gamma \cdot l(Opt)$
2. **Local Optimality**: P is T-locally optimal for $T = \alpha \cdot l(Opt)$. A path P is T-locally optimal if every subpath P' of P with $l(P') \leq T$ is a shortest path
3. **Uniformly Bounded Stretch (UBS)**: P is $(1 + \epsilon)$-UBS. A path P has $(1 + \epsilon)$-UBS if for every subpath P' of P with end points s', t', the inequality $l(P') \leq (1 + \epsilon) \cdot l\big(Opt(s', t')\big)$ holds

Due to the fact that too many admissible paths can be found, Abraham et al. introduce a limited yet useful subset of the class “admissible alternative paths”, namely “single via paths”: Given a start s, a goal t, and a via-node v, a via path P_v is the concatenation of the shortest path from s to v and the shortest path from v to t. This definition is an unnecessary restriction, as Bader et al. (2013) will work out later on, but such routes have interesting properties. P_v has got the lowest stretch of all routes going through node v, and, more importantly, the local optimality can be violated just around node v. This fact will be used, amongst others, for further improvements of the conditions (Abraham et al., 2013).

The conditions just described are used as hard constraints for a not further defined target function $f(\cdot)$. This function is used to sort candidates and return the first admissible path. A possible target function may seek for routes having low “limited sharing”, high “local optimality”, and low “uniformly bounded stretch”. If the use case is to find multiple alternative routes, then just “limited sharing” needs to be calculated regarding the shortest path and all alternative routes already found. Both, “local optimality” and “uniformly bounded stretch” refer to only the path in question.

(Luxen & Schieferdecker, 2012) present an improvement of the algorithm of Abraham et al. regarding query times. The authors propose a fast algorithm that stores a small precomputed set of via-nodes for pairs of regions within the graph, i.e. they focus on a small candidate set to be tested efficiently. They base their via-node routing on top of Contraction Hierarchies (Geisberger et al., 2009, Bauer et al., 2010) and achieve routes with higher quality with faster query times while having negligible memory overhead.

Another improvement is done in (Kobitzsch, 2013), where the author motivates the contribution with the fact, that the selection process of the known via-node algorithm is unsatisfying, since testing all potential candidates proves expensive due to many shortest path queries. Existing algorithms order the candidates heuristically with potentially better candidates being discarded. Kobitzsch uses a different approach by making the viability check fast enough to test all potential candidates. Thus, the problem is reduced to a small graph representing all potentially viable alternative paths.

2.4. Quality Metrics for Alternative Graphs

The central reference for quality metrics for alternative graphs is (Bader et al., 2011), a paper that is based on Dees’ master’s thesis (Dees, 2010). Besides that, preliminary aspects have been published before in (Dees et al., 2010). The main concept is to compute a set of alternative routes which, in general, can share nodes and edges, and subpaths of the alternative routes can potentially be combined to new alternative routes. Thus, Bader et al. motivate and define the concept of an alternative graph (AG) as the union of several paths having the same start and goal as a compact representation of multiple alternative routes. They define several attributes quantifying the quality of an alternative graph using mathematical definitions of the graph structure and show that it is already NP-hard to optimize a simple objective function combining just two of the proposed attributes and therefore turn to heuristics. The three measures are described as follows:

1. **Total Distance**: This measure describes the extent to which the routes defined by the AG are non-overlapping. The maximum value is reached when the AG consists of disjoint paths only. The mathematical definition of total distance will need a scaling, since otherwise long non-optimal paths would be encouraged.
2. **Average Distance**: This measure describes the path quality as the average stretch on an alternative path. The mathematical definition will need an averaging in order to avoid a high weight to large numbers of alternative paths that are all very similar.
3. **Decision Edges**: This measure describes the complexity of the AG and is used to retain the representation easily understandable for human users.

After depicting the measures prosaically, we turn to the formal definitions. Let $G = (V, E)$ be a graph with an edge weight function $w: E \to \mathbb{R}_+$. Given a source node s and a target node t, an AG $H = (V', E')$ is a graph with $V' \subseteq V$ such that for every edge $e \in E'$ there exists a simple s-t-path in H containing e. For every edge (u, v) in E' there must be a path from u to v in G and the edge weight $w(u, v)$ must be equal to the path's weight. $d_G(u, v)$ denotes the shortest path distance from u to v in G, analog $d_H(u, v)$ is the shortest path distance from u to v in H. Based on that, the formal definition of the quality metrics for a given alternative graph $H = (V', E')$ is:

Total Distance: $$\sum_{e=(u,v)\in E'} \frac{w(e)}{d_H(s,u) + w(e) + d_H(v,t)}$$

Average Distance: $$\frac{\sum_{e\in E'} w(e)}{d_G(s,t) \cdot totalDistance}$$

Decision Edges: $$\sum_{v\in V'\setminus\{t\}} outdegree(v) - 1$$

As already stated above, it is NP-hard to optimize a reasonable combination of the measures just explained, thus Bader et al. use heuristics to compute an AG. They calculate a shortest path, insert it into the AG, gradually calculate further alternative paths, and insert them greedily into the AG regarding the optimization of a target function.

(Radermacher, 2012) is a bachelor's thesis that efficiently implements the concept of (Bader et al., 2011). Basically, Radermacher combines a Multi-Level-Dijkstra (Delling et al., 2011) with the penalty method that is augmented with path analysis.

(Kobitzsch et al., 2013) present a viable implementation of (Bader et al., 2011) such that it can be used interactively. They modify the penalty algorithm through a multi-level partitioning together with the penalization scheme for the route and its adjacent edges. Furthermore, they modify the function that tests if a candidate is feasible and introduce further speed-ups using Customizable Route Planning (Delling et al., 2011, Delling & Werneck, 2013) and Dynamic Level Selection. Kobitzsch et al. state that (Bader et al., 2011) compute up to 20 paths and perform a selection based on priority terms afterwards. Since Kobitzsch et al. focus on query times, they take a different approach by considering the potential value to the alternative graph. Thus, a path must offer at least one deviation of a certain length, and the detours are checked for their stretch.

At the same time, (Paraskevopoulos & Zaroliagis, 2013) has been published proposing an algorithm that creates alternative graphs with higher quality. They suggest a pruning stage preceding the heuristic method for finding alternative paths, and introduce filtering and fine tuning of both, plateau algorithm and penalty algorithm.

3. Quality Metrics in Constrained Free Space

The previous section illustrated related work regarding quality metrics for alternative routes and alternative graphs in street networks. Abraham et al. state that a proper alternative route should be substantially different from a reference path ("limited sharing"), should not have unnecessary detours ("local optimality"), and should be not much longer than the shortest path ("uniformly bounded stretch"). Similarly, Bader et al. proposed that a good alternative graph should have low overlap of the included routes (high "total distance"), low stretch of included alternatives (low "average distance"), and low complexity (few "decision edges").

In this section, we discuss the transferability of the measures from road networks to constrained free space scenarios. From a general point of view, we can consider only four instead of six measures, since some measures of alternative routes and alternative graphs are similar.

In the following, "limited sharing" and "total distance" will get a unified treatment as they both limit the amount of edges that alternatives have in common. Similarly, "uniformly bounded stretch" and "average distance" are treated together as they both rely on the idea that alternatives should not be excessive in length. The measure of "local optimality", that means even subpaths should be short, and the idea of counting "decision edges" are the remaining concepts from literature to be adapted for constrained free space scenarios.

3.1. Limited Sharing & Total Distance

One central idea for both, alternative routes and alternative graphs, is linked to the length of the edges that alternatives have in common. The terminology was "limited sharing" for alternative routes and "total distance" for alternative graphs. The central difference between these two ideas is that "limited sharing" applies to pairs of paths while "total distance" measures whether the integration of a given path into an already existing alternative graph is sensible. In practice, optimizing an alternative graph using this measure depends on the ordering of alternatives considered.

The most important question for the application of these measures in free space scenarios is how overlap or sharing can be defined in an unambiguous way.

Even the implementation of a simple shortest path algorithm such as Dijkstra's algorithm tends to keep the shortest path as much as possible to the left (or right). As constrained free space scenarios potentially have plenty of equal-length paths, this tendency realizes to significantly different shortest path from A to B and vice versa. *Figure 2* illustrates this idea.

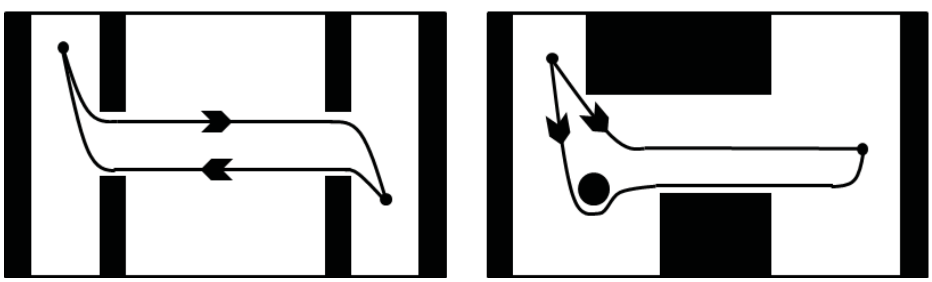


Figure 2. Two examples representing the problem of non-overlapping routes due to implementation details.

The reason why the overlap definitions inspired by street networks is not applicable lies in the high ambiguity of equivalent routes of equivalent meaning. For example, the four routes depicted in *Figure 3* are clearly different albeit human users would discuss whether the two middle routes are actually alternatives. If the map was at continental scale such that no interaction between both routes is to be expected (e.g., airplane navigation), we would accept them as proper alternatives. If, however, this is an indoor scenario where pedestrians on these two routes can see and talk to each other, we would likely identify them as equivalent.

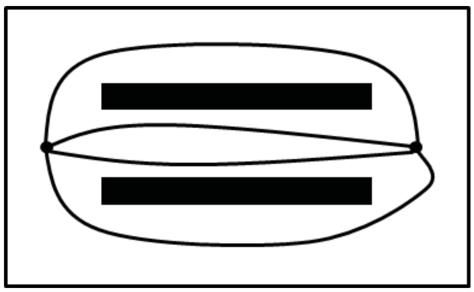


Figure 3. Three or four alternative routes, based on the map scale.

In order to combat this problem, we need a way to decide which points of two different routes actually "overlap" in an application-dependent and map-dependent way. We identify the following three general strategies to extend the measures of overlap to our scenario.

As the original measures were defined for paths in graphs, it would be desirable to consistently map all free space paths to a graph such that different edges mean semantically different movements. Then, two paths that share a specific semantic movement in a building, like going through a specific hallway, will have increased overlap.

There are many ideas of automatically or manually creating such graphs for specific classes of constrained free space navigation. However, realizing a graph means to realize a tradeoff between map complexity and expressiveness. When, for example, a long hallway is represented by a single edge such that all users of the hallway have overlap, this edge can hardly get a sensible embedding into the map. If, however, the graph shall get a visual representation in the map, the complexity will be higher and overlap will become more and more unclear. For the concepts to automatically generate navigation graphs including navigation meshes, straight skeletons, grid graphs and the like, the number of edges and at the same time the quality of a possible overlap measurement depends on the complexity of the involved geometry. Therefore, a general solution to define overlap will not be reached. However, if the application uses any of these techniques anyways, one should consider the possibility of using the graph at least to some extent. Obvious ideas to define a (potentially ambiguous) overlap is to consider the joint traversal of polygons or the identical sequence of passed edges.

A second approach would be the identification of connected spaces such that overlap can be defined from the spaces that two routes have in common. From a general point of view, this amounts to some sense of map topology. Ideally, it would be great if every point was part of one and only one such connected space. This is not always the case, but room names in buildings are a remarkable example where this works. Another sense of topology can be generated from homotopy of routes. That is, two routes have overlap as long as they can be continuously deformed into each other inside a map (see *Figure 3*). However, this concept is, again, a binary one and does not distinguish between small obstacles and large detours. Additionally, homotopy is only applicable to pairs of routes and, therefore, not obviously applicable in alternative graph situations.

This fact motivates the third general approach to extend overlap to constrained free space: We can just replace the binary and counting nature of all overlap measures by a fully continuous framework in which distances of routes are used to assess overlap. This is elegant in the sense that the classical graph-based definitions of overlap can be seen as special cases in which the distance is zero or non-zero. A threshold can then be used to differentiate overlapping and non-overlapping trajectories. On the other hand, one should also consider the integration of continuous measures of overlap in alternative route generation.

3.2. Uniformly Bounded Stretch & Average Distance

Bounding the stretch of a path is a straightforward technique to limit the amount of detours while generating alternative routes. However, when stretch is chosen too small, some alternatives cannot be uncovered. The ideal amount of stretch depends on the application, for example, how many alternatives will be used in the next step, and the environment: At an airport, longer alternatives might be acceptable and lead to completely different journeys through shops; in manufacturing and robotics, however, every detour costs money.

Additionally, the length of a route in a map representation for constrained free space can be highly different from the length in reality. For example, navigation meshes often use central points of larger polygons or edges as waypoints. This makes routes longer than they might be in reality. To the contrary, corner graphs have the property that every length in the derived graph is the shortest among all routes between start and goal.

3.3. Local Optimality

In order to avoid unnecessary detours, the measure of local optimality was introduced in (Abraham et al, 2013). In their situation this was an important feature, because they created alternatives by concatenating two shortest paths leading to situations, where the combined path has got extreme turning points. They optimized such situations by checking around the point of contact of these two shortest paths that no sensible shortcuts exist. In the context of alternative graphs, Bader et al. (2011) realize the same problem, but they push the solution into a post-processing step. We think that this is due to the situation that even alternative graphs can be used to generate overly long alternatives, which imply the need for post-processing anyways.

While local optimality can be strictly defined on a graph level, it is not clear how to define it for continuous free space. The question is how to handle detours that occur only due to inaccuracies in the map-to-graph translation. Additionally, the vast amount of possible choices in free space makes the approach computationally demanding or even infeasible. This all boils down to two questions: What is an “optimal” path and what is a “locally optimal” path. When applying local optimization outside the area of street networks, we think that one should consider local optimization as an application-dependent post-processing step, as the meaning of optimal and local are otherwise unclear.

Additionally, local optimality could be implemented with a different optimization goal: Not the shortest alternative route is to be found, but the simplest one. If one is really interested in optimizing the length, there is a large body of research on line simplification which can be adapted to this situation. But, in many cases this is in contrast to application goals as shortest paths tend to scrape along geometry or cross on unnatural diagonals.

3.4. Decision Edges

“Decision edges” count the number of decisions that can be made in an alternative graph. For a vertex with one edge going out, it is zero as there is no alternative decision (see left-hand side of *Figure 4*). For a vertex with three outgoing edges, however, it is two, as one edge has to be taken, but there would have been two alternatives. For the complete alternative graph, one takes the sum over all alternative choices. The goal in designing alternative graphs is to keep the value of “decision edges” small in order to have a small set of alternatives. However, if it is too small, too many additional alternatives might be discarded.

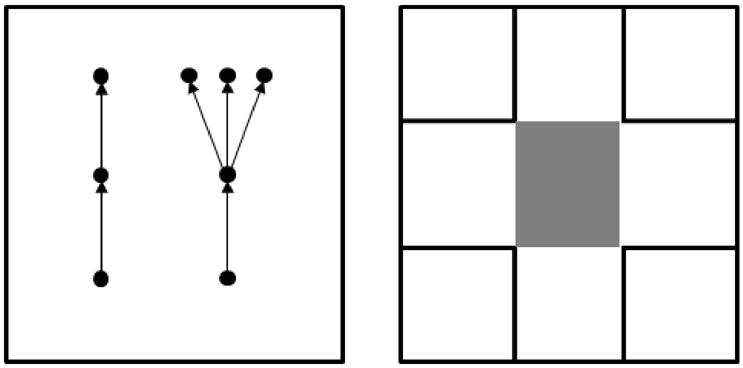


Figure 4. Left: An outdegree of 0 means that no decision can be made, an outdegree of 3 means two decisions can be made besides the necessary flow. Right: Schematic representation of a crossroads where the gray area may represent the location of a decision.

Translating this feature to constrained free space scenarios is similar to the discussion for overlap. One can even define decisions in free space from overlap: A decision is taken at a time where overlap changes. Thus, in some sense, it amounts to extend overlap from edges to vertices.

From a practical perspective, one can again use any existing graph and the associated decisions at graph vertices. However, it is unclear what their actual meaning is. With additional modeling effort, one can integrate the definition of decision in constrained free space into the map creation process. For buildings, for example, a decision edge could be represented as a polygon completely filling a crossing (see right-hand side of *Figure 4*). A decision is taken once a route crosses a different set of edges of this polygon.

While it is clear that in a street network every turn means some sort of decision, it is not clear whether any isolated decision comes up in maritime, pedestrian or plane navigation. Therefore, we think that one should be careful in adaptation of this feature.

3.5. Mutual Interference of Quality Metrics

In the previous subsections, we have presented several approaches to transform the measures for generating alternative routes and alternative graphs to constrained free space scenarios. While we propose various possible ways for each of these measures, one should keep in mind that they actually form deep-rooted interwoven features. When changing overlap, one has to carefully think about what this means for decision edges and vice versa; local optimality can have a strong impact on the definition of both, decision edges and overlap. Furthermore, local optimization can bring bad alternatives into the limits given by the stretch. Figure E depicts the most important links between those measures.

4. Conclusion

In this paper, we first introduced various concepts in the area of alternative routes and alternative graphs as they have been invented for street networks. We showed how constrained free space can be transformed into graphs such that the classical algorithms designed for street networks would be applicable. As we explained, however, the semantic correspondence of vertices and edges with real-world streets and crossings is not evident for constrained free space models, especially not, when they are automatically generated.

Therefore, we discuss the ideas from both worlds, alternative routes and alternative graphs, with which the quality of alternative routes has been measured in street networks in order to extract small sets of truly alternative routes or sufficiently small alternative graphs from the vast amount of possible alternative routes. We discuss methods of extending the classical quality metrics to constrained free space and balance their opportunities and limitations.

Finally, we discuss that all of the numerous choices are interlinked and need to be considered together instead of in isolation. Choosing a map representation has implications for the viability of measures such as overlap and decision edges, the maps themselves have impact on how these measures help in identifying useful alternatives, and changing one of the involved abstractions impacts the overall system.

Therefore, we propose to discuss alternative routes in constrained free space scenarios in an application-dependent context. Many choices that might be reasonable for indoor navigation and computer games could be unreasonable for maritime navigation and airplanes. Still, we believe that our aim of integrating constrained free space scenarios into the area of alternative route research will stimulate discussion and the development of novel and possibly universal ways of selecting alternatives. Additionally, the expected integration of complicated modes of mobility in intermodal navigation (pedestrian, bicycle, mobile robots in production scenarios) illustrates the need for an integrated treatment of environments and alternatives.

References

Abraham I, Delling D, Goldberg A, Werneck R (2010) Alternative Routes in Road Networks. In: Proceedings of the 9th International Symposium on Experimental Algorithms (SEA). Lecture Notes in Computer Science 6049, Springer, pp. 23-34

Abraham I, Delling D, Goldberg A, Werneck R (2013) Alternative routes in road networks. Journal of Experimental Algorithmics (JEA) 18. ACM, pp. 1-3

Bader R, Dees J, Geisberger R, Sanders P (2011) Alternative route graphs in road networks. Theory and Practice of Algorithms in (Computer) Systems. Springer, pp. 21-32

Bast H, Delling D, Goldberg A, Müller-Hannemann M, Pajor T, Sanders P, Wagner D, Werneck R (2015) Route planning in transportation networks. arXiv preprint arXiv:1504.05140

Bauer R, Delling D, Sanders P, Schieferdecker D, Schultes D, Wagner D (2010) Combining hierarchical and goal-directed speed-up techniques for dijkstra's algorithm. Journal of Experimental Algorithmics (JEA) 15. ACM, pp.1-31

Camvit (2009) Cambridge Vehicle Information Technology Ltd. – Choice Routing. Online. http://www.camvit.com/camvit-technical-english/Camvit-Choice-Routing-Explanation-english.pdf

Chen Y, Bell M, Bogenberger K (2007) Reliable pre-trip multi-path planning and dynamic adaption for a centralized road navigation system. In: Proceedings of the 8th International IEEE Conference of Intelligent Transportation Systems. IEEE, pp. 14-20

Dees (2010) Computing Alternative Routes in Road Networks. Master's thesis, Karlsruhe Institute of Technology, Fakultät für Informatik

Dees J, Geisberger R, Sanders P, Bader R (2010) Defining and computing alternative routes in road networks. arXiv preprint arXiv:1002.4330

Delling D, Goldberg A, Pajor T, Werneck R (2011) Customizable Route Planning. In: Proceedings of the 10th International Symposium on Experimental Algorithms (SEA). Lecture Notes in Computer Science 6630, Springer, pp. 376-387

Delling D, Wagner D (2009) Pareto Paths with SHARC. In: Proceedings of the 8th International Symposium on Experimental Algorithms (SEA). Lecture Notes in Computer Science 5526, Springer, pp. 125-136

Delling D, Werneck R (2013) Faster Customization of Road Networks. In: International Symposium on Experimental Algorithms (SEA). Lecture Notes in Computer Science 7933, Springer, pp. 30-42

Dijkstra E (1959) A note on two problems in connexion with graphs. Numerische mathematik 1(1). Springer, pp. 269-271

Eppstein D (1994) Finding the K Shortest Loopless Paths in a Network. In: Proceedings of the 35th Annual IEEE Symposium of Foundations of Computer Science (FOCS), pp. 154-165

Geisberger R, Kobitzsch M, Sanders P (2010) Route planning with flexible objective functions. In: Proceedings of the 12th Workshop on Algorithm Engineering and Experiments (ALENEX). SIAM, pp. 124-137

Geisberger R, Sanders P, Schultes D, Delling D (2008) Contraction hierarchies: Faster and simpler hierarchical routing in road networks. International Workshop on Experimental and Efficient Algorithms. Springer, pp. 319-333

Graf F, Kriegel HP, Renz M, Schubert M (2010) PAROS: pareto optimal route selection. In: Proceedings of the 2010 ACM SIGMOD International Conference on Management of data. ACM, pp. 1100-1202

Kobitzsch M (2013) An alternative approach to alternative routes: HiDAR. European Symposium on Algorithms. Springer, pp. 613-624

Kobitzsch M, Radermacher M, Schieferdecker D (2013) Evolution and evaluation of the penalty method for alternative graphs. In: Proceedings of the 13th Workshop on Algorithmic Approaches for Transportation Modelling, Optimization, and Systems (ATMOS). Schloss Dagstuhl – Leibniz-Zentrum für Informatik, pp. 94-107

Luxen D, Schieferdecker D (2012) Candidate sets for alternative routes in road networks. Journal of Experimental Algorithmics (JEA) 19. ACM, pp. 2-7

Martins E (1984) On a Multicriteria Shortest Path Problem. European Journal of Operational Research 26(3), pp. 236-245

Paraskevopoulos A, Zaroliagis C (2013) Improved alternative route planning. OASIcs – OpenAccess Series in Informatics 33. Schloss Dagstuhl – Leibniz-Zentrum für Informatik

Radermacher M (2012) Schnelle Berechnung von Alternativgraphen. Bachelor’s thesis, Karlsruhe Institute of Technology, Fakultät für Informatik

Scott K (1997) Finding alternatives to the best path

Werner M (2014) Indoor Location-Based Services: Prerequisites and Foundations. Springer

Werner M, Feld S (2014) Homotopy and alternative routes in indoor navigation scenarios. In: Proceedings of the 5th International Conference on Indoor Positioning and Indoor Navigation (IPIN). IEEE, pp. 230-238

Yen J (1971) Finding the K Shortest Loopless Paths in a Network. Management Science 17(11), pp. 712-716

Indoor Spatial Data Model for Wayfinding: A Case Study of the Masaryk University

Andrea Kynova

Masaryk University, Institute of Computer Science

Extended Abstract

This paper describes a process of deriving building topology from data of a Building Documentation System (BDS) maintained by the Masaryk University, Brno (Czech Republic). The BDS contains information about more than 300 buildings, 22,000 rooms, 23,000 doors and 200,000 technological devices. Its primary purpose is Facility Management and therefore it is not sufficient for wayfinding. To be able to use it for this purpose, the data model has been analyzed, adjusted and expanded for several key information with respect to IndoorGML standard (OGC 2014).

The BDS is composed of two parts: Building Passport and Technology Passport (Herman et al. 2014). The Building Passport contains most of the BDS data which is related to wayfinding. It includes geometry of buildings and their parts (floors, rooms, doors and windows). *Figure 1* presents an example of Building Passport data visualization (Kozel et al. 2014). The data is stored in a geodatabase in separate feature classes. Each object in the database has its unique location code. This location code consists of a part determining building, a part determining floor of the building and finally a part determining particular room, door or window. Based on the location code, every room, door or window is assigned to one floor of a building.

Rooms are represented by polygon geometry. Rooms on one floor are connected through doors or free space passages, together referred to as passages in this paper. The passages are essential for deriving floor topology.

A door in the database has polygon geometry, unique location code (not always filled in), floor location code and location codes of rooms it connects (not always filled in, not always correct). Free space passages in the data were created artificially by cutting too long corridors or too large rooms with complex geometry into several smaller rooms. In the current data model, free space passages are not considered. However, a free space pas-

LBS 2016
13th Conference on Location-Based Services
Vienna, 14–16 November 2016

Published in "Proceedings of the 13th International Conference on Location-Based Services", edited by Georg Gartner and Haosheng Huang, LBS 2016, 14-16 November 2016, Vienna, Austria.

sage geometry and information which rooms it connects can be derived by analyzing rooms geometry.

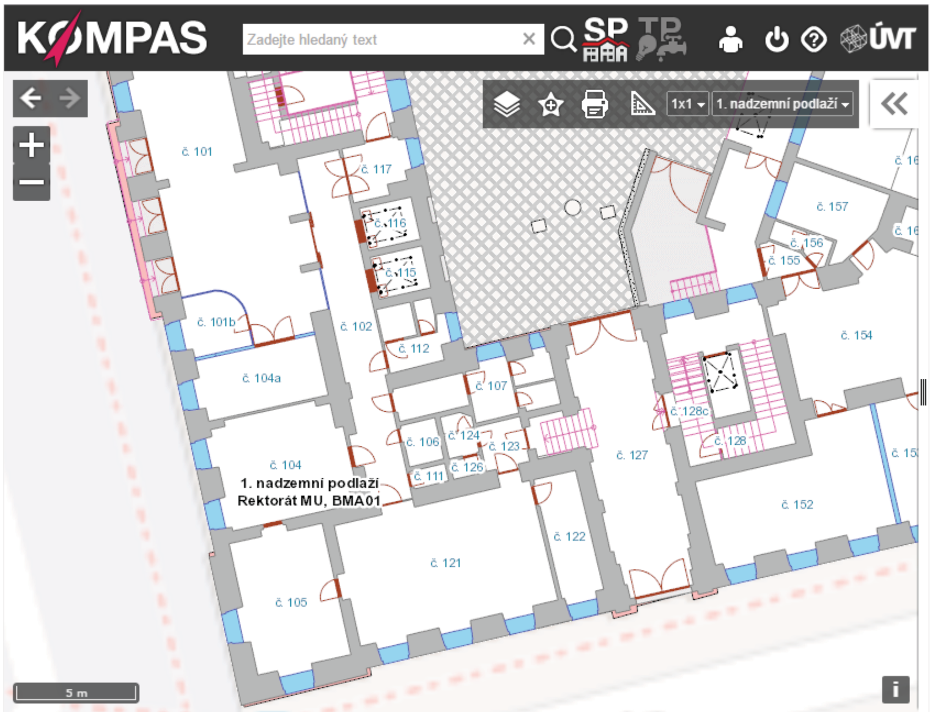


Figure 1. Visualization of Building Passport data in the Kompas web GIS (Kozel et al. 2014).

The current data model lacks information about connections between floors. In case of the Masaryk University buildings, floors are connected by elevators or staircases. Elevators are part of the Technology Passport data that provides information about devices of electrical installation, water supply etc. and relations between devices (Kroutil 2012). The information about elevators can be used to find out which rooms (elevator shafts) the elevator goes through and so can be used to define one part of floor connections.

In case of staircases, the current state of the database isn't sufficient to derive floor connection automatically. A separate feature class is used to store staircases. The feature class contains a multiline geometry (see *Figure 2*), where each stair of the staircase is represented by a line. The upward direction of the staircase is marked with an arrow (perpendicular to stair lines). As attributes, the feature class should provide location codes of rooms the staircase goes from and leads to. However, values of the location codes' attributes aren't filled in at all. The incompleteness doesn't allow to derive staircase floor connection automatically.

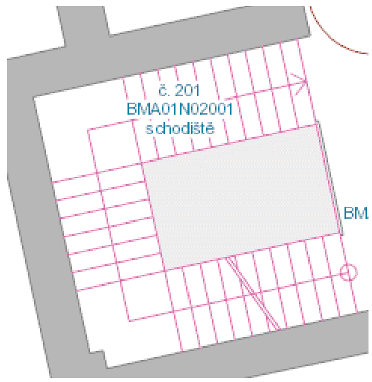


Figure 2. Multiline representation of a staircase.

In this case study, a topology of the Masaryk University headquarters was derived. At first, passages between rooms at the same floor were defined by a Python script using ArcPy library. A new feature class was created to store passages. It contains a passage geometry and location codes of rooms the passage connects. Doors were processed prior to free space passages. The longer axis of the door polygon was used as passage geometry. Location codes of rooms connected by the door were found by intersecting room layer with points drawn in a given distance from the door.

The script processes rooms' geometry to identify free space passages between rooms. Rooms of interstorey staircases cause problems during the processing because of their overlays with other rooms on the same floor. It would be better to treat them separately, but unfortunately it isn't possible to distinguish interstorey stairs and levelling stairs. Therefore, manual corrections of the result had to be performed.

Floor connections were automatically derived from the Technology Passport data of elevators. In the Technology Passport, even elevator shafts are considered as devices. Each elevator has several elevator shafts, one in each floor it goes through. The relation between elevator and its shafts is referred to as inner-outer devices' relation. Based on this knowledge, a table of elevators and rooms they go through was prepared using SQL and was used to define "vertical passages" of building topology. Due to the incompleteness of the staircase data, the rest of floor connections was added manually to complete whole topology of the building.

The result of the process described above provides information about room adjacency and will be used as an input for Door-to-Door algorithm (Liu & Zlatanova 2011) to define a path network useable for indoor routing. The derivation of the building topology was significantly affected by the primary purpose of the input data which differs from wayfinding and navigation. This study depicts necessary changes in the Masaryk University BDS data to be applicable for wayfinding purposes.

References

Herman L, Russnak J, Stachon Z, Mikstein D (2014) Cartographic Symbols for 3D Visualization in Facility Management Domain. In Georg Gartner, Haosheng Huang. Proceedings of the 11th International Symposium on Location-Based Services. Vienna: Vienna University of Technology, 2014. pp. 164-167. ISBN 978-1-907075-07-0.

Kozel J, Kovács P, Spurná J, Bohumel P, Kýnová A (2014) Kompas - web GIS of Masaryk University. 2014. https://kompas.muni.cz. Accessed 26 September 2016

Kroutil P (2012) Technologický pasport Masarykovy univerzity. Praha: ARCDATA Praha, s.r.o., 2012. s. 98-100. ISBN 978-80-904450-8-6.

Liu L, Zlatanova S (2011) A "door-to-door" Path-finding Approach for Indoor Navigation. In: Proceedings Gi4DM 2011: GeoInformation for Disaster Management, Antalya, Turkey, 3-8 May 2011. International Society for Photogrammetry and Remote Sensing (ISPRS), 2011.

OGC (2014) OGC Indoor Geography Markup Language (IndoorGML) Encoding Standard, Version 1.0. http://docs.opengeospatial.org/is/14-005r3/14-005r3.html. Accessed 26 September 2016

The Usability Analysis for the Use of Augmented Reality and Visual Instructions in Navigation Services

Anahid Basiri*, Pouria Amirian**, Adam Winstanley***

* The Nottingham Geospatial Institute, The University of Nottingham
**Products and Innovation, Ordnance survey
***The Department of Computer Science, Maynooth University

Abstract. The use of Augmented Reality and visual cues as a part of navigational instructions, in addition to conventional audio and textual instructions, may improve the experience of the users of the navigation services. This approach can be also more compatible with the way people give instructions in everyday life; People usually associate directions with visual cues (e.g. "turn right at the square") when giving navigational instructions in their daily conversations. In this regard, landmarks as the unique and easy-to-recognise features can play an important role. Such easy to remember features, which are available both indoors and outdoors, can be helpful when exploring an unfamiliar environment. A Landmark-based navigation service can make users sure that they are on the correct route, as the user is reassured by seeing the landmark whose information/picture has just been provided as a part of navigational instruction. Such advantages of use of landmarks visual information as a part of the instructions can decrease the time of travel and improve the experiences of the users. This paper assesses how landmarks can improve the performance of pedestrian movements following landmark-based navigational instructions.

Keywords. Visual Instructions, Augmented Reality, Landmarks

1. Introduction

Many of the currently available navigation systems provide users with textual or audible navigational instructions, which are mainly about the turning points. In such "turn-by-turn" navigation, the directions are associated with distances, e.g. "turn right after 250 metres". Such a navigational strat-

Published in "Proceedings of the 13th International Conference on Location-Based Services", edited by Georg Gartner and Haosheng Huang, LBS 2016, 14-16 November 2016, Vienna, Austria.

egy works very well for machine/robot navigation, as sensors sense and measure distances and headings. However, people give navigational instructions in a slightly different format in their daily conversations. People associate directions with visual cues, such as “turn left at the church”. Such visual cues utilise easy-to-recognise and unique features and objects.

This strategy might be more attuned to the interests of pedestrians, since they move with relatively lower speed; therefore they can notice visual landmarks easily. In addition, such unique and easy-to-recognise features help people to memorise the path they have taken and also give a better understanding of their surroundings, especially when they are exploring unfamiliar environments. Landmarks are also interesting features in their own right for many people, such as tourists.

Landmarks are available both inside and outside buildings. Therefore any navigation service that provides the users with navigational instructions based landmarks, can potentially provide seamless (indoors and outdoors) navigation solutions. Seamless navigation is one of the most challenging parts of pedestrian navigation. Seamless navigation is the topic of many research projects (Cheng et al., 2014; Zhang et al., 2012; Basiri et al., 2016; Li et al., 2013; Hansen et al., 2009). In this regard, landmarks can be used as reference points in positioning and navigation. This paper shows the effect of using landmarks, as a part of positioning and navigation services, on the performance and the experiences of the users of the navigation services.

In contrast with drivers, pedestrians have a higher degree of freedom in their movements. They can walk across open areas such as squares, parks, grasslands or pedestrian malls, which can be traversed freely in any direction (Gaisbauer and Frank, 2008). As current turn-by-turn navigational instructions designed to be given to vehicle’s drivers are mostly based on graph-based or street network-based algorithms, this way of navigating is not fully suitable for pedestrians as they do not only move on streets (Pielot and Boll, 2010; Amirian et al., 2015). Therefore landmarks can be used to provide seamless positioning and more desirable navigation services to pedestrians, who, unlike drivers, can go into and through buildings to get to their destinations, who move at a relatively low speed and for whom the purpose of their travel might not only be to get to the destination, but also to explore an unfamiliar area and indulge in sightseeing along the way. Landmarks could be assets to memorise an unfamiliar environment where users visit for the first time. Also providing information on landmarks (such as name, type, colour) makes the user sure that he/she is taking the correct path and has not got lost, as the user sees the objects whose information is included in the navigational instruction.

This paper shows the effect of using the photographs of landmark as a part of navigational instructions provided to the pedestrian on the performance of navigation services and spatial awareness of pedestrians. To do so, the users are provided with a photograph of to-be-seen landmarks as a part of their navigational instructions, i.e. landmark-based navigation (May et al., 2005). Landmark based navigation is a kind of navigation service in which users are provided with navigational instructions, such as turn right, go straight, turn left, etc. whenever they approach each landmarks (Fang et al., 2011). This is more compatible with human-to-human interactions and the interests of tourists and visitors (Basiri et al., 2014).

In order to implement the proposed landmark-based navigation service, the proposed service by Basiri et al. (2016) is considered and the implemented service for the campus of Maynooth University (NUIM) is assessed. In this implementation the buildings and important features, such as statues, historic monuments and buildings with unique architecture were stored in a spatial database as outdoor landmarks. Indoor landmarks such as main entrances and unique decorative objects and boards were also stored. For each landmark at least four photographs from different points of view but with the same distance and tilt were captured. Attributes such as names in English, names in Irish (Gaelic), age, feature category and some descriptive information were also collected and stored in the database. This database is used for both purposes of positioning and navigation.

Users can take a photograph of a registered and labelled landmark and send it to a web service provider for further process. Using image processing, feature extraction and feature matching, and thanks to the uniqueness of the landmarks, it is possible to find the landmark corresponding to the one in the database. Then using scale and rotation of the photograph taken by user (which can be measured by the landmark's size and tilt), the relative position of the user with respect to the landmark can be calculated.

In addition to localisation, the landmarks are provided as a part of navigational instructions. The instructions provided to the users contain text and pictures of the nearest landmark to be seen on the way. In showing a picture of a landmark, location and heading (direction) of user movement are considered to find the most similar picture to the view of the user among available pictures (Cao and McDonald, 2012). Receiving the picture of the nearest landmark on the way, users can also enjoy a guided tour by getting information about each building while navigating.

In order to study the impact of providing image-based navigational instructions on the movement of the users journey, a survey is conducted and also an experiment is done. The results of survey shows that 82% the participants, including NUIM students and staff, found the landmark based navigation easier to follow specially if they are in unfamiliar and/or architecturally complex areas, such as inside of the buildings where they have never been to. However, 32% of the participants of the survey believe that showing the photographs of the landmarks can take the journey time longer. To study the impact of the visual navigation, a group of 252 students and children, 7-21 years old, were randomly assigned to two different groups. Then each was asked to follow navigational instructions for 25 minutes and find as many hidden objects as they could. The first group was provided with the textual navigational instructions, while the second group received the landmark-based navigational instructions. Once the 25 minute finished, the conductors of the experiment counted the numbers of found eggs each participant could find. The data showed that the mean number of found eggs by the participants who were provided with the image based navigational instructions is 10 eggs more than the mean number of found eggs by the participants receiving textual/traditional instruction (with the p-value of 1.3%). This improvement can enhance the field-based training activities and team projects, which require students to have a better spatial awareness of their surroundings.

The next section of the paper explains how landmarks can be used for positioning and navigation purposes and the implementation of the service is shown. Then the third section evaluates the effect of landmark-based navigation versus traditional navigation services.

2. The Use of Visual Clues in Pedestrian Navigation

Landmarks can have an important role in navigation, in particular pedestrian navigation services. As exploring an unfamiliar environment, pedestrians first notice outstanding objects or structures at fixed locations. These unique objects and/or features are easy to recognise and can be kept in memory without difficulty (Schechtner, 2005) so they are essential in route navigation and locale navigation strategies. Landmarks become more recognisable and therefore helpful for navigation when people move slowly, which is the case for pedestrians. The importance of landmarks for pedestrian navigation and wayfinding instructions is proved by many studies (Michon and Denis, 2001; Denis, 2003; Lovelace et al., 1999; Raubal and Winter, 2002).

Landmarks are stationary, distinct and salient objects or features, which serve as cues for structuring a mental representation of the surrounding area. Any object can be perceived as a landmark if it is unique enough in comparison to the adjacent items. A landmark can be defined as any object or feature, which is easily recognisable, such as a monument or a building. Landmarks are one of the interests of tourists, most often due to notable physical features, cultural references or historical significance. People often use landmarks for casual navigation, such as when giving directions verbally or when sketching a route map.

In general, landmarks have a fixed and known position, relative to which users can localise themselves. Landmarks should be carefully chosen to be easy to identify; for example, a large building has priority over a small one. A feature, which has significant contrast to the background, is a good option to be considered as landmark since its image would be easily recognisable to users. Such objects have to possess a certain saliency, which makes them remarkable and distinctive. So the surrounding area determines the characteristics a point must have to be perceived as a landmark (e.g. a shopping centre may not be very outstanding in urban areas, but becomes a salient landmark when being situated in a rural village).

Availability of landmarks both indoors and outdoors helps to provide the seamless positioning service to the users. The motivations behind using images of the landmarks for positioning purposes include being computationally and financially cheap, and the ability to be used on readily available mobile devices almost all equipped with camera. Users can take a photograph of a registered landmark and then send/upload it for image processing and feature matching. The feature-matching engine can extract and identify the landmark of which the photograph has been taken. To do so, image processing, feature extraction and feature matching techniques are applied. Then scale and rotation (tilt) of the photograph is calculated, using the actual sizes of different façades of the landmark have been already stored in a database or can be measured from the images in the database. Based on scale and rotation, the vector representing relative location of the user with respect to the landmark can be calculated. Since absolute positions of landmarks are available in the database, the absolute position of the user can easily be calculated and then used in path finding and navigation services (Basiri et al, 2016).

3. Evaluation

The implementation of the landmark-based navigation system, is fully explained in (Basiri et al., 2016), this section evaluates the users opinion and the usability of the service. Since the navigational instructions contain some information about landmarks, which can be seen from the user's point of view (see figure 1), this approach may be more compatible with tourist navigation applications. In addition, users feel that it is less likely that they may get lost, since they are being provided with the pictures of landmarks, to be seen shortly. So they are reassured that they are on the right path, however this needs to be tested.

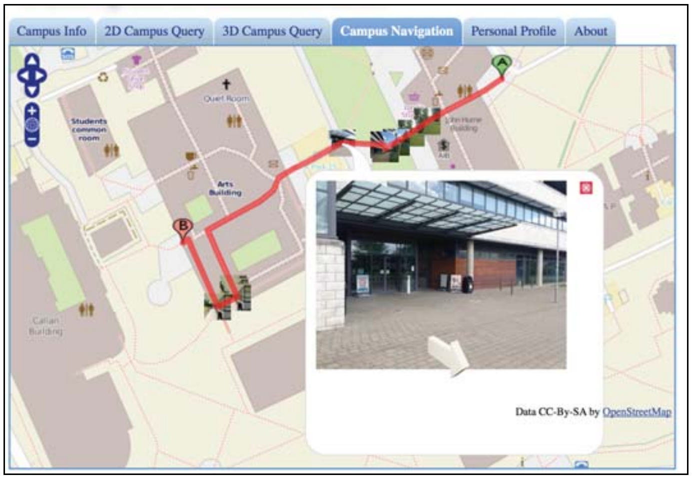


Figure 1. Visual navigational instructions in eCampus web application

In order to study the impact of providing image-based navigational instructions on the movement of the users patterns and/or quality of movement, a survey is conducted and also an experiment is done.

A simple form was distributed among the users of the implemented services, i.e. staff and students of NUIM who have been registered with the e-Campus. The questionnaire, including 6 questions, asks about (a) their experiences with traditional navigation apps, and (b) if the use of landmarks could improve the quality of navigation services, and (c) if so how.

Based on the analysis of the comments and evaluation marks results of survey shows that 82% the participants, found the landmark based navigation easier to follow in comparison with traditional navigation services, in particular if they are in unfamiliar and/or architecturally complex areas, such as inside of the buildings where they have never been to. However, 32% of the participants of the survey believe that showing the photographs of the landmarks can take the journey time longer. To see if this statement is true an experiment is made to measure the number of destinations an individual can go within the fix period of time while being navigated with and without photographs of landmarks.

A group of 252 students and children, 7-21 years old, were randomly assigned to two different groups. Then each individual was asked to follow navigational instructions for 15 minutes and find as many hidden objects as they could in 25 minutes.

The first Group was provided with the textual navigational instructions, while the second group received the image of the landmarks as a part of navigational instructions. Once the 25 minute of the geocaching game,

”Easter Egg Hunt” finished, the conductors of the experiment counted the numbers of found eggs each participant could find. The data showed that the mean number of found eggs by the participants who were provided with the image based navigational instructions is 10 eggs more than the mean number of found eggs by the participants receiving textual/traditional instruction.

Using a simulator, the results were re-randomised into two new groups and measured the differences between the means of the new groups. This simulation was repeated 150 times plotted the resulting differences as given in figure 2.

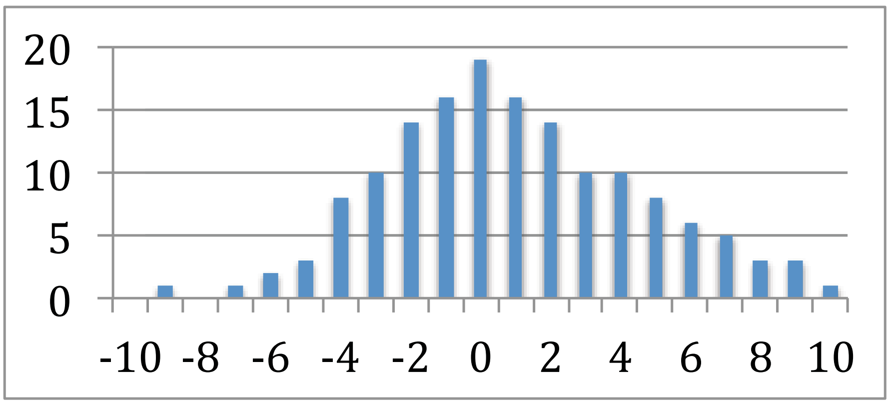


Figure 2. Distribution of the difference between means of treatment and control groups

The statistical significance of the landmark-based navigational instructions is tested, see figure 2. The null hypothesis assume that the achieved results are by chance, i.e. finding 10 more objects within the same time interval is not statistically significant and has happened by chance. The alternative hypothesis to this is the statement that assumes providing landmark-based navigation service is contributing to the achieved results, i.e. the 10 more objects found by the second group is statistically significant which has not just happened all by chance.

To see if providing the photographs of landmarks as a part of navigational instruction is statistically significant, the significance level (Alpha) set to 5% as this is the level for most of similar significance tests in social sciences and engineering. The sample (treatment group) size is 126 and the distribution of control group is available (based on the results of the re-randomisation of the groups, i.e. control group), therefore the possibility of achieving such results is 0.7% which is less smaller than significance level (5%) and therefore the null hypothesis can be rejected.

The possibility of finding 10 or more objects within a 25-minute test by the group receiving the landmark based navigational instructions is low enough to claim that providing the images of the landmarks as a part of the navigational instructions can help the pedestrians to follow the navigational instructions better. This can be applied in field based courses such as surveying engineering, geography, geology and structure engineering, where the teaching and related activities requires better understanding of the environment. Having been tested this application within an educational centre (NUIM campus) with participation of students can bring more certitude on the practicality of it.

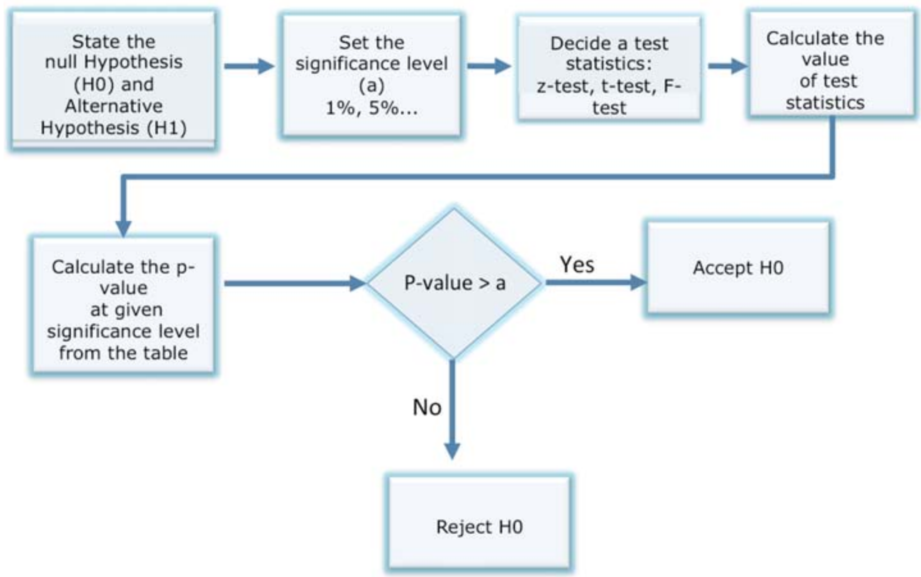


Figure 3. The process of the statistical significance test

4. Conclusion

Landmarks are often used for casual navigation, such as giving verbal directions, by ordinary people. This paper used the photographs of the landmarks to provide navigation services to pedestrians. The landmark based navigation service can provide users with the reassurance that they are on the correct path. In order to study the effect of providing the photographs of landmarks and a part of navigational instructions, a survey and an experiment were conducted. The results of survey shows that 82% the participants found the landmark based navigation easier to follow specially if they are in unfamiliar and/or architecturally complex areas. Also an experiment was conducted to study if landmark based navigation can help the pedestrians to follow the navigational instructions better; two groups of 126 participants were asked to follow navigational instructions for 25 minutes and find as many hidden objects as they could, while receiving the textual and landmark based navigational instructions, respectively. The data showed that the mean number of found eggs by the participants who were provided with the image based navigational instructions is 10 objects more than the mean number of found eggs by the participants receiving textual/traditional instruction (with the p-value of 1.3%). This results shows that the use of photographs of landmarks as a part of navigational instructions can be a better way for pedestrian navigation who move with relatively lower speed and therefore being more aware of their surrounding areas.

References

Amirian, P., Basiri, A., Gales, G., Winstanley, A.C. and McDonald, J. (2015). The Next Generation of Navigational Services Using OpenStreetMap Data: The Integration of Augmented Reality and Graph Databases, OpenStreetMap in GIScience, Lecture Notes in Geoinformation and Cartography 2015, pp 211-228

Basiri, A., Amirian, P, and Winstanley, A. (2014). Use of Graph Databases in Tourist Navigation Application, Computational Science and Its Applications–ICCSA 2014, pp 663-677.

Basiri, A., Amirian, P., Winstanley, A., Marsh, S., Moore, T., & Gales, G. (2016). Seamless Pedestrian Positioning and Navigation Using Landmarks. Journal of Navigation, 69(01), 24-40.

Brenner, B. and Elias, B. (2003). Extracting landmarks for car navigation systems using existing GIS databases and laser scanning. In ISPRS Archives, Vol. XXXIV, Part 3/W8, Munich, Germany.

Cao, Y. and McDonald, J. (2012). Improved feature extraction and matching in urban environments based on 3D viewpoint normalization. Computer Vision and Image Understanding, 116(1), 86–101.

Cheng, J, Yang, L., Li, Y. and Zhang, W. (2014). Seamless outdoor/indoor navigation with WIFI/GPS aided low cost Inertial Navigation System, Physical Communication. Available online 9 January 2014, ISSN 1874-4907.

Denis, T.M. (2003). Referring to Landmark or Street Information in Route Directions: What Difference Does It Make? In Spatial Information Theory. Lecture Notes in Computer Science, Vol. 2825, W. Kuhn, M. Worboys, S. Timpf, Eds., Heidelberg: Springer, 384-397.

Elias, B. (2003). Determination of Landmarks and Reliability Criteria for Landmarks. Technical Paper, ICA Commission on Map Generalization, 5th Workshop on Progress in Automated Map Generalization, IGN, Paris, France.

Etienne, S. and Séguinot, V. (1993). Navigation by Dead Reckoning and Local Cues. Journal of Navigation, 46, 364-370. doi:10.1017/S0373463300011802.

Fang, Z., Li, Q., Zhang, X. and Shaw, S.L. (2011). A GIS data model for landmark-based pedestrian navigation, International Journal of Geographical Information Science, DOI:10.1080/13658816.2011.615749

Gaisbauer, C. and Frank, A.U. (2008). Wayfinding Model for Pedestrian Navigation. The AGILE International Conference on Geographic Information Science, 1-9.

Hansen, R., Wind, R., Jensen, C.S. and Thomsen, B. (2009). Seamless Indoor/Outdoor Positioning Handover for Location-Based Services in Streamsp. In Tenth International Conference on Mobile Data Management: Systems, Services and Middleware, 267-272.

Holm, S. (2009). Hybrid ultrasound-RFID indoor positioning: Combining the best of both worlds. IEEE Int. Conf. RFID, Orlando, Florida, 155-162.

Lee, J.K., Grejner-Brzezinska, D.A. and Toth, C. (2012). Network-based Collaborative Navigation in GPS-Denied Environment. Journal of Navigation, 65, 445-457. Doi: 10.1017/S03734633 12000069.

Li, X., Wang, J., and Li, T. (2013). Seamless Positioning and Navigation by Using Geo-Referenced Images and Multi- Sensor Data. Journal of Sensors, 13(7), 9047–9069.

Lovelace, K., Hegarty, M., Montello, D. (1999). Elements of Good Route Directions in Familiar and Unfamiliar Environments. In Spatial Information Theory, Proc. International Conference COSIT ’99, C. Freksa, D. M. Mark, Eds., Heidelberg: Springer, 65-82.

Lynch, K.(1960). The image of the city. MIT Press, p. 48.

May, A.J., Ross, T. and Bayer, S.H. (2005). Incorporating Landmarks in Driver Navigation System Design: An Overview of Results from the REGIONAL Project. Journal of Navigation, 58, 47-65. Doi: 10.1017/S0373463304003054.

Michon, P.E. and Denis, M. (2001). When and Why Are Visual Landmarks Used in Giving Directions? In Spatial Information Theory, Proc. International Conference COSIT 2001, Heidelberg: Springer, 292-305.

Millonig, A. and Schechtner, K. (2005). Developing Landmark-based Pedestrian Navigation Systems. Proceedings of the 8th International IEEE Conference on Intelligent Transportation Systems. 0-7803-9215-9/05. pp 196-202.

Pielot, M. and Boll, S. (2010). "In Fifty Metres Turn Left":Why Turn-by-turn Instructions Fail Pedestrians. Haptic, Audio and Visual Interfaces for Maps and Location Based Services.

Raubal, M. and Winter, S. (2002). Enriching Wayfinding Instructions with Local Landmarks, in Geographic Information Science. Lecture Notes in Computer Science, 2478, M.-J. Egenhofer, D. M. Mark, Eds., Heidelberg: Springer, pp. 243-259.

Redish, D. (1999). Beyond the cognitive map: from place cells to episodic memory. Cambridge: MIT.

Schechtner, M.K. (2005). Developing Landmark-based Pedestrian Navigation Systems. Proceedings of the 8th International IEEE Conference on Intelligent Transportation Systems Vienna.

Siegel, W. and White, S.H. (1975). The Development of Spatial Representations of Large-scale Environments. Advances in Child Development and Behaviour, 10, 9-55. H.W. Reese, Ed., New York: Academic Press.

Vepa, R. (2011). Ambulatory Position Tracking of Prosthetic Limbs Using Multiple Satellite Aided Inertial Sensors and Adaptive Mixing. Journal of Navigation, 64, 295-310. doi:10.1017/S0373463310000494.

Werner, S., Krieg-Brückner, B., Mallot, H., Schweizer, K. and Freksa, C. (1997). Spatial Cognition: The Role of Landmark, Route and Survey Knowledge in Human and Robot Navigation. In Informatik aktuell, M. Jarke, K. Pasedach, K., Pohl, Eds., Berlin: Springer, pp. 41- 50.

Zhang, T. and Xu, X. (2012). A new method of seamless land navigation for GPS/INS integrated system. Measurement, 45(4), 691-701, ISSN 0263-2241.

FLIP – FLexible Indoor Position Estimator

Reinhard Müllner* **, Thomas Burgess*, Heinrich Schmitzberger**

* indoo.rs GmbH
** JKU Linz

Extended Abstract

This paper presents FLexible Indoor Position (FLIP), an efficient algorithm for use in fingerprint based indoor localization systems, such as the indoo.rs Navigation System (iNS). Fingerprint based positioning in complex buildings makes comparisons to large reference fingerprint sets. Since mobile devices have limited storage, memory, computation and power usage limitations, making an on-terminal system working well is challenging. Additionally, reported Received Signal Strength Indication (RSSI) values differ between devices, so that naive approaches for fingerprint similarity fail (cf. Caso et al. 2015). This proposal presents the FLexible Indoor Position (FLIP) estimator, which addresses both these issues – efficient device independent positioning for complex buildings. FLIP was evaluated on the raw UJIIndoorLoc data and yielded a median positioning error of 4.8m.

The described approach is applied in the radio based indoor positioning context, but is actually applicable to any kind of transmitter signals in environments where effects like reflections, damping etc. do not allow simpler approaches.

FLIP aims to identify which references are most relevant regarding the observation, and only use these to estimate positions (cf. Swangmuang and Krishnamurthy 2008). The identification first makes an adjustable fast reference selection to reduce further calculations, and then the more elaborate refinement. Since the refinement process effort is arbitrarily configurable, it can be optimized either for accuracy or efficiency. Therefore it can be used in many situations.

LBS 2016
13th Conference on Location-Based Services
Vienna, 14–16 November 2016

Published in "Proceedings of the 13th International Conference on Location-Based Services", edited by Georg Gartner and Haosheng Huang, LBS 2016, 14-16 November 2016, Vienna, Austria.

The reported received signal strength of devices is not a physical measurement but only an indication (RSSI) and therefore dependent on the device specifications. As a consequence the reported RSSI of different device types are not directly comparable. In order to make RSSI comparable between diverse devices, the actual distribution of received signal strengths are approximated to a normal distribution (Fig. 1 left) and the standard z-score is transformed to range [0, 1] by the Gauss error function. This transforms the raw device-dependent RSSI to a normalized device-independent representation as shown in Fig. 1 right.

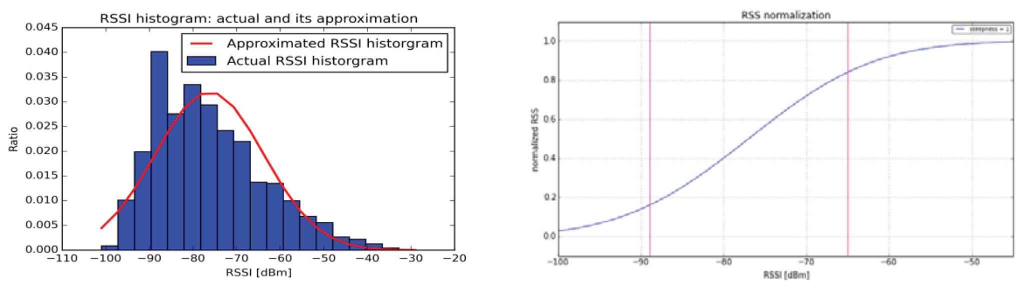


Figure 1. Left: Typical histogram of RSS and its normal-distributed approximation; Right: Received radio signal strength normalization function. Bars represent 1σ deviation.

A fast and simple indicator of similarity between sets of radio observations is the transmitter intersection score – the number of transmitters seen in both sets (cf. Sha et al. 2015). As the points may therefore form multiple disjoint regions, the set is only used to reduce search space in further processing.

Transmitter RSSI maps are typically irregular, as seen in Fig. 2. Instead of operating in ordinary space (as applied in related work, f.i., in Hu et al. 2015) FLIP transforms the transmitter coverage zone to a spherical form, and uses an edge distance score to rate similarity. An even reference density is required for this approach to work well, which is ensured by using interpolation of radio map RSSI data to a uniform grid.
The transformation of the transmitter coverage zone in ordinary space to radio space is realized by determining the number of reference points which receive the transmitter at least the normalized RSSI applying the dimensionality of radio scattering, which depends on the floor radio permeability (Fig. 3).

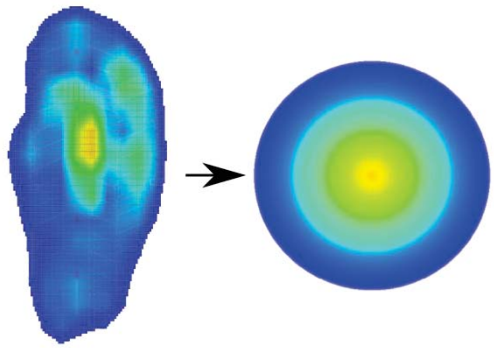


Figure 2. Left: Transmitter coverage zone on a floor plan (in physical space). Right: Same zone transformed into radio space. Lighter colors mean higher received signal strength of the transmitter.

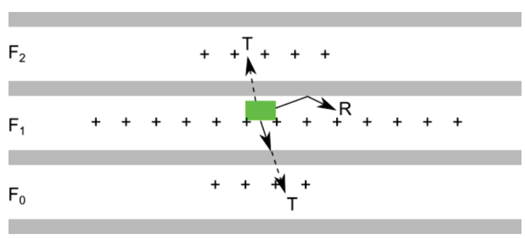


Figure 3. Due to reflections and damped transmissions through floors the spread dimensionality is higher than quadratic but lower than cubic. The green box represents a transmitter and the + signs are representing reference points.

A reference point is considered to be geometrically close to the observation if the normalized RSSI to a set of commonly visible transmitters is close to equal where the number of commonly visible transmitters related to the union of the visible transmitters by both - reference and observation is high and at least 3. Intuitively, a difference in the normalized RSSI of the stronger transmitter has a higher impact than the same difference of a weaker transmitter. This is reflected by the distance difference to the transformed coverage zone center in radio space. This center distance difference is an indicator for dissimilarity. Since the similarity is going to be calculated, the distances to the edge of the transformed coverage zone are used (Fig. 4).

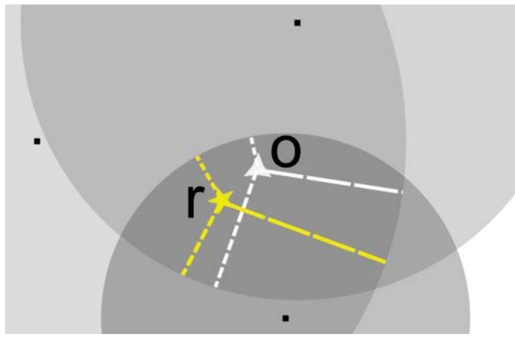


Figure 4. Transformed transmitter coverage zone edge distance of a close reference point (r) and the observation (o).

The similarity between a reference to an observation is obtained by calculating the sum of the common part of the commonly visible transmitter edge distances normalized by the sum of both observation and reference edge distances of all their visible known transmitters. Unknown transmitters are observed transmitters which were not visible by any reference of the FLIP map and are therefore not considered.

The most similar and therefore relevant references wrt. the observation are ordered by their similarity score and are used for the building, floor and position estimation; using the score as a weight.

References are grouped by their assigned building and floor and
The summed similarity scores of the (building and) floor grouped references as a weight is used for calculating the estimated probability being the correct building and floor of the observation.

A 2d Gaussian fit (Fig. 5) is applied on the reference positions weighted by their similarity score. The estimated position of the observer is the centroid of this fit.

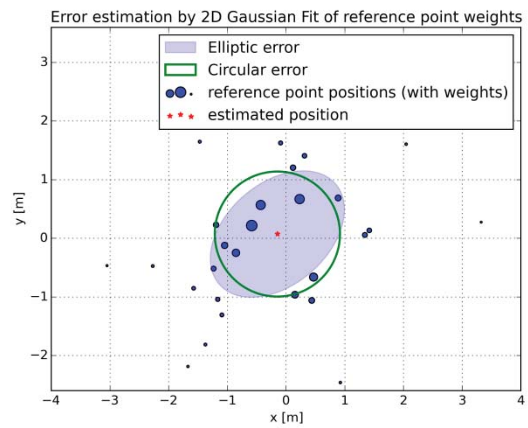


Figure 5. The position and error is estimated by the most relevant reference points, by their position and weight. The position is estimated by the mean of the weights. The light blue area is the 1σ of the weights. The green circle represents the circular error.

A visual overview of the algorithm is shown in Fig. 6.
The algorithm is separated in two phases:

- Processing the radio map to get the FLIP map and derived data for the second phase. Required once per radiomap.
- Processing the observation for location estimation of the observer.

FLIP uses a memory efficient pre-calculated compact summary representation of radio fingerprint reference maps (FLIP map) that can be loaded and used offline even on weak mobile devices. The FLIP map contains the required data in a way to minimize both, the data space requirements and the calculation effort for the refinement process.
Based on the FLIP map a reference point based view is required to get a comparable similarity score.

To estimate the position of the terminal device, its radio measurements (observation) are used, which have to be transformed to a representation to be processed by FLIP.
At that point the actual position estimation is ready to be performed. In the first step the most relevant reference points regarding the observation are going to be identified.
The next step calculates the similarity of the references, which are identified as

most relevant to the observation. This leads to a differentiated evaluation of reference point relevance.
Based on the most relevant reference points enriched with similarity information the location of the radio observing device is estimated. This includes the estimation of the building and the floor.

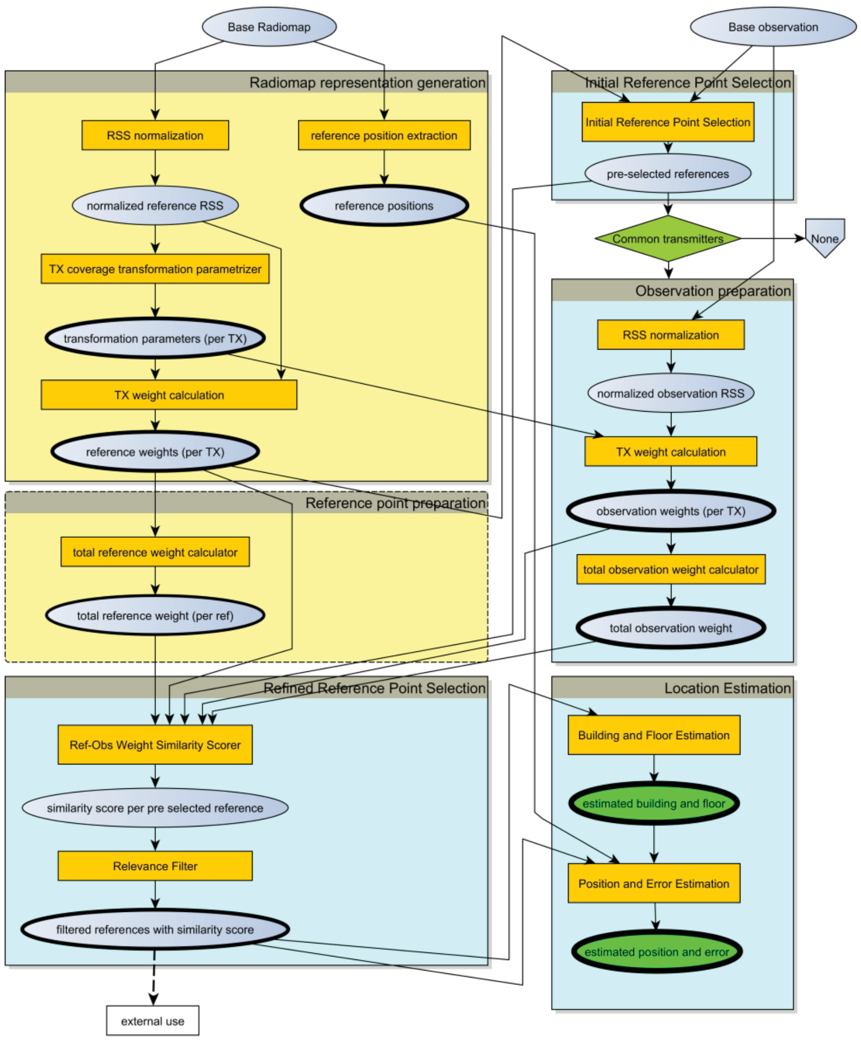


Figure 6. Overview of the FLIP algorithm. Elliptic boxes represent data, rectangle boxes functions, and diamonds conditions. Yellow groups belong to phase 1, bluish to phase 2.

FLIP was compared to other methods [Berkvens et al. 2015, Choi et al. 2015, Knauth et al. 2015] using the UJIIndoorLoc [Torres-Sospedra et al. 2014] database, as shown in Table 1. The error quantile distribution and the floor accuracy in Fig. 7.

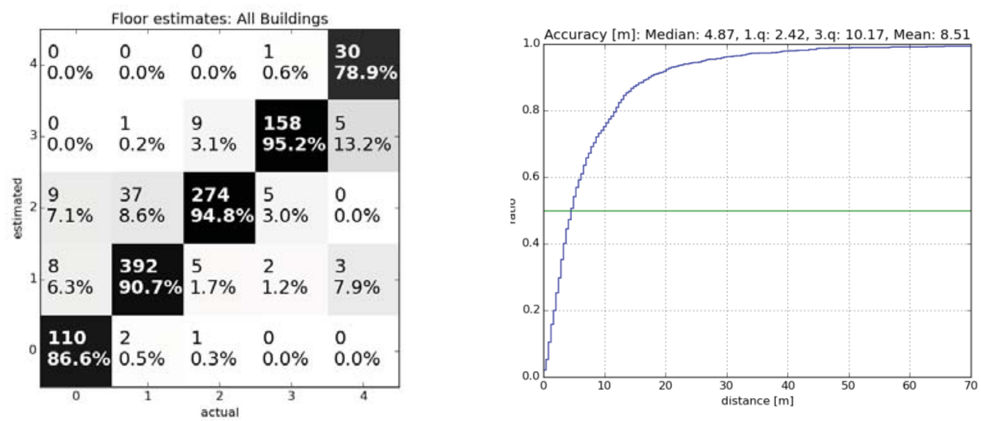


Figure 7. Left: Floor confusion matrix over all buildings. Right: Quantile distribution of position error distance. The blue curve indicates the results over all buildings, the median is indicated by the horizontal line.

It could be shown that the results are similar to competing approaches but more flexible to be also able to be deployed in mobile devices for longer use without much battery loss and still acceptable accuracy.

The median error obtained was 4.87 m (4m when separating data by building). The mean positioning error of 8.5 m is significantly larger than the median, due to outliers 70 m when building was misidentified. Building and floor misidentification rate was at 0.3% and 8.3% respectively. Results are comparable to other more elaborate methods [Choi et al. 2015 (2), Knauth et al. 2015 (3)], and far superior to other [Berkvens et al. 2015 (1)].

Only FLIP deals with device differences, and only flip and FCWC is fast performing.
The results refer to an initial selection of reference points of $N_{ref} = 300$, which is 1.5 of the total number of reference points.

Approach	**Building**	**Floor**	**Pos error [m]**		**Comp.**	**Fast**
	err [%]	*err [%]*	*mean*	*median*		
SPFP [3]	0	4	7.7	N/A	No	No
FCWC [3]	0	6	9.7	7	No	Yes
MLE [1]	4.86	14.76	19.13	8.29	No	No
kNN [1]	4.86	14.58	18.96	8.29	No	No
kNN [2]	0.2	11.5	9.69	N/A	No	No
PCA-LDA [2]	0	7.7	8.16	N/A	No	No
PCA-LDA (AP) [2]	0	3.6	7.59	N/A	No	No
ELM-AE [2]	0	7.3	7.65	N/A	No	No
ELM-AE (AP) [2]	0	6.7	7.64	N/A	No	No
FLIP	0.3	8.3	8.51	4.87	Yes	Yes

Table 1. Positioning results on UJIIndoorLoc data.

References

Berkvens et al. (2015), "Localization performance quantification by conditional entropy," in Proc. Int Indoor Positioning and Indoor Navigation (IPIN) Conf, pp. 1–7, Oct. 2015.

Caso et al. (2015), "A Mixed Approach to Similarity Metric Selection in Affinity Propagation-Based WiFi Fingerprinting Indoor Positioning". Sensors 15, Nr. 11 (30. Oktober 2015): 27692–720. doi:10.3390/s151127692.

Choi et al. (2015), "Machine learning for indoor localization: Deep learning and semi-supervised learning," in USB On-Site Proceedings of the Sixth International Conference on Indoor Positioning and Indoor Navigation (IPIN), 2015.

Hu et al. (2015), "Improving Wi-Fi Indoor Positioning via AP Sets Similarity and Semi-Supervised Affinity Propagation Clustering". International Journal of Distributed Sensor Networks 2015 (2015): 1–11. doi:10.1155/2015/109642.

Knauth et al. (2015), "Fingerprint calibrated centroid and scalar product correlation rssi positioning in large environments," in Proc. Int Indoor Positioning and Indoor Navigation (IPIN) Conf, pp. 1–6, Oct. 2015.

Sha et al. (2015), "NRLoc: Neighbor Relative RSS-Based Indoor Localization System". In Algorithms and Architectures for Parallel Processing: 15th International Conference, ICA3PP

2015, Zhangjiajie, China, November 18-20, 2015, Proceedings, Part I, herausgegeben von Guojun Wang, Albert Zomaya, Gregorio Martinez Perez, and Kenli Li, 609–21. Cham: Springer International Publishing, 2015. http://dx.doi.org/10.1007/978-3-319-27119-4_42.

Swangmuang and Krishnamurthy (2008), "On clustering RSS fingerprints for improving scalability of performance prediction of indoor positioning systems". In *Proceedings of the first ACM international workshop on Mobile entity localization and tracking in GPS-less environments*, 61–66. San Francisco, California, USA: ACM, 2008.

Torres-Sospedra et al (2014), "Ujiindoorloc: A new multi-building and multi-floor database for wlan fingerprint-based indoor localization problems," in Indoor Positioning and Indoor Navigation (IPIN), 2014 International Conference on, pp. 261–270, IEEE, 2014.

Comparison of Different Vector Distance Measure Calculation Variants for Indoor Location Fingerprinting

Guenther Retscher, Julian Joksch

Department of Geodesy and Geoinformation, Research Group Engineering Geodesy, TU Wien, Vienna, Austria

Abstract.

The study-at-hand discusses Wi-Fi location fingerprinting in an indoor environment. Wi-Fi is a predestinated signal-of-opportunity which can be used for positioning of a mobile user as most devices nowadays incorporate a Wi-Fi card and it is available in many buildings and public spaces. For the determination of the user location in the fingerprinting method signal strength observations are carried out in two phases. In the first training phase signal strength measurements from the visible Wi-Fi Access Points are collected to build-up a fingerprint database. In the following positioning phase, a user can be located and tracked if he carries out similar measurements and compares them with the values in the fingerprinting database. For the matching a distance criterion is applied to obtain the best estimation of the users' location. In analytical form the use of nine different vector distances for such an approach is investigated. The selected distances included the Manhattan, Euclidean, Chebyshev, Canberra, Cosine, Sorensen, Hellinger, Chi-square and Jeffrey vector distance. In the test bed in an office environment four multiple-SSID (Service Set Identification) Wi-Fi networks existed at a physical single Access Point location. From the results in this investigation it could be seen that not the use of all signal strength measurements yields to a better positioning solution but the measurements to one network out of the four provides a better performance. The achievable positioning accuracies depend mainly on the selection of the vector distance and matching algorithm. Furthermore, the Access Point architecture and configuration are determinant factors. In most tests in the selected office environment the Cosine vector distance provided the overall best performance followed by the Euclidean and Hellinger distance. Only with the Chebyshev distance significantly larger positioning errors occurred. In average a minimum mean distance error of

LBS 2016
13th Conference on Location-Based Services
Vienna, 14–16 November 2016

Published in "Proceedings of the 13th International Conference on Location-Based Services", edited by Georg Gartner and Haosheng Huang, LBS 2016, 14-16 November 2016, Vienna, Austria.

around 1.4 m could be achieved when using a single network in a multiple-SSID configuration.

Keywords. Location fingerprinting, matching algorithms, vector distance measures

1. Introduction

The number of mobile applications for the processing of location data increases continuously more and more. Since smartphones can receive and process GNSS and Wi-Fi signals the demands on availability, reliability and accuracy for positioning has also increased. Outdoors the accuracy can reach a view meters, but indoors it is usually much lower. Because GNSS signals can only be attenuated received in buildings, other systems had to be developed, which use the same hardware, the cellular phone. Using an existing Wi-Fi technology, an indoor absolute positioning system can be built with little effort and low costs.

In this analytical study the use of the location fingerprinting method is evaluated. A test area in an office environment with a regular grid of reference points was built therefore. At each reference point (RP) the so-called fingerprint, the unique signature of the received signal strength (RSS) of surrounding Wi-Fi Access Points (APs), was measured and stored in a training database. In the next step, fingerprints of off-grid test points TPs were taken in the positioning phase. By the similarity of the fingerprints of test and reference points the position of the test points can be obtained, by using several vector distances and matching methods. In this study deterministic fingerprinting algorithms based on the nearest neighbour (NN), K-nearest neighbour (KNN) and K-weighted nearest neighbour (KWNN) matching algorithms are investigated. The estimated position is then the position of the fingerprint with the minimum vector distance *VD*. Most commonly the Euclidean distance is employed for this task which is calculated for each AP in the positioning phase from the fingerprinting database values obtained in the training phase. The Euclidean distance is a special case of the more universal Minkowski distance. Apart from this vector distances the use of the Manhattan, Chebyshev, Canberra, Cosine, Sorensen, Hellinger, Chi-Square and Jeffrey distance are assessed. The resulting positioning performance of these nine different calculation variants is analyzed and compared in detail. In the field test site RSS measurements to six APs of four different multiple Wi-Fi networks (i.e., multiple-SSID (Service Set Identification) which offer different MAC addresses at a single physical AP) and a combined database of all networks are available for comparison. Thereby four different user orientations were measured in the training phase and two in the positioning phase describing the possible movement directions of the user.

The paper is organized as follows: Firstly, the basics of location fingerprinting are examined and summarized in section 2. It is discussed that fingerprinting is a so-called feature-based localization technology. In section 3 the fingerprinting matching approaches are evaluated and then in section 4 the suitable vector distance *VD* calculation variants. The field campaign set-up and test bed are presented in section 5 followed by a detailed assessment of the achieved positioning results in section 6. Finally, concluding remarks and an outlook on future work are given in section 7.

2. Basics of Wi-Fi Location Fingerprinting

Location fingerprinting is a feature-based positioning method. This term was introduced by Niedermayr & Wieser in 2012 to describe that any type of spatially varying features can be used for positioning. In contrast to common localization methods where usually distances, distance differences or angles are measured so that the coordinates can easily be computed using analytical geometry, the position is obtained by comparison of measured location-dependent features with given reference values associated with specific positions. According to Niedermayr & Wieser (2012) the features need to fulfil the following requirements: (1) the signal field varies significantly with varying location (the spatial gradient should be high), (2) the field is constant in time or its temporal variation is predictable, and (3) the feature corresponding to the field is observable and can be uniquely quantified. The major advantage of this type of positioning technology is that they do not require an unobstructed line-of-sight (LOS) between the mobile user and known reference points (or satellites, in the case of GNSS). Figure 1 illustrates the concept of feature-based positioning.

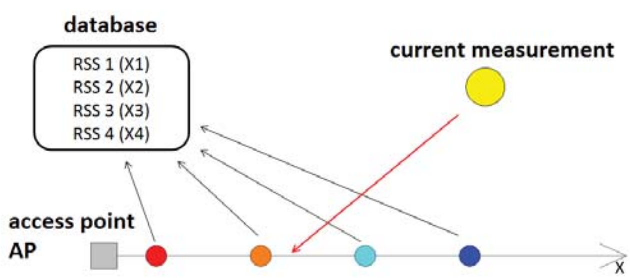


Figure 1. Operational principle of feature-based positioning

Within this positioning procedure a feature is selected, such as the received signal strength (RSS) of transmitters. Using a single RSS measurement, however, will usually not yield a unique solution. Thus, when using Wi-Fi for instance, the signal power of several Wi-Fi transmitters, i.e., the hotspots or Access Points (APs), has to be measured at the mobile client. From the comparison of the measured RSS and the reference RSS stored in a database the position of the user can be estimated. The reference values can either be derived in advance from georeferenced measurements taken during a mapping phase and stored in a database, or from numerical models. Commonly reference measurements are performed on a number of reference points (RPs) distributed throughout the area of interest in a so-called training or off-line phase instead of the use of simulated models (which yield usually in much lower positioning accuracies). A database of RSS values measured on all RPs is built-up during this phase. The requirement is that the location of the RPs has to be determined in a local (e.g. related to the building in the case of indoor positioning) or global coordinate system (usually required for outdoor positioning). In the positioning or on-line phase, simply speaking, then the current location of the user is obtained by matching of the on-line measured RSS with the values in the RSS database. In other words, with the feature then the user's location is estimated by matching measurements with the closest predetermined location fingerprints included in so-called fingerprinting or radio maps (Niedermayr & Wieser, 2012; Retscher, 2016). The matching methods are described in the following section 3.

Fingerprinting was firstly employed for Wi-Fi (or WLAN) positioning with the system RADAR in 2000 (Bahl and Padmanabhan, 2000; Kjærgaard, 2008). It is more robust to environmental effects on the RSS than using the RSS-based lateration algorithm. This is because the location fingerprinting algorithm constructs a search space according to the previously-measured RSS distributions in the radio maps. The advantage of constructing a fingerprinting database is that it can be used to consider a great number of detrimental effects from the surrounding environment, such as reflections and obstructions, into the radio maps and thus increases the accuracy for finding the best matching position based on RSS in the positioning phase (Retscher et al., 2012). Figure 2 shows an example for a radio map of a Wi-Fi AP derived from the training measurements using a smartphone in the test site (compare Figure 5).

The main problems in fingerprinting, however, are that the construction of a fine radio map leads to high workload and heterogeneous mobile devices measure RSS differently. Spatial interpolation techniques are usually employed for densification of the radio map and different devices are used for RSS measurements in the training phase to form a joint database (Retscher, 2016).

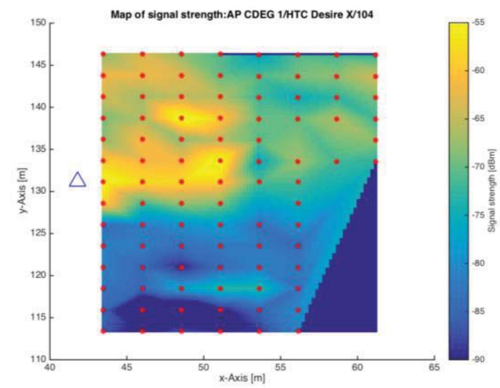


Figure 2. Example of a radio map of a single Wi-Fi Access Point (AP) in the class room of the test site (after Retscher & Roth, 2016)

3. Matching Approaches

The matching methods are classifications which define either which reference RSS values are incorporated into the position of the test points TPs ($\hat{l}_t$) – with weighting where appropriate – or which are rejected. Figure 3 illustrates the principle idea for the definition of the distance relationship between the DB of the training phase and the positioning phase (Retscher & Hofer, 2016). In the simplified case shown here RSS scans are measured to three APs (AP 1, 2 and 3) from two test points TP 1 and 2. The allocation of the positioning scans with the fingerprints in the DB is specified regarding to their corresponding minimum distance. In other words, the one that has the minimum vector distance *VD* is determined as the estimated location according to the selected distance of each training location. In the shown case then the scan is allocated to TP 1.

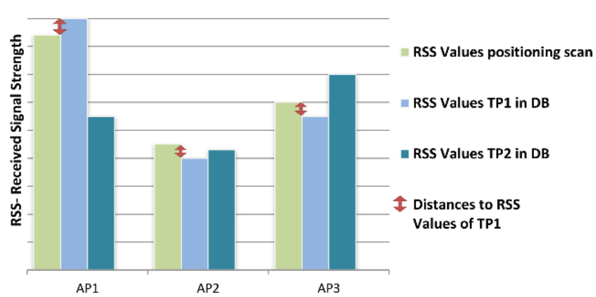


Figure 3. Allocation of RSS scans in the positioning phase to the training fingerprinting database DB (after Retscher & Hofer, 2016)

In this study only deterministic fingerprinting algorithms based on the nearest neighbour (NN), k-nearest neighbour (KNN) and k-weighted nearest neighbour (KWNN) matching algorithms are investigated. These are the most commonly employed algorithms and have been introduced by Bahl and Padmanabhan (2000). Their principle is briefly described in the following.

3.1. Nearest Neighbour (NN)

In this algorithm the distance vector d_t which contains the respective vector distances to all RPs $(d_1, d_2, d_3, \dots, d_R)$ is defined. Afterwards the minimum is determined and the coordinates are assigned to the TP as given in the following mathematical relationship:

$$d_t = \begin{bmatrix} d_{r=1} \\ d_{r=2} \\ d_{r=3} \\ \vdots \\ d_{r=R} \end{bmatrix} \rightarrow \min(\, d_t) \rightarrow r \tag{1}$$

with $\hat{l}_t = l_r$ where l_r is the coordinate vector of RP_r.

3.2. K-Nearest Neighbour (KNN)

In case of the KNN method a weighting of the nearest neighbours is performed. Thereby the weights are evenly split around the K RPs to be used and afterwards the coordinates l_r are multiplied by the respective weighting factor w_r and are divided by the sum of all w. The weighting factor w_r is the weighting from RP_r described in the form:

$$w_r = \frac{1}{K}, \; K \geq 2 \tag{2}$$

with

$$\hat{l}_t = \sum_{r=1}^{K} \frac{w_r}{\sum_{r=1}^{K} w_r} \cdot l_r. \tag{3}$$

Huang (2014) discusses that the accuracy increases if a K value of up to 10 in maximum is used and then it decreases again. That's why the calculation was carried out in this work with K values up to 10. The empirical determination revealed that $k = 3$ led to the best result (see Figure 7 in section 6.2).

3.3. K-Weighted Nearest Neighbour (KWNN)

For this method a weighting w_r is calculated in dependence of the respective vector distance $VD(s_t, s_r)$:

$$w_r = \frac{1}{|VD(s_t, s_r)|} \tag{4}$$

where $s_r$is the fingerprint from RP_r and s_t is the fingerprint from TP_t.

Similar as in the KNN method $\hat{l}_t$ is calculated from equation (3) to obtain the coordinate vector.

3.4. Positioning Accuracy

The most important aspect in the analysis and assessment of a localization method is the achievable positioning accuracy. Apart from the requirement to achieve acceptable positioning accuracies, of course also the performance and the costs have to be considered. In the following, it is briefly summarized how the positioning accuracies in the analyses in this study are defined and characterised.

Usually, the Mean Square Error MSE is employed to describe the achievable positioning accuracy. Universal is valid:

$$MSE(\hat{l}_t) = \left|(\hat{l}_t - l_t)^2\right| \tag{5}$$

with $\hat{l}_t = \begin{bmatrix} \hat{x}_t \\ \hat{y}_t \end{bmatrix}$.

From it follows:

$$MSE(\hat{x}_t, \hat{y}_t) = (\hat{x}_t - x_t)^2 + (\hat{y}_t - y_t)^2 \tag{6}$$

and further of the Root Mean Square Error (RMSE):

$$RMSE(\hat{x}_t, \hat{y}_t) = \sqrt{(\hat{x}_t - x_t)^2 + (\hat{y}_t - y_t)^2}. \tag{7}$$

Because it concerns, in this context, the distance error of the ascertained coordinates of the $\hat{l}_t$ of the corresponding test points TPs respective their true coordinates l_t, the error definition $RMSE(\hat{x}_t, \hat{y}_t)$ becomes – as in preceding literature (see e.g. Moghtadaiee & Dempster, 2015) – the distance error DE at further down as:

$$DE(TP_t) = \sqrt{(\hat{x}_t - x_t)^2 + (\hat{y}_t - y_t)^2}. \tag{8}$$

To obtain the mean distance error (short: MDE) an average over all TPs is calculated as given in equation (9):

$$MDE(\hat{l}) = \frac{1}{T} \cdot \sum_{t=1}^{T} DE(TP_t). \tag{9}$$

With equations (5) up to (9) all error measures are defined which are used in the analyses in this study. In the following, the application of the matching approaches in combination with different vector distances *VD* is discussed in more detail.

4. Vector Distance Calculation Variants

The following derivations of the different vector distances *VD* are based on the similarity relation of vectors. For the derivation of the different *VD*s the RSS vector s of a measurement point is described in its universal form:

$$s = \begin{bmatrix} RSS_{\mathrm{p=1}} \\ RSS_{\mathrm{p=2}} \\ RSS_{\mathrm{p=3}} \\ \vdots \\ RSS_{\mathrm{p=P}} \end{bmatrix} \tag{10}$$

containing the RSS_p values to all visible APs whereby the variable $\mathrm{p} = 1,2, \dots, \mathrm{P}$ describes the elements of the vector s, namely the averaged RSS values for each AP. p is therefore the number of APs.

Several different approaches are possible to derive *VD*s (see e.g. Machaj & Brida, 2011 or Moghtadaiee & Dempster, 2015). In the following, the derivations are started with the universal Minkowski distance which then leads to three special cases of this *VD*. Furthermore, six other *VD*s are introduced which are used in the comparing performance analysis in this study.

4.1. Minkowski Distance

The following equation describes the universal Minkowski distance L_q:

$$L_q = \sqrt[q]{\sum_{p=1}^{P} \left| s_{t,p} - s_{r,p} \right|^q} \tag{11}$$

where $s_{t,p}$ is the RSS_p of the fingerprint TP_t measured in the positioning phase on the test point to be positioned, $s_{r,p}$ the RSS_p of the fingerprint RP_r measured in the training phase on the reference point, q the norm parameter and L_q is the norm q between two points. The following three vector distances are defined by change of the norm parameter q.

4.2. Manhattan Distance

By choosing $q = 1$ for the norm parameter in the Minkowski distance formula, one receives the Manhattan distance L_1. This VD represents the distance between two points in a right-angled grid (see the two distances in Figure 4 with the same length) and is also called city-block distance, boxcar distance or taxicab distance. This *VD* is used for the calculation of the distance between two buildings (or crossroad points) in grid-shaped cities, such as in Manhattan, New York – hence the name Manhattan distance (Krause, 1986). The Manhattan distance L_1 results in the following equation:

$$L_1 = \sum_{p=1}^{P} \left| s_{t,p} - s_{r,p} \right|. \tag{12}$$

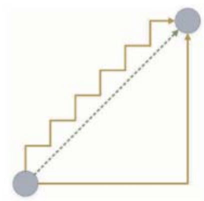


Figure 4. Illustration of two examples for the Manhattan distances with same length (brown lines) and the Euclidean distance (dotted green line) (after Favre-Bulle P, 2015)

4.3. Euclidean Distance

The Euclidean distance L_2 is the most common used vector distance and describes the distance of the shortest direct path between two points in the Euclidean space. This *VD* is also a special case of the Minkowski distance if a value of 2 is used for q. Then L_2 can be derived from L_q in the form:

$$L_2 = \sqrt{\sum_{p=1}^{P} \left| s_{t,p} - s_{r,p} \right|^2}. \tag{13}$$

4.4. Chebyshev Distance

By setting $q = \infty$ within formula (11) describing the Minkowski distance, the Chebyshev distance L_∞ is derived. This derivation is also called maximum value distance calculation and determines the maximum absolute difference between the two vector pairs $s_{t,p}$ and $s_{r,p}$. Then L_∞ can be described by the following formula:

$$L_\infty = \max_p \left| s_{t,p} - s_{r,p} \right|. \tag{14}$$

4.5. Canberra Distance

The Canberra distance d_{Can} is similar to the Manhattan distance L_1, however, the distance is weighted by the sum of the absolute values. Every summand of d_{Can} has therefore a value between 0 and 1. The mathematical relationship is given by:

$$d_{Can} = \sum_{p=1}^{P} \frac{\left| s_{t,p} - s_{r,p} \right|}{\left| s_{t,p} \right| + \left| s_{r,p} \right|}. \tag{15}$$

4.6. Cosine Distance

The Cosine distance d_{Cos} describes rather the similarity between two vectors than a distance. The right term in equation (16) can have a value between -1 and 1. The higher the value, the more alike are the two vectors. By the deduction of this term by 1, one can interpret the result as a *VD*.

$$d_{Cos} = 1 - \frac{\sum_{p=1}^{P} s_{t,p} \cdot s_{r,p}}{\sqrt{\sum_{p=1}^{P} s_{t,p}^2} \cdot \sqrt{\sum_{p=1}^{P} s_{r,p}^2}} . \tag{16}$$

4.7. Sorensen Distance

The Sorensen distance, also called Bray Curtis distance, is another derivation of the Manhattan distance L_1, where its value is normalized. Then all values are positive and lie between 0 and 1. In case of $d_{Sor} = 0$, $s_t = s_r$ which means that there are two equal vectors. The mathematical relationship is:

$$d_{Sor} = \frac{\sum_{p=1}^{P} |s_{t,p} - s_{r,p}|}{\sum_{p=1}^{P} (s_{t,p} + s_{r,p})} . \tag{17}$$

4.8. Hellinger Distance

For this distance the norm from the square roots of the fingerprint vectors s_t and s_r is used divided by $\sqrt{2}$. This results in:

$$d_{Hell} = \frac{1}{\sqrt{2}} \cdot \left\| \sqrt{s_t} - \sqrt{s_r} \right\|_2 . \tag{18}$$

4.9. Chi-square Distance

The Chi-square distance is similar to the Euclidean distance L_2 but is weighted by a factor $\rho_p = \frac{s_{t,p} + s_{r,p}}{2}$ and therefore defined as:

$$d_{Chi} = \sum_{p=1}^{P} \frac{\left(s_{t,p} - \rho_p\right)^2}{\rho_p} . \tag{19}$$

4.10. Jeffrey Distance

Finally, for the Jeffrey distance also ρ_p is used and then the *VD* has the form:

$$d_{Jeff} = \sum_{p=1}^{P} \left(s_{t,p} \cdot \log_{10}\left(\frac{s_{t,p}}{\rho_p}\right) + s_{r,p} \cdot \log_{10}\left(\frac{s_{r,p}}{\rho_p}\right) \right) . \tag{20}$$

Apart from the Minkowski distance these nine vector distances *VD*s are analysed regarding their performance and achievable positioning accuracies. The following section 5 describes first the indoor test bed and section 6 the major results of the campaign.

5. Indoor Testbed and Measurements

The indoor test bed is located on the ground floor of a multi-storey office building of the TU Wien – Vienna University of Technology. Figure 5 shows the location of the 93 reference points RPs (illustrated as black dots) distributed in a regular grid with spacing of around 2.5 m between the grid points and the randomly selected six test points TPs (blue dots). The RPs cover mainly three different areas, i.e., parts of a class room in the upper left area, an area with desktop computers in the upper right part and the foyer in the lower part of the test site. The distribution of all six visible Access Points APs CDEG-1 to -6 (indicated as red triangles) is also shown in the Figure. Figure 6 givens some impressions of how the test bed looks like. As can be seen in the left Figure 6, an entresol exists in the foyer whereby the maximum ceiling height is 5 m.

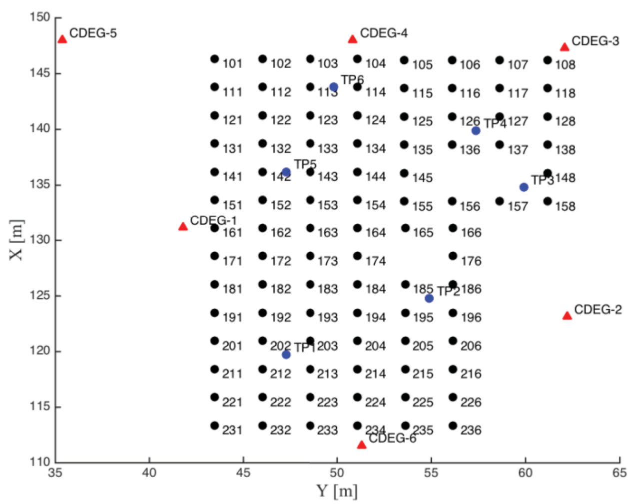


Figure 5. Distribution of reference points RPs (black dots), test points TPs (blue dots) and Access Points APs (red triangles) in the indoor test bed

The three different areas in the test bed have been chosen to provide different conditions for Wi-Fi signal propagation regarding damping and shielding of the radio signals. An other specific feature of the test bed is that in total four different Wi-Fi networks are provided. Besides, these consist of the network eduroam, tunet, tunetguest and wlanipsec. These networks are so-called multiple-SSID (short for Service Set Identifier) Wi-Fi networks. In this case several networks at a physical AP location and a single transmitter as offered. In other words, there are four Wireless Local Area Networks (WLANs) (1, 2, 3 and 4) with native as 1 and mapping to 4 different SSIDs (one, two, three and four) on any of the six APs receivable throughout the whole test bed. A different encryption for the networks is usually applied. On overview about the characteristics of the four networks is given in Table 1. As can be seen the networks are either encrypted or not. With this set-up the rights are defined how a user may access the Wi-Fi network. Therefore, each network adapter needs his own MAC address. Thus, RSS to 24 different MAC addresses could be measured. Additional RSS measurements to other visible APs in this area were omitted as they could not be received on the majority of the TPs. The measured RSS ranged between -64 to -85 dBm (see section 6.1 for further details).

Figure 6. Impressions from the indoor test bed showing the foyer on the right and the class room on the left

SSID	Characteristics
eduroam	Network for students, staff and participants of this international network
tunet	Network for students and staff as well as visiting scholars and conference participants. The network is encrypted.
tunetguest	Alternative for network tunet, not encrypted.
wlanipsec	Network only for staff of TU Wien while using a VPN (Virtual Private Network) connection.

Table 1. Overview of the characteristics of the four different multiple-SSID networks visible in the test bed

6. Discussion of Evaluation Results

In this section the major results of the investigations are presented. At the beginning of this section general aspects are briefly mentioned and the measurement results and corrections for fingerprinting are discussed in the following. Here the empirical determination of the optimum value for *K* in the matching approach is elaborated first followed by a detailed discussion of the achieved distance error DE and the mean distance error MDE. The calculations were performed with newly developed MatLab routines (Joksch, 2016).

6.1. General aspects

In the training phase of the fingerprinting approach RSS scans on in total 93 reference points RPs (compare Figure 5) were measured in four different user orientations aligned to the axes of the building. The main reason for measuring in four different orientations is that the Wi-Fi signals are significantly shielded by the human body of the observer if he is located between the AP and the mobile device. For the evaluation, however, only an average over all four orientations was used. The measured RSS values $RSS_{r,p,m}$ are averaged on each RP per SSID using the following relationship:

$$\overline{s}_{r,p} = \frac{\sum_{m=1}^{M_{r,p}} RSS_{r,p,m}}{M_{r,p}} \tag{21}$$

where $RSS_{r,p,m}$ are the measurements m of the RSS to AP_p on RP_r and $M_{r,p}$ is the number of measurements to AP_p on RP_r.

The averaged values have then been summarized in the fingerprint vector s_r on each RP_r in the form:

$$s_r = \begin{bmatrix} \overline{s}_{r,p=1} \\ \overline{s}_{r,p=2} \\ \overline{s}_{r,p=3} \\ \vdots \\ \overline{s}_{r,p=P} \end{bmatrix}. \tag{22}$$

Also on the six test points TPs scanned in the positioning phase the measured RSS values were averaged as given in:

$$\overline{s}_{t,p} = \frac{\sum_{m=1}^{M_{t,p}} RSS_{t,p,m}}{M_{t,p}} \tag{23}$$

where $RSS_{t,p,m}$ are the measurements m of the RSS to AP_p on TP_t and $M_{t,p}$ is the number of measurements to AP_p on TP_t.

Again the averaged values are included in the fingerprint vector s_t on each TP_t:

$$s_t = \begin{bmatrix} \overline{s}_{t,p=1} \\ \overline{s}_{t,p=2} \\ \overline{s}_{t,p=3} \\ \vdots \\ \overline{s}_{t,p=P} \end{bmatrix}. \tag{24}$$

As an example Table 2 presents the fingerprint vectors for the AP CDEG-1 with the four multiple-SSID networks measured on the six test point TP 1 up to TP 6. When looking at the RSS values of the four different networks, i.e., eduroam, tunet, tunetguest and wlanipsec, it can be seen that the RSS values are quite similar and the variations are low compared to short-time fluctuations of the RSS in the test bed as reported by Retscher & Roth (2016) and Retscher & Tatschl (2016a). Also a significant difference in RSS values on the six different TPs can be seen. This is advantageous for positioning using fingerprinting as the fingerprints should be unique on each user locations throughout the test site. For the AP CDEG-6, however, the RSS difference on five of the six TPs is much smaller. It only varies between -65 to -72 dBm. Only the measurements on TP 6 are different with a value of around -80 dBm (see Joksch, 2016 for further details). Then it would be more difficult to estimate the correct user's location if only this single AP would be used. In addition, only on two test points, i.e., TP 5 and 6, no signal could be received from AP CDEG-2. This two TPs are located in the class room and on these locations the Wi-Fi signal of AP CDEG-2, which is outside quite far away (compare Figure 5), was shielded due to the walls and their structure for the whole duration of the field campaign. In this case where no RSS signal can be received a value of -99 dBm is assigned in the fingerprinting vector.

SSID	TP 1	TP 2	TP 3	TP 4	TP 5	TP 6
eduroam	-84.0	-81.0	-68.0	-65.0	-56.4	-62.8
tunet	-85.0	-81.5	-68.2	-64.5	-56.0	-63.0
tunetguest	-85.0	-80.4	-66.5	-66.5	-56.0	-64.5
wlanipsec	-82.5	-80.8	-67.5	-65.3	-55.3	-63.0

Table 2. Example for RSS values in [dBm] in the fingerprint vector s_t of one AP CDEG-1 for the four different multiple-SSID networks on the six TPs

6.2. Determination of the K-Value for the Matching Method

For the empirical determination of the optimum value for K for the K-nearest neighbour (KNN) or K-weighted nearest neighbour (KWNN) matching algorithm (see section 3.2 and 3.3 respectively) the Euclidean distance is calculated where all RSS measurements of the four multiple-SSI networks were utilized. As can be seen from Figure 7 the results do not follow the theoretical relationship described in section 3.2. On account of the minimum for a MDE of 2.24 m with $k = 3$, this value is selected for the further evaluation in this study.

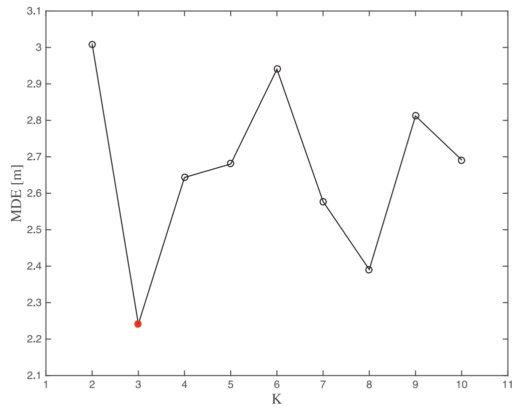


Figure 7. Progression of the MDE in [m] for rising *K*-values from 1 to 10 (minimum obtained *K*-value of 3 is highlighted in red)

6.3. Vector Distance Results Comparison

The different vector distances *VD*s described in section 4 in combination with the matching approaches NN, KNN and KWNN are calculated for every of the six TPs within every SSID network. Then in the following, the *VD*s were sorted in dependence of their dimension and the usable distances were taken. As described in section 3.1 to 3.3, the correct value is the first one for the NN and the first three values for KNN and KWNN method. Afterwards the positions $\hat{l}_t = (\hat{x}_t, \hat{y}_t)$ are calculated using the relationship $\hat{l}_t = l_r$ for the NN where l_r is the coordinate vector of RP_r and respectively equation (3) in the case of the KNN and KWNN matching approach.

In the next step, the resulting distance errors (DE) and mean distance errors (MDEs) calculated with equations (8) and (9) given in section 3.4 of the four different multiple-SSID networks were analyzed. Table 3 presents the DEs in the four different SSID networks and in total whereas Table 4 summarizes the MDEs in the SSID network eduroam of all six TPs for each of the nine *VD*s introduced in section 4. As can be seen from Table 3 if one looks at the column of the total DE, the minimum DE of around 0.30 m is achieved for the Euclidean and Hellinger *VD*s. Furthermore, these two *VD*s do not result in the largest DE. The maximum DE of 8.96 m occurs when using the Chebyshev *VD* in the SSID network tunetguest.

In general, the lowest overall DE occurred in the eduroam network. Thus, in the following only results in this SSID network are presented. Further results concerning the MDE and the four SSID networks are presented in Retscher and Joksch (2016) and have proven that the eduroam network is the one to be chosen. Here it could be seen that the smallest MDE in eight of nine cases occurred. Thereby the smallest MDE is achieved four times for the KWNN matching approach where *K* was set to 3. For all vector distances the largest MDEs in the eduroam network was obtained if the NN approach is employed. This can also be observed if one looks at Table 4 and Figures 8 to 10. The difference between the smallest MDE and the largest is about 1.10 m (range of 1.40 to 3.50 m). The use of the Cosine distance resulted in a MDE of 1.39 m for the KNN and 1.40 m for the KWNN. The next best results with differences of only 2 to 3 cm was achieved with the Euclidean and Hellinger distance. The Chi-square and the Jeffrey MDE differs only by 8 cm. Also the results with the Manhattan, Sorensen (MDE 1.67 m) and Canberra distance (MDE 1.88 m) lie under the overall MDE of 1.90 m using the KWNN matching approach. With the Chebyshev distance the worst result with a MDE of 2.42 m was achieved.

Table 4 presents the MDEs separately for each of the six test points TP 1 to TP 6 in the eduroam SSID network. The smallest MDE resulted in only 0.43 m on TP 6 using the Cosine, Chi-square and Jeffrey *VD* and the KWNN matching approach. The MDE of the Euclidean distance was slightly higher, i.e., 0.58 m. This cannot be seen as a significant difference as the localization accuracy of Wi-Fi fingerprinting is usually not that high. If one looks at Figures 8 to 10, however, it can be seen that positioning accuracies can be higher, i.e., on the half meter level, than what usually is achieved in many tests reported in the literature. Qualifying it must be mentioned that the performance and achievable positioning accuracies depend very much on the environment and the signal propagation conditions during the measurements. It is always reported that the repeatability might be a problem. A suitable strategy to retrieve this situation might be the use of continuously recorded RSS measurements in the area of interest. Retscher and Tatschl (2016a and b) have developed a differential Wi-Fi positioning approach where RSS scans are performed on selected points in the test bed. This points are equipped with low-cost Raspberry Pi's serving as reference stations as it is done in a differential GNSS network. Then it is possible to derive corrections in real-time which are applied by the mobile client.

6.4. MDE Comparison for Euclidean and Cosine *VD*

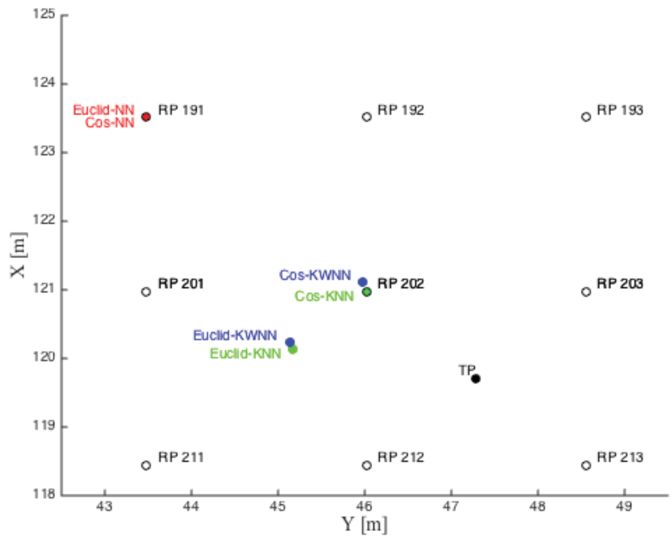
Figures 8 to 10 provide a graphical representation of the positioning accuracies for each TP when using the Euclidean and Cosine *VD*. As can be seen the results can be quite different. In general, the KNN and KWNN matching approaches outperform the NN approach. The resulting positioning errors lie in the range of around 0.40 up to 5.40 m (compare Table 4). The best result is obtained on TP 5 in this range using both *VD*s and KNN and KWNN approach. This test point is located in the class room (compare Figure 5). On the other hand, the worst result is achieved under the entresol in the foyer where TP 1 is located using the NN algorithm.

		eduroam		tunet		tunetguest		wlanipsec		total	
		min	**max**	**min**	**max**	**min**	**max**	**min**	**max**	**min**	**max**
Man-hattan	NN	1.27	5.38	1.27	5.38	1.27	5.38	1.27	6.83	1.27	5.38
	KNN	0.60	2.99	0.95	4.67	0.60	7.20	0.60	4.67	0.60	4.67
	KWNN	0.55	3.01	1.16	4.87	0.71	7.83	0.63	4.79	0.66	4.72
Eucli-dean	NN	1.27	5.38	1.27	5.38	1.27	5.38	1.79	6.46	1.27	4.57
	KNN	0.42	2.46	0.42	3.90	1.74	7.20	0.42	5.49	0.42	5.49
	KWNN	0.35	2.57	0.32	3.49	1.59	7.73	0.33	5.48	0.31	5.18
Cheby-shev	NN	1.27	6.46	1.27	4.57	1.27	8.96	1.79	6.46	1.79	6.34
	KNN	0.60	4.67	0.42	3.90	1.34	4.35	2.15	7.20	0.42	5.56
	KWNN	0.73	4.69	0.34	3.72	1.39	4.72	2.13	7.654	0.35	5.57
Can-berra	NN	1.27	5.38	1.27	5.38	1.27	5.38	1.27	6.83	1.27	5.38
	KNN	0.95	2.99	0.95	4.67	0.60	7.20	0.60	4.67	0.60	4.67
	KWNN	0.54	3.03	1.11	4.921	0.72	7.76	0.62	4.82	0.68	4.70
Cosine	NN	1.27	5.38	1.27	5.38	1.27	5.38	1.79	6.46	1.79	4.57
	KNN	0.42	2.46	0.42	3.90	1.74	5.49	0.42	5.49	0.60	5.87
	KWNN	0.43	2.68	0.59	3.02	1.30	4.01	0.29	5.48	0.82	5.62
Soren-sen	NN	1.27	5.38	1.27	5.38	1.27	5.38	1.27	6.83	1.27	5.38
	KNN	0.60	2.99	0.95	4.67	0.60	7.20	0.60	4.67	0.60	4.67
	KWNN	0.55	3.01	1.16	4.87	0.71	7.83	0.63	4.80	0.67	4.72
Hell-inger	NN	1.27	5.38	1.27	5.38	1.27	5.38	1.79	6.46	1.27	4.57
	KNN	0.42	2.46	0.42	3.90	1.74	7.20	0.42	7.20	0.42	2.99
	KWNN	0.35	2.59	0.30	3.55	1.61	7.67	0.32	7.76	0.30	3.08
Chi-square	NN	1.27	5.38	1.27	5.38	1.27	5.38	1.79	6.46	1.27	4.57
	KNN	0.42	2.46	0.42	3.90	1.74	7.20	0.42	7.20	0.42	2.99
	KWNN	0.43	2.72	0.53	3.21	1.43	8.16	0.27	8.33	0.42	3.17
Jeffrey	NN	1.27	5.38	1.27	5.38	1.27	5.38	1.79	6.46	1.27	4.57
	KNN	0.42	2.46	0.42	3.90	1.74	7.20	0.42	7.20	0.42	2.99
	KWNN	0.43	2.72	0.53	3.21	1.43	8.16	0.27	8.33	0.42	3.17

Table 3. DEs in [m] in the four different SSID networks and in total for the different *VD*s
Green marked values indicate the minimum DE and red the maximum DE of each vector distance *VD*.

		TP 1	TP 2	TP 3	TP 4	TP 5	TP 6
Man-hattan	NN	5.38	1.79	4.01	1.79	4.60	1.27
	KNN	2.99	2.15	2.46	0.60	1.52	0.95
	KWNN	3.01	2.21	2.56	0.61	1.07	0.55
Eucli-dean	NN	5.40	1.79	4.01	1.79	4.57	1.27
	KNN	2.15	2.15	2.46	0.60	0.42	0.95
	KWNN	2.21	2.19	2.57	0.63	0.35	0.58
Cheby-shev	NN	1.79	4.01	6.46	1.79	4.57	1.27
	KNN	3.64	2.15	4.67	0.60	2.83	0.95
	KWNN	3.55	2.22	4.69	0.76	2.58	0.73
Can-berra	NN	5.38	4.01	4.01	1.79	4.57	1.27
	KNN	2.99	2.15	2.46	1.79	1.52	0.95
	KWNN	3.03	2.22	2.62	1.76	1.11	0.55
Cosine	NN	5.38	4.01	4.01	1.79	4.57	1.27
	KNN	1.79	2.15	2.46	0.60	0.42	0.95
	KWNN	1.91	2.25	2.68	0.65	0.48	0.43
Soren-sen	NN	5.40	1.79	4.01	1.79	4.57	1.27
	KNN	2.99	2.15	2.46	0.60	1.52	0.95
	KWNN	3.01	2.21	2.56	0.61	1.07	0.55
Hell-inger	NN	5.38	4.01	4.01	1.79	4.57	1.27
	KNN	2.15	2.15	2.46	0.60	0.42	0.95
	KWNN	2.22	2.22	2.59	0.64	0.35	0.57
Chi-square	NN	5.38	4.01	4.01	1.79	4.57	1.27
	KNN	2.15	2.15	2.46	0.60	0.42	0.95
	KWNN	2.30	2.30	2.72	0.68	0.44	0.43
Jeffrey	NN	5.38	4.01	4.01	1.79	4.57	1.27
	KNN	2.15	2.15	2.46	0.60	0.42	0.95
	KWNN	2.30	2.30	2.72	0.68	0.44	0.43

Table 4. MDEs in [m] in the SSID network eduroam of all six TPs for the different *VD*s
Green marked values indicate the minimum MDE and red the maximum MDE of each vector distance *VD*. The underlined values are the smallest MDE.



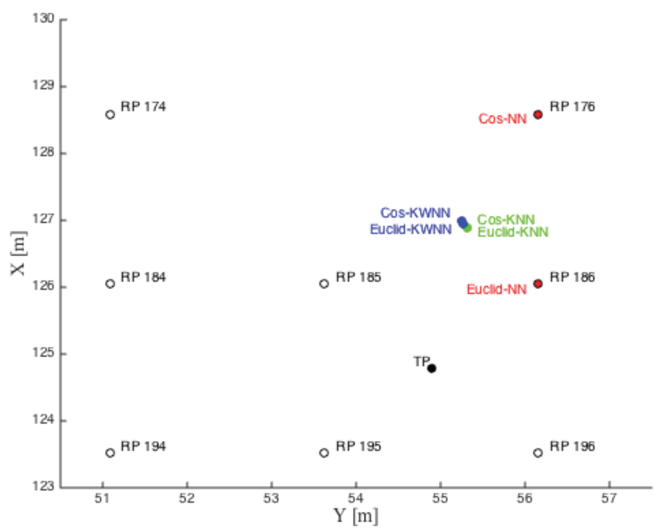
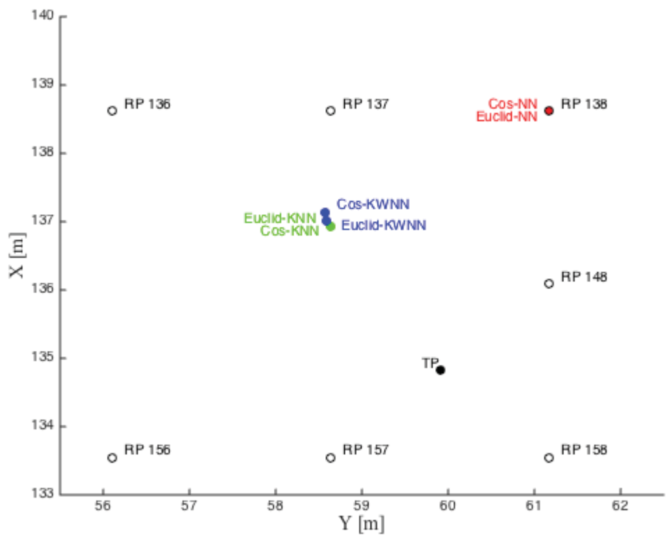


Figure 8. Comparison of the positioning errors in the eduroam network for TP 1 and TP 2 for the Euclidean and Cosine vector distance *VD* and NN, KNN and KWNN matching approach



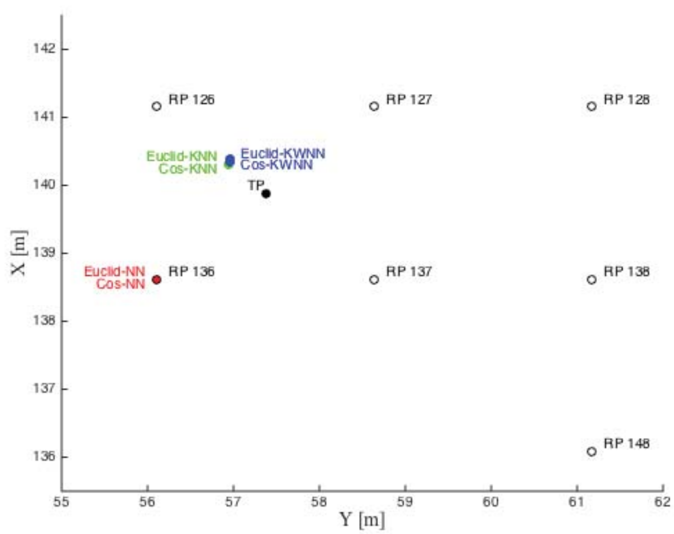


Figure 9. Comparison of the positioning errors in the eduroam network for TP 3 and TP 4 for the Euclidean and Cosine vector distance *VD* and NN, KNN and KWNN matching approach

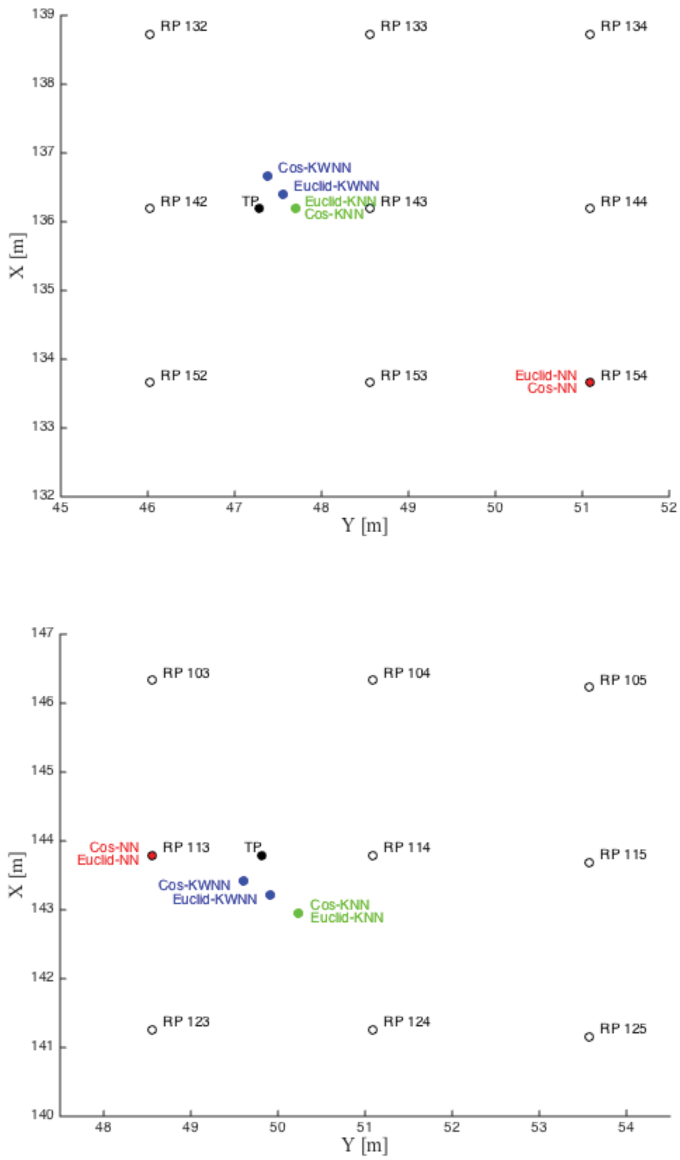


Figure 10. Comparison of the positioning errors in the eduroam network for TP 5 and TP 6 for the Euclidean and Cosine vector distance *VD* and NN, KNN and KWNN matching approach

6.5. Discussion of the Major Outcome

For the assessment of the quality of positioning using Wi-Fi fingerprinting the distance errors DEs and mean errors MDEs were analyzed. It was found that one network should be selected if multiple-SSID networks are existing. In the building of TU Wien where four multiple-SSI networks are provided the network eduroam resulted in the best positioning accuracy and performance. It is not recommended to average over all existing networks. This would lead to a false weighting of the observations.

If one looks at the results using the nine different vector distances *VD*s which were investigated no significant differences between most of them are found. Thus, it cannot be recommended in general, which *VD* should be chosen as the right selection depends very much on the surrounding environment and the present interference conditions affecting the propagation of the Wi-Fi signal. The most commonly employed Euclidean distance in fingerprinting showed no significant MDE difference to the slightly better performing Cosine vector distance (see also Retscher & Joksch, 2016). Figures 8 to 10 have shown that the resulting positions on the TPs obtained with the KNN and KWNN are mostly the closest to the true location of the TP. The DE is then around half a meter. Only the NN positions are further away from the true location.

7. Concluding Remarks and Outlook

Current investigations are focused on the additional integration of continuous long-time measurements to consider temporal and spatial signal variations of the Wi-Fi signal propagation. A concept and first test results of using reference stations which continuously scan and measure the RSS of the surrounding APs are presented in Retscher & Roth (2016). Another possibility to increase the performance of fingerprinting is the additional use of the compass data from the smartphone sensors and an orientation dependent fingerprinting DB.

Apart from the standard deterministic fingerprinting approaches further ongoing investigations are considering probabilistic approaches (see e.g. Honkavirta et al., 2009). The Mahalanobis distance is a suitable *VD* in this respect and has been tested by Ettlinger & Retscher (2016) for a combination of Wi-Fi positioning with fingerprinting using present ambient geomagnetic fields. In this case, the nearest neighbours are determined by using conditional probabilities.

Further future work concerns performance tests in 3D environments using Wi-Fi fingerprinting with the different vector distances. Field tests reported in the paper from Retscher and Hofer (2016) were performed in the same office building where 3D scenarios, such as the navigation of a mobile user from the building entrances to an office in the third floor, have been tested. In the evaluation only the Euclidean distance and the NN approach have been used so far and a combined solution of all four available multiple-SSID networks. Thus, in the further analysis it should be focused on the eduroam SSID network with an eventual usage of the KNN or KWNN approach.

Integration with the inertial sensors embedded in the smartphone is also a promising strategy. If the measurements of the accelerometer and gyroscope are used continuous positioning and navigation via dead reckoning (DR) is possible. In this case, the drift of the inertial navigation sensors can then be compensated if a Wi-Fi positioning solution is available. Furthermore, in DR, for instance, the step length is adapted if the user climbs stairs or uses an elevator as identified by the Wi-Fi absolute positioning system. Retscher & Hofer (2016) have demonstrated that this strategy is the right direction for localization of mobile devices. Furthermore, the additional use of the barometric pressure sensor which can nowadays be found in many smartphones is also planned. Then an additional determination of the altitude of the user is possible (see Retscher, 2007 for further details and processing strategy).

References

Bahl P & Padmanabhan V N (2000) ‘RADAR: An In-building RF-based User Location and Tracking System. INFOCOM 2000, Proceedings of the 19th Annual Joint Conference of the IEEE Computer and Communications Societies, Tel-Aviv, Mar 26-30, Vol. 2, 775-784

Ettlinger A F & Retscher G (2016) Positioning Using Ambient Magnetic Fields in Combination with Wi-Fi and RFID. 7th International Conference Indoor Positioning and Indoor Navigation IPIN 2016, October 4-6, Alcalá de Henares, Madrid, Spain

Favre-Bulle P (2015) Design and Implementation of an Adaptive Indoor Positioning System Based on Received and Interpolated Signal Strengths. Master Thesis, TU Wien

Hofer H & Retscher G (2016) Combined Out- and Indoor Navigation with Smart Phones Using Intelligent Check Points. this conference

Honkavirta V, Perälä T, Ali-Lötty S & Piche R (2009) A Comparative Survey of WLAN Location Fingerprinting Methods. WPNC’09, 243-251

Huang H (2014): Post Hoc Indoor Localization Based on RSS Fingerprinting in WLAN. Master thesis, University of Massachusetts, U.S.A.

Joksch J (2016) Vergleich von unterschiedlichen Distanzberechnungen bei der Indoor-Positionierung mittels Fingerprinting-Verfahren. Bachelor Thesis, TU Wien, Austria (in German)

Kjærgaard M B (2008) Location Fingerprinting. Retrieved August 2016, from http://wiki.daimi.au.dk/mikkelbk/location_fingerprinting.wiki

Krause E F (1986) Taxicab Geometry; an Adventure in Non-Euclidean Geometry, 1st publ. New York, NY: Dover Publ.

Machaj J & Brida P (2011) Performance Comparison of Similarity Measurements for Database Correlation Localization Method. 3rd International Conference Intelligent Information and Database Systems ACIIDS 2011, Part II, 452–461

Moghtadaiee V & Dempster A G (2015) Vector Distance Measure Comparison in Indoor Location Fingerprinting. IGNSS Symposium, July 14-16, Gold Coast, Australia

Mok E & Retscher G (2007) Location Determination Using WiFi Fingerprinting Versus WiFi Trilateration. Journal of Location Based Services, 1:2, 145-159

Niedermayr S. & Wieser A. (2012) Combination of Feature-based and Geometric Methods for Positioning. in: Schwieger V., Böttinger S., Zheng B. (eds.) Proceedings of the 3rd International Conference on Machine Control & Guidance, March 27-29, Stuttgart, 301-310

Retscher G. (2007) Augmentation of Indoor Positioning Systems with a Barometric Pressure Sensor for Direct Altitude Determination in a Multi-storey Building. Journal of Cartography and Geographic Information Science (CaGIS), 34: 4:305-310

Retscher G (2016) Indoor Positioning. Chapter 9, Encyclopedia of Geodesy, Springer Verlag

Retscher G & Hofer H (2016) Wi-Fi Location Fingerprinting Using an Intelligent Checkpoint Sequence. FIG Working Week, May 2-6, Christchurch, New Zealand

Retscher G & Joksch J (2016) Analysis of Nine Vector Distances for Fingerprinting in Multiple-SSID Wi-Fi Networks. 7th International Conference Indoor Positioning and Indoor Navigation IPIN 2016, October 4-6, Alcalá de Henares, Madrid, Spain

Retscher G & Roth F (2016) Wi-Fi Fingerprinting with Reduced Signal Strength Observations from Long-time Measurements. this conference

Retscher G & Tatschl T (2016 a) Differential Wi-Fi – A Novel Approach for Wi-Fi Positioning Using Lateration. FIG Working Week, May 2-6, Christchurch, New Zealand

Retscher G & Tatschl T (2016 b) Indoor Positioning Using Wi-Fi Lateration – Comparison of two Common Range Conversion Models with Two Novel Differential Approaches. IEEE Xplore, 2016 Ubiquitous Positioning Indoor Navigation and Location Based Service (UPINLBS), November 3-4, Shanghai, PR China

Retscher G, Zhu M. & Zhang K (2012) RFID Positioning. in Chen R. (ed.): Ubiquitous Positioning and Mobile Location-Based Services in Smart Phones. Hershey PA, U.S.A.: IGI Global, 69-95

Contacts

Guenther Retscher and Julian Joksch

Department of Geodesy and Geoinformation, Research Group Engineering Geodesy, TU Wien, Gusshausstrasse 27-29 E120/5, 1040 Vienna, Austria
E-Mail: guenther.retscher@tuwien.ac.at
or jjoksch@me.com

An Improved Indoor Positioning System Based on WLAN

Mohsen Ahmadkhani *, M.R.Malek *

* Department of GIS, Faculty of Geodesy and Geomatics, K.N.Toosi University of Technology, mahmadkhani@mail.kntu.ac.ir, mrmalek@kntu.ac.ir

Extended Abstract

Despite of widespread usage of Global Positioning System (GPS), this system is considered inefficient for indoor areas. Although the most prominent positioning system is Global Positioning System, this system uses some electromagnetic waves which are unable to pass thick obstacles such as concrete roofs and trees [1]. Thus, it cannot be considered as a robust infrastructure for indoor positioning purposes. Since, other signal networks like Wireless Local Area Network (WLAN) can be an appropriate alternative for indoor spaces. In addition, widespread usage of mobile smart instruments has provided the possibility of ubiquitous system's development.

Several methods have been proposed to obtain indoor positions which are generally based on received radio waves from fixed points. Time of Arrival (TOA), Time Difference of Arrival (TDOA), Angle of Arrival (AOA) and Location fingerprinting can be used in this case. It is noteworthy that some of these methods are not really appropriate for indoor areas which maybe contain complex structure [2]. Time of Arrival, Time Difference of Arrival and Angle of Arrival methods use triangulation techniques so direct lines of sight are desired for them. And also acquisition of accurate time and angle of received signal without professional instruments, which are usually expensive, sounds almost impossible. Furthermore, for most of indoor areas such as commercial centers and museums direct line of sight is rarely available and signals are likely to be affected by multipath phenomena [3].

In recent years methods based on Inertial Measurement Units (IMU) have been proposed and programmed [4], [5]. These methods which are usually called Pedestrian Dead Reckoning (PDR) often employ sensors such as Gyroscope, Accelerometer and Magnetic sensors to obtain the position of the client [6]. It can be regarded as an important limitation along the objectives of the Ubiquitous systems. Such systems are restricted to clients equipped

Published in "Proceedings of the 13th International Conference on Location-Based Services", edited by Georg Gartner and Haosheng Huang, LBS 2016, 14-16 November 2016, Vienna, Austria.

by platforms having these expensive modern sensors. Therefore, the methods using WLAN signals are usually preferred for location based services.

WLAN Fingerprinting can be regarded as a most appropriate technique that uses signal strength as an identification parameter, which can be simply obtained. Furthermore, fingerprinting does not have any special infrastructure to establish and it can be conveniently laid out. In order to apply this method there are several ways to recognize the pattern of signals received from active transmitters. Stochastic method, Artificial Neural Network and K-Nearest Neighbor methods are some of classic pattern recognition techniques [7] that were investigated in this study. In this article these three methods were scrutinized and relatively compared, eventually an enhanced method has been offered. After using several data sets in order to assess the pattern recognition techniques, the proposed method got the first rank of the accuracy and also other techniques were ranked based on the accuracy.

One of the most important differences between indoor positioning systems might be utilizing of various algorithms to recognize the spatial pattern. In this study, three popular classic methods including Probabilistic algorithm, Nearest Neighbor and Artificial Neural Network were investigated. The flowchart presented in *Figure 1* has depicted the major steps of the study.

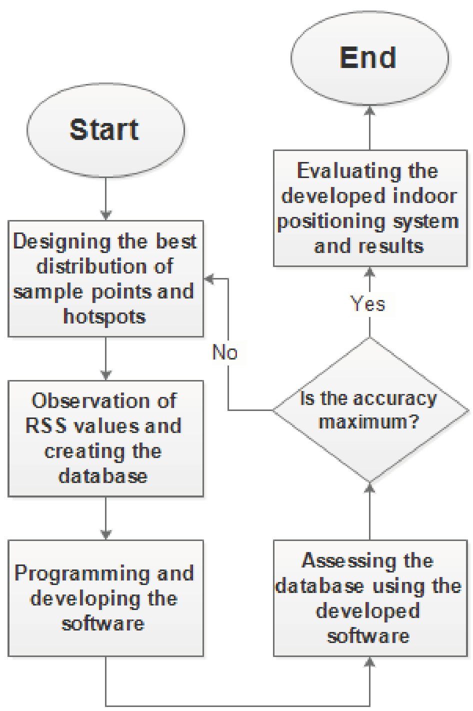


Figure 1. The flowchart of the study.

This study focuses on Nearest Neighbor in Signal Space method as the most accurate method among all and tries to enhance the output accuracy of the method. NNSS Method computes the difference between received signal strength in a point from each transmitter and the received strength of that signal in the rest of the sample points (*Equation 1*).

$$d_j = \sqrt{\sum_{i=1}^{m}(S_i - S_{ij})^2}\ , j = 1,2, \ldots, n \qquad (1)$$

Where S_{ij} be jth sample point of the database from ith transmitter and S_i received signal strength from ith hotspot in online phase and also for m hotspots and n sample points, i= 1,2,…,m and j=1,2,…,n [8].

By applying this formula, the most likely sample point as the location of the observer can be obtained. Since the number of sample points in the design of the model in offline phase is limited and the distance between two adjacent sample points is constant in the whole model, the accuracy might be affected. Regarding these limitations, in order to increase the output accuracy of the system, the medium of first and second candidate location points was proposed as the position of the user. After applying this change, the highest accuracy was acquired (*Figure 4*). The study area was the third floor of the building of Geomatics faculty of K.N.Toosi university of Technology (*Figure 2*). For this building with dimensions of 70×14 meters, totally 6 hostspots with reasonable distribution, covering the whole area, were taken into account. The best distance between each adjacent pair was 0.9 m and for each sample point four directions were observed and recorded in to the database and also JAVA programming language was chosen to develop the user friend software. *Figure 3* depicts an instance of the database.

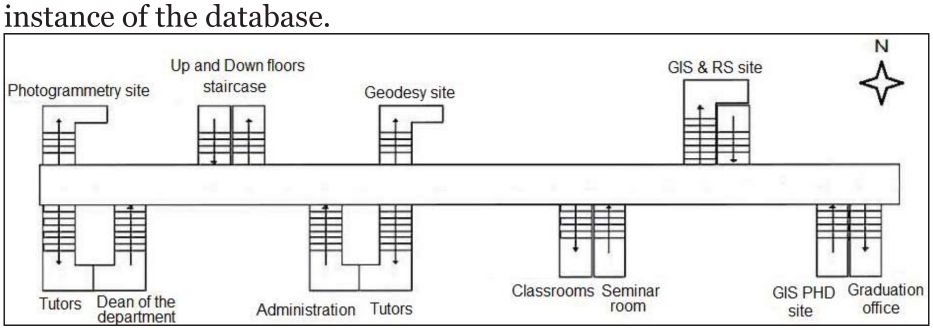


Figure 2. Plan of the study area.

	id [PK] serial	number integer	point_num integer	direction character(1)	kntu1 integer	personal_ap integer	afagh_16t integer	azp integer	default1 integer	stc_n6 integer
1	1	1	1	N	-44	-80	-89	-95	-67	-88
2	2	2	1	E	-45	-73	-95	-91	-60	-91
3	3	3	1	S	-43	-80	-90	-92	-56	-91
4	4	4	1	W	-42	-81	-95	-90	-68	-95
5	5	5	2	N	-43	-81	-89	-95	-74	-90
6	6	6	2	E	-43	-79	-95	-91	-58	-90
7	7	7	2	S	-40	-78	-95	-91	-58	-90
8	8	8	2	W	-44	-80	-89	-95	-60	-95

Figure 3. A part of the produced database.

In order to evaluate the accuracy of each method, observations in the online phase were categorized in 6 separate classes containing 10, 20, to 60 observation in each class. Based on the output results of the system, although the accuracy of Artificial Neural Network raised up to 2.7 m by increase in the number of observations, it showed the worse accuracy among all methods. Probabilistic and KNN methods with final accuracy of 1.8 and 0.9 meters respectively were more accurate than ANN. Our extended Nearest Neighbor method was the most accurate method almost in all sets of observations. In the first observation class, ANN with 3.6 m, KNN and Probabilistic methods with 2.7 m were not really reliable to locate the position of the user, however, extended KNN with 1.5 m seemed more acceptable than the rest of methods (See *Figure 4*).

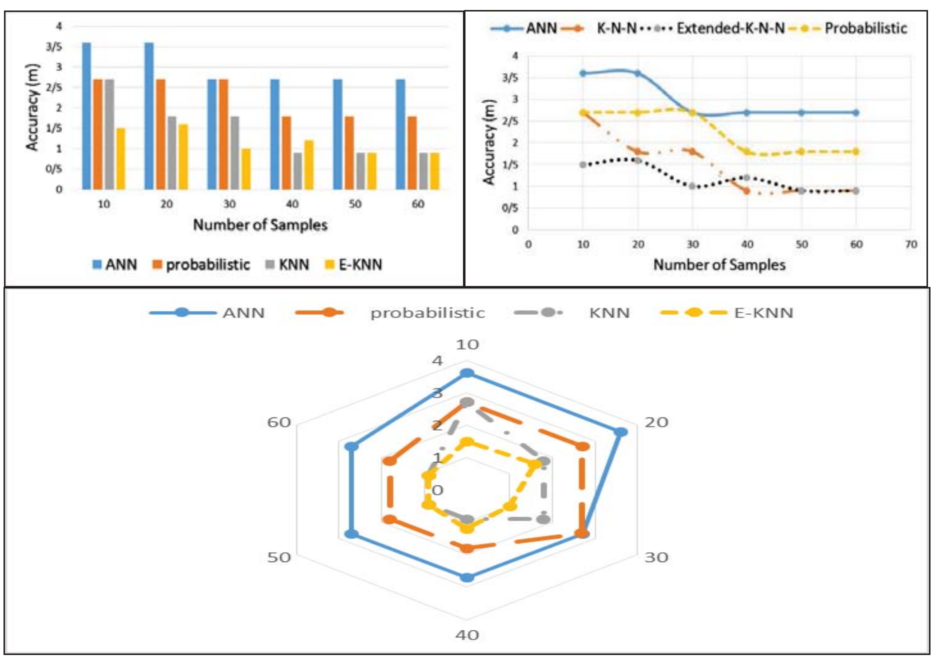


Figure 4. The behavior of accuracy trend in all methods in the considered sets of observation.

References

[1] Kjærgaard, M. B., Blunck, H., Godsk, T., Toftkjær, T., Christensen, D. L., & Grønbæk, K. (2010, May). Indoor positioning using GPS revisited. In International conference on pervasive computing (pp. 38-56). Springer Berlin Heidelberg.

[2] Lin, T. N., & Lin, P. C. (2005, June). Performance comparison of indoor positioning techniques based on location fingerprinting in wireless networks. In 2005 international conference on wireless networks, communications and mobile computing (Vol. 2, pp. 1569-1574). IEEE.

[3] Townsend, B. R., Fenton, P. C., DIERENDONCK, K. J., & NEE, D. R. (1995). Performance evaluation of the multipath estimating delay lock loop. Navigation, 42(3), 502-514.

[4] Wang, H., Sen, S., Elgohary, A., Farid, M., Youssef, M., & Choudhury, R. R. (2012, June). No need to war-drive: unsupervised indoor localization. In Proceedings of the 10th international conference on Mobile systems, applications, and services (pp. 197-210). ACM.

[5] Wang, H., Lenz, H., Szabo, A., Bamberger, J., & Hanebeck, U. D. (2007, March). WLAN-based pedestrian tracking using particle filters and low-cost MEMS sensors. In 2007 4th Workshop on Positioning, Navigation and Communication (pp. 1-7). IEEE.

[6] Chen, L. H., Wu, E. H. K., Jin, M. H., & Chen, G. H. (2014). Intelligent fusion of Wi-Fi and inertial sensorbased positioning systems for indoor pedestrian navigation. Sensors Journal, IEEE, 14(11), 4034-4042.

[7] Vahidnia M. and Malek, M.R and Mohammadi, N., A. Alesheikh (2013):" A Hierarchical Signal-Space Partitioning Technique for Indoor Positioning with WLAN to Support Location-Awareness in Mobile Map Services", Wireless Personal Communications, Volume 69, Issue 2, Page 689-719.

[8] Küpper, A. (2005). Location-based services: fundamentals and operation. John Wiley & Sons.

Combined Out- and Indoor Navigation with Smart Phones Using Intelligent Check Points

Hannes Hofer, Guenther Retscher

Department of Geodesy and Geoinformation, Research Group Engineering Geodesy, TU Wien, Vienna, Austria

Abstract. Apart from a GNSS receiver, smart phones are nowadays equipped with further components, such as inertial sensors, a digital compass and a wireless module, which can be used for navigating. The aim of this work is to combine the data of these components in order to improve the accuracy of positioning in both outdoor and indoor areas. The idea behind is to intelligently choose check points along the user's trajectory and recognize them by using the wireless module by using a WLAN fingerprinting strategy. The inertial sensors and the digital compass were used to detect changes in positioning.

The combination of the methods is an obvious solution. In this work a new approach is developed where fingerprinting is used to recognize certain points – referred to as check points – when they are passed and an inertial navigation system is used to calculate the positions between them. These check points are placed in an intelligent way so that they must be passed and can distinguished well by the fingerprinting algorithms. In this work we present the results by using fingerprinting algorithms to recognize these intelligent check points (iCPs).

Keywords. Wi-Fi positioning, location fingerprinting, training phase, reference points, intelligent check points, inertial sensors, sensor fusion

1. Data Recording and Analyzing (DAAS)

For investigation of the iCP approach a data recording and analyzing system (DAAS) was developed. The DAAS is composed of an Android App and a MATLAB framework. The arrangement of the components is shown in Fig-

LBS 2016
13th Conference on Location-Based Services
Vienna, 14–16 November 2016

Published in "Proceedings of the 13th International Conference on Location-Based Services", edited by Georg Gartner and Haosheng Huang, LBS 2016, 14-16 November 2016, Vienna, Austria.

ure 1. The Combined Positioning System App CPS is able to record RSS values and orientation data on selected locations with the *"CPS Kompass WiFi-Scanner"*. Along a trajectory the *"CPS Sensor-WiFi-Recorder"* can be used to record continuously RSS values and sensor data.

The recorded data can be imported to the MATLAB framework and the positioning can be simulated with different approaches off-line. With the DAAS databases for different phones and test trajectories can be build. As a specific simulation can make use of the same data different approaches can be compared. A next step is the further development of a new App version so that the data of the magnetic field sensor and the gyroscope can be combined with the received signal strengths (RSS) values.

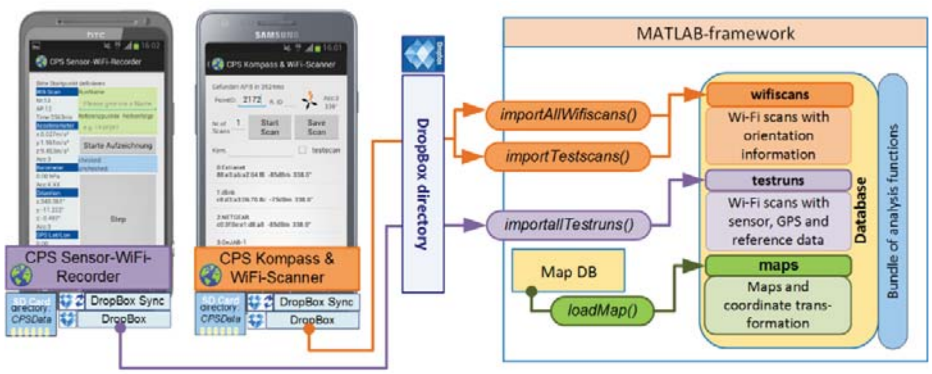


Figure 1. DAAS - arrangement of the components.

2. Wi-Fi Fingerprinting

To calculate a position with the wireless modules, the RSS of Access Points (APs) of an already existing wireless network can be used. A common strategy is to scan for the RSS values on a definite grid of positions and save the scans in a database. For the positioning a scan with the wireless module must be carried out. The detected RSS values are used to find the position in the database where they fit best. In this work the wireless fingerprinting algorithms with a nearest neighbour strategy were implemented.

For this purpose, RSS values were recorded for 49 positions to simulate the calibration and position phase. The DAAS was used to simulate the nearest neighbour fingerprinting algorithms and recognize iCPs without moving. The aims were to find the best averaging strategy for RSS values and to investigate whether better results can be achieved if the orientation of the smart phone is considered additionally. Results of the tested variants of the fingerprinting algorithms can be seen in Figure 2.

The overall best results were achieved by using the arithmetic mean for averaging and if minimal RSS values are assigned for Access Points which are not always found by a scan.

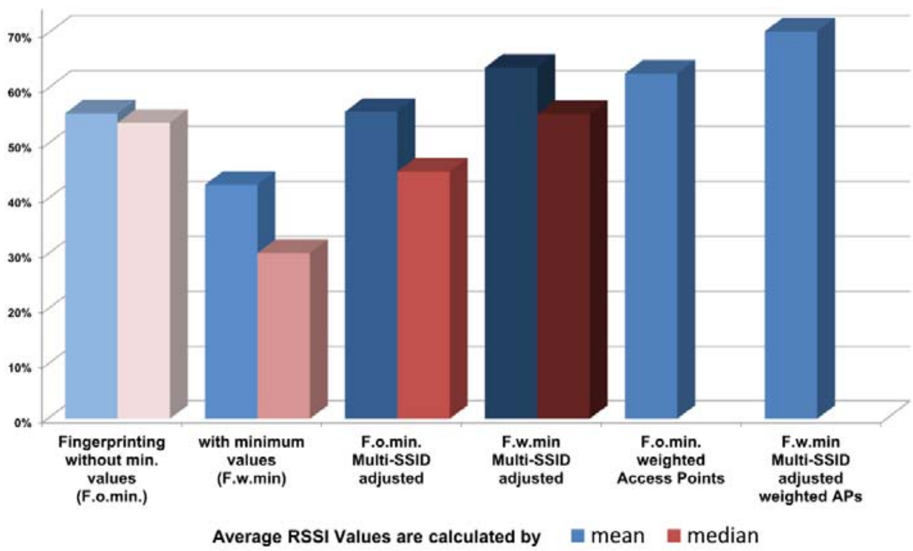


Figure 2. Recognition rates (RR) of Wi-Fi fingerprinting of the tested 49 positions – variants.

By considering of the orientation no significant improvement could be achieved, but the wireless scans in the training phase can be reduced significantly, because wireless scans must be done on less positions and only in necessary orientations. Furthermore, future investigations concerning fingerprinting are dealing with a meaningful selection of Access Points so that their RSS values are well distinguishable for each location in the database.

3. Inertial Navigation (IN)

The inertial sensors and magnetometer embedded in the smart phone can be used to identify the orientation of the phone and use it as a digital compass. By combining the data of the orientation and the accelerometer a change of the position can be recognized. Then a travelled distance can be traced based on inertial navigation. To recognize a position, change a step detection algorithm was implemented. This algorithm analyses the accelerometer data and a detect a step when a peak is found and a defined threshold is exceeded. An example of the accelerometer data and the detected steps is shown in Figure 3.

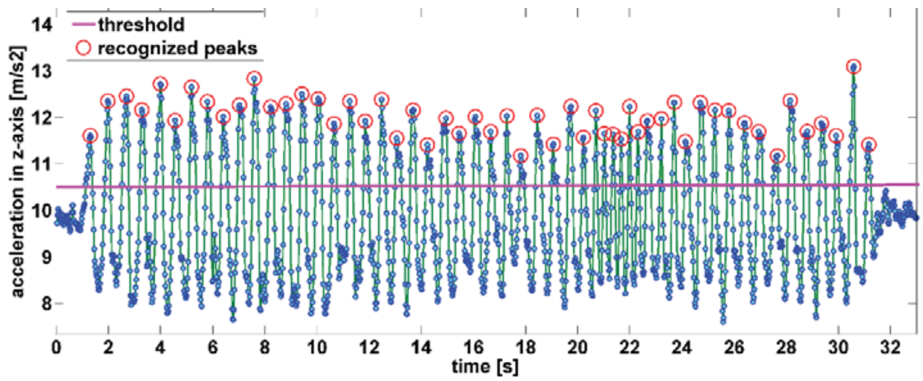


Figure 3. Accelerometer data from z-axis and detected steps.

For the inertial navigation algorithm, the step detection algorithm was combined with orientation data of the smart phones at the step time as can be seen in Figure 4 as example.

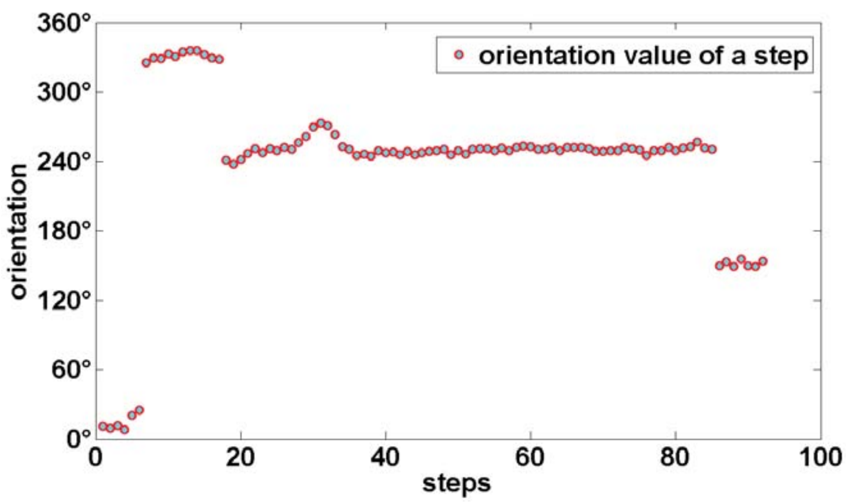


Figure 4. Example of orientation values at step from android orientation sensor.

The disadvantage of inertial navigation, however, is that the starting position must be known and there is always a drift of the calculated position to the real position, which increases with every new calculation when moving along.

4. Recognition of the iCPs

For more tests 17 iCPs positions were chosen form the 49 analyzed positions as discussed in chapter 2. This iCPs are divided up in 4 sections, which must be passed in logic sequence. For example, the first section is the entrance section. The aim was to detect the used entrance with a Wi-Fi fingerprinting strategy. By considering this logic sequence and give some APs a higher weighting it was possible to recognize the 17 iCPs with a rate of 92,9 percent. This results are illustrated in Figure 5.

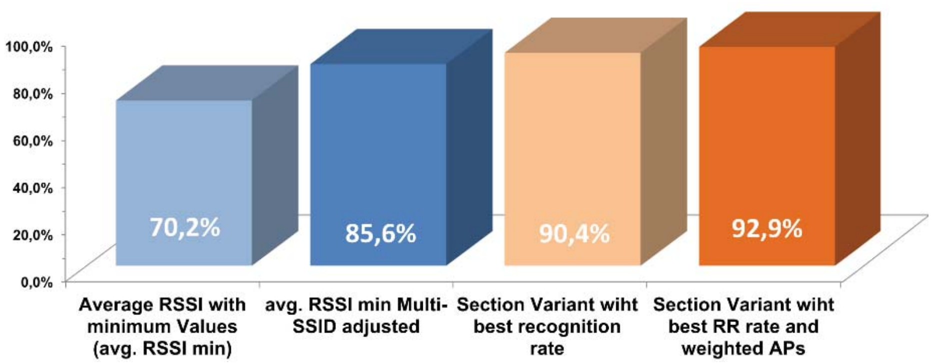


Figure 5. Average recognition rate of Wi-Fi Fingerprinting by dividing in sections.

For recognition of the iCPs while moving, the number of possible iCPs is reduced by using a logical sequence how they can be passed. So always only a limited number of iCPs is observed. If a minimum Euclidean distance between the measured RSS values and the RSS values in the database is found, then the iCP is recognized as can be seen in Figure 6.

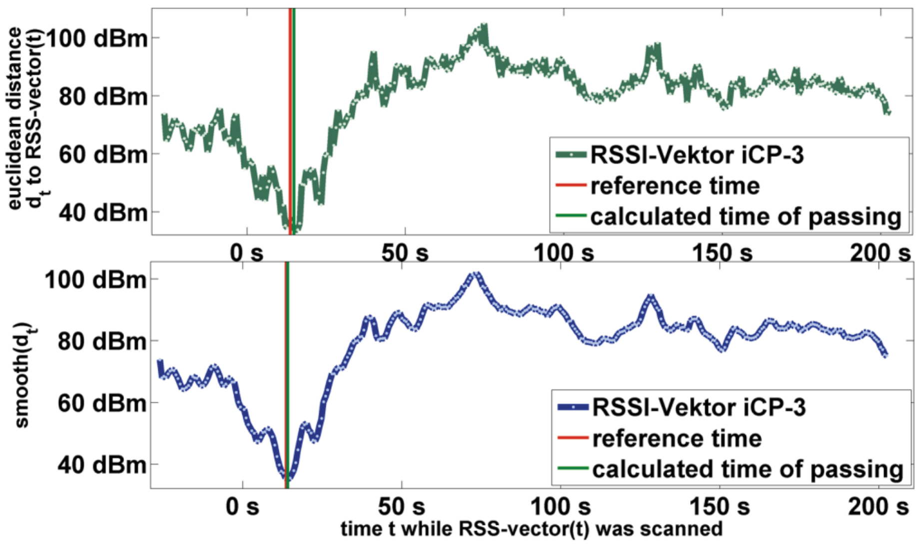


Figure 6. Euclidean distances of a certain iCP calculated from continuous RSS scans while walking along a trajectory.

In the test runs the iCPs were recognized in movement with an accuracy of 2.5 m on average. For further work more RSS values should be considered instead of using one minimum value.

5. Inertial Navigation with iCPs

To combine the inertial navigation and the iCPs the current position is corrected at the position of recognized iCP. Also information of the possible passing direction and step size (stairs) was considered. Figure 7 and Figure 8 show the joined trajectories TR-Ei5 and TR-E8 and compares GPS, inertial navigation and iCP supported inertial navigation.

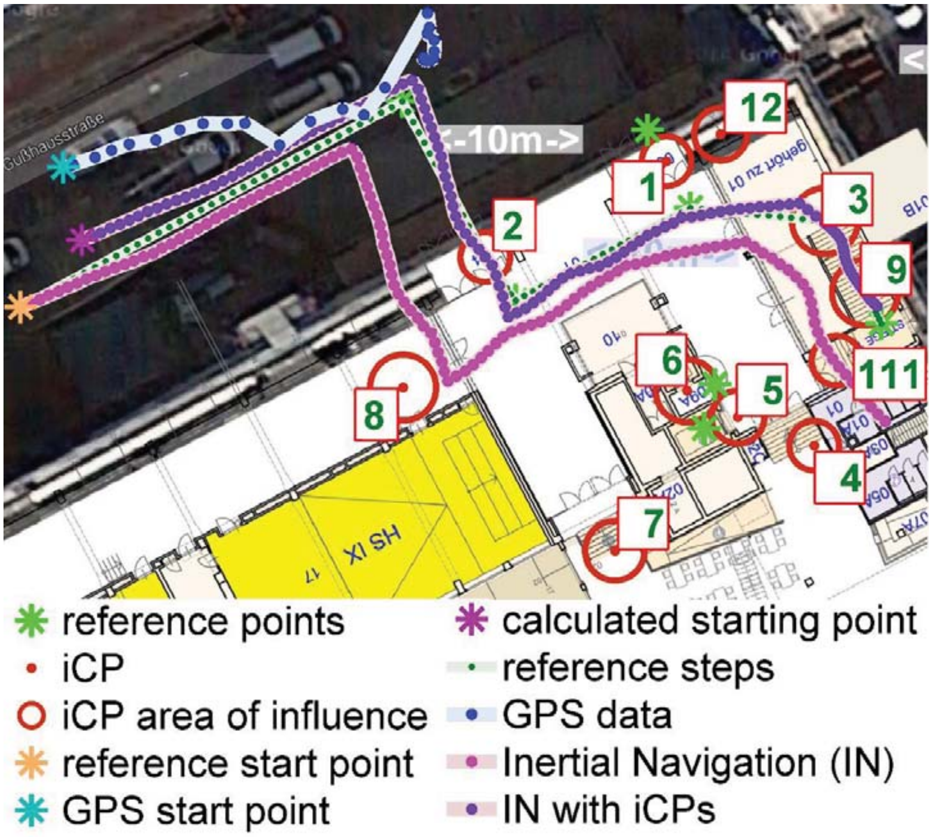


Figure 7. Test run TR-EI5.

With the described combination of sensors and wireless module higher accuracies then with using the GPS receiver only could be achieved. If sensors and modules are combined current test results showed an achievable positioning accuracy of 1.9 m on average. In contrast, the accuracy achieved with inertial navigation was 4,3 m and with GPS was 16.7 m on average, if GPS was available at all. Details of the results are shown in Table 1.

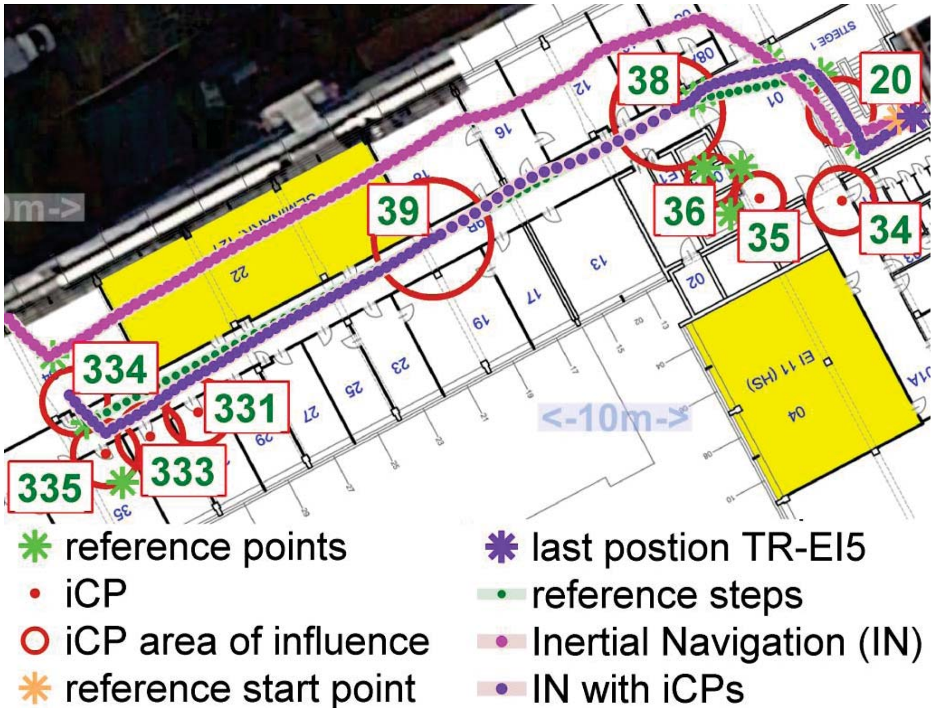


Figure 8. Test run TR-EI8.

Test runs	average			end position			maximal			start pos.	
	GPS	IN	iCP-IN	GPS	IN	iCP-IN	GPS	IN.	iCP-IN	GPS	iCP-IN
TR-EI1	34,5	2,9	2,3	36,6	3,5	2,2	45,7	4,3	4,5	45,5	3,0
TR- EI2	20,7	6,0	4,0	25,8	4,0	2,0	37,4	10,0	11,3	37,4	11,3
TR- EI3	16,4	3,2	1,9	31,3	3,5	0,0	31,3	6,4	4,8	1,4	2,0
TR- EI4	12,8	4,3	1,5	22,6	8,5	1,0	22,6	8,5	4,7	20,4	1,5
TR- EI5	14,7	4,2	1,9	32,2	5,9	1,1	32,2	6,4	5,5	8,9	5,5
mean	***19,8***	***4,1***	***2,3***	***29,7***	***5,1***	***1,3***	***33,8***	***7,1***	***6,2***	***22,7***	***4,7***
TR- EI6		4,8	1,5		8,7	2,1		9,2	2,7	***N.A.***	
TR- EI7		3,8	1,1		4,6	3,1		6,9	3,7		
TR- EI8		5,5	1,3		6,5	0,5		8,0	3,4		
mean		***4,7***	***1,3***		***6,6***	***1,9***		***8,0***	***3,3***		
All values are in meter.											

Table 1. Results - Comparison of GPS, inertial navigation and iCP supported inertial navigation.

6. Conclusions

With the presented iCP supported inertial navigation it was possible to solve the disadvantages of this navigations type. The drift of the calculated position can be corrected with the recognition of iCPs. By using the iCP algorithms it is not necessary to know the start position anymore perform inertial navigation. A needed start position for the inertial navigation can be calculated when an iCP is passed.

Another advantage of the iCP approach compared to common fingerprinting is the reduction of needed reference points. Commonly a raster of reference points where the RSS values are measured are defined. With the iCP approach only RSS values on way points have to be measured for the calibration of the system.

For a further development of the iCP approach some more improvements could be investigated. For Example, the recognition of an iCP with one minimum value can be expanded by using a threshold or using a pattern recognition approach for sensor and RSS data. Also it might be meaningful to research on stochastic methods for iCP recognition.

Contacts

Hannes Hofer and Guenther Retscher

Department of Geodesy and Geoinformation, Research Group Engineering Geodesy, TU Wien, Gusshausstrasse 27-29 E120/5, 1040 Vienna, Austria
E-Mail: h.hannes@gmx.at
or guenther.retscher@tuwien.ac.at

A Hidden Markov model for indoor tracking Based on Bluetooth fingerprinting and Grid filtering

Xingyu ZHENG*, Yi LONG***,Yong SHI**,Yue XU*
*School of Geographic Science, Nanjing Normal University,MOE Key Laboratory of Virtual
Geographical Environment, Nanjing 210023, China;
**School of Information Engineering, Nanjing Normal University Taizhou College, Taizhou 225300, China

Extended Abstract

With the popularization of smartphone and the development of mobile internet, people's demand on location-based services has increased. Indoors, users are often repeating the same movements, such as walking between main door, office, rest rooms. As a result, massive of pedestrian tracks have been produced. Fingerprint location algorithm based on Wi-Fi or Bluetooth is a popular method in indoor locating. However, this method has many weaknesses including unsteadiness and low robustness, because it generally uses the mean value and its variance of single point Rssi to locate. Grid filters the incorrect positions returned from indoor. Localization, especially under signal fluctuation or fingerprint ambiguity. The Hidden Markov model and Grid filtering of this approach would achieve a higher position accuracy and efficiency. Map information is often available and may contribute to location filtering. Recently, a number of researchers take the position sequence information into consideration. Xiaoguang(2014) had found a fine-grained walk pattern of indoor pedestrians the reliability of the reports. Zhou(2014) had proposed activity sequence based indoor pedestrian localization using smartphones. Zhang(2015) proposed a wireless positioning method based on Deep Learning arm to deal with the variant and unpredictable wireless signals. Jimmy(2013) proposed directional HMM algorithm which can learn user habits and improve the accuracy of indoor localization system. However, the HMM models are trained with the trajectory and the HMM indoor position algorithm relays on the correct and certain data(He, S., & Chan 2015). Borriello(2003) proposed Bayesian Filtering which include the grid filtering to estimate the position. But the HMM model still cannot deal well with the ambiguities resulting and bring the amount of calculation. Therefore, a key challenge here is how to deal with the ambiguities resulting from fingerprinting and the data fusion of big spatial data and limited topology information.

***Corresponding author

LBS 2016
13th Conference on Location-Based Services
Vienna, 14–16 November 2016

Published in "Proceedings of the 13th International Conference on Location-Based Services", edited by Georg Gartner and Haosheng Huang, LBS 2016, 14-16 November 2016, Vienna, Austria.

To solve this problem, we propose an indoor fingerprint positioning method based on the combination of grid filtering and hidden Markov model. This method includes both offline and real time positioning stages. Firstly, during the on-line phase, we firstly divide the indoor space as the grid evenly, and then build accessibility gird based on the local position and set the execution rate. The confidence level of obstacles (or barriers) is set as 0. For obtaining the probability of other positions, we use the historical mobile transition probability, and build an offline estimating range. Secondly, we establish station probabilities based on the nearest neighbor location fingerprint algorithm and grid filtering. During the offline stage, we use mobile signal to get the data and remove noises with Kalman filter, and then store the data into our fingerprint database. While starting on-line locating, this method will judge if it's the first time to locate. The nearest neighbor algorithm will be used for locating if it is the initial point, if not, the prediction database, built according to the location of the former point, will provide a constrained positioning area, and then match the data with fingerprint database to find the closest position. The indoor positioning coordinates can be got based on the nearest neighbor location fingerprint. Thirdly, algorithm then the probabilistic model is constructed. In order to achieve more accurate moving probability model, The prediction accuracy of Hidden Markov model is greatly improved by adding the constraints of grid filtering and updating the database which rule out the influence on the historical data of pedestrian. So, the best pedestrian route is found and the fingerprint based positioning algorithm is modified. The method proposed by this paper can greatly improve the positioning accuracy and stability of pedestrians in the room, verifying the effectiveness of the proposed method. The work results show the improvement on localization accuracy in coping with the turbulent wireless signals.

An experiment in Nanjing normal university used this method and the experiment area is a 15M*10M laboratory room. The presented HMM can deal with ambiguities resulting from Bluetooth fingerprinting. The algorithm is computationally efficient because of the update of the HMM and Grid filtering, based on the positions of Bluetooth fingerprint and grid filtering. Through mining spatial temporal distribution regularities of tracing points, and inputting time orders and appearance probabilities into fingerprint database, the tracing effect of this new method is significantly increased compared to fingerprint positioning algorithm without considering indoor pedestrian tracks. The comparison of two algorithm result is below.

Method	Area	Accuracy/m	Time/s
KNN	n	2.95	3.1s
KNN+HMM+GRID	3-9	2.15	1.1

Table 1. comparison of evaluation index

The location results achieved 2.15m precision more precise than the k-Nearest Neighbor fingerprinting approach. The experiment proved the improvement of accuracy and stability on indoor location. Also, being verified its effectiveness this method can be used in providing route proposal and navigation in shopping mall, museum and airport.

Reference

Niu, X., Li, M., Cui, X., Liu, J., Liu, S., & Chowdhury, K. R. (2014). Wtrack: hmm-based walk pattern recognition and indoor pedestrian tracking using phone inertial sensors. Personal & Ubiquitous Computing,18(8), 1901-1915.

Zhou, B., Li, Q, Mao, Q, Tu, W & Zhang, X. (2014). Activity sequence-based indoor pedestrian localization using smartphones. IEEE Transactions on Human-Machine Systems, 45(5), 562-574. Zhang, W., Liu, K., Zhang, W., Zhang, Y., & Gu, J. (2016). Deep neural networks for wireless localization in indoor and outdoor environments.Neurocomputing, 194(C), 279-287.

Nielsen, J. J., Amiot, N., & Madsen, T. K. (2013). Directional hidden markov model for indoor tracking of mobile users and realistic case study. Vde Verlag Gmbh, 1 - 6.

He, S, & Chan,S.H.G.(2015). Wi-fi fingerprint-based indoor positioning: recent advances and comparisons. IEEE Communications Surveys & Tutorials, 18(1), 1-1.

Fox, D, Hightower, J, Liao, L, Schulz & Borriello, G. (2003). Bayesian filtering for location estimation. Pervasive Computing IEEE,2(3), 24-33.

Static Positioning with the Aid of GPS and Cellular Network for Android OS Smartphones

Aleksander Ozga[*], Guenther Retscher[**]

[*] Institute of Electronics, Lodz University of Technology, Lodz, Poland
[**] Department of Geodesy and Geoinformation, Research Group Engineering Geodesy, TU Wien, Vienna, Austria

Abstract. Global Positioning System (GPS) is nowadays the most familiar and widely used positioning technique. With the emerging growth in the number and types of mobile devices, it is being installed as a standard service in modern mobile phones (smartphones). However, it has some limitations due to the availability of the signal in some specific circumstances and its stability. For that reason, cellular network techniques for precise location estimation with the use of mobile phones were developed. In this paper, we investigate GPS accuracy influenced by different conditions and compare it with cellular network positioning. It was possible thanks to a measurement campaign performed on the campus of Lodz University of Technology in Poland. This work demonstrates the comparison between different positioning methods together with their accuracies, providing an overview on the reliability of the results for different urban scenarios.

Keywords. Cellular network positioning, GPS accuracy, static GPS measurements

1. Method

1.1. Measurement Set-up

The hardware consisted of a smartphone, which for static measurements was placed on a tripod with a rotational platform. The constant height was preserved, whereas the orientation was changed each thirty minutes so that the user could compare the results for different azimuth angles. This amount of time was sufficient for statistical reasons and in order to obtain stable results.

LBS 2016
13th Conference on Location-Based Services
Vienna, 14–16 November 2016

Published in "Proceedings of the 13th International Conference on Location-Based Services", edited by Georg Gartner and Haosheng Huang, LBS 2016, 14-16 November 2016, Vienna, Austria.

Figures 1., 2. The measurement aperture in an outdoor and indoor location.

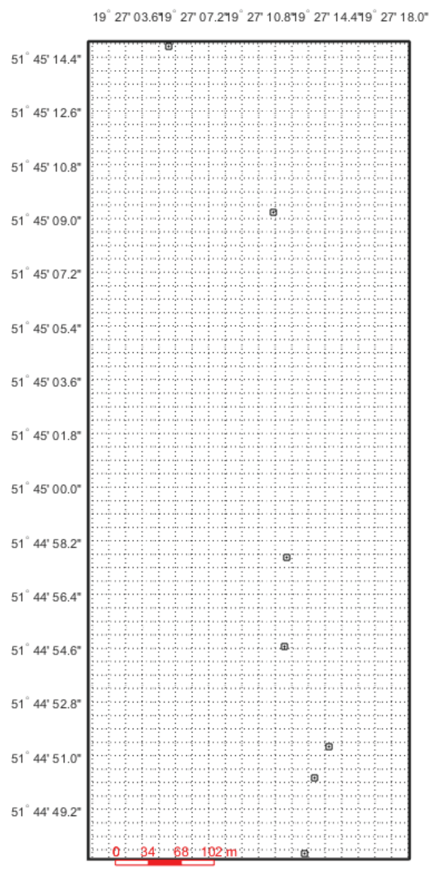
They were provided by constant number of four times 1,800 probes and measurement time of two hours. The data was collected with the aid of an Android App implemented in previous projects at Lodz University of Technology. The scripts employed for signal processing and detailed analysis had been developed with the aid of Matlab.

1.2. Measurement Points Choice

The points chosen for static collection of data had to be accessible for 2-hour measurement. Moreover, they vary not only in locations, but also satisfy different conditions influencing localization accuracy. That makes them representative for the analysis. Factors such as environment and surroundings (trees, open air locations), urban areas characteristics (crossings, buildings), as well as the weather, should be taken into consideration. In this plenty of in- and outdoor scenarios, the ground truth of the measurement points was estimated with a traditional measuring tape. In some points the software did not work properly estimating the network coordinates (no_data) or just provided constant value instead of varying data expected. For one point of interest (POI), referred to as ‘staw’, the data was corrupted and for that reason discarded from the analysis. For the remaining locations the results, varying with orientation, will be further discussed.

POI Name	Real_lat	Real_lon	Cell_lat	Cell_lon	Description	Date
weeia	51.752563	19.453221	51.7512584	19.4525845	indoor ground floor	31.03.
lodex	51.747290	19.453846	varying	varying	indoor 4th floor window	03.04.
staw	51.747586	19.454062	varying	varying	outdoor building shadowing	20.04.
garaz	51.754099	19.451647	51.7471068	19.4538508	outdoor building canyon	20.04.
grad	51.746587	19.453696	no_data	no_data	outdoor open space area	21.04.
dwz	51.748518	19.453382	no_data	no_data	outdoor park green area	21.04.
mosir	51.749344	19.453428	51.7471004	19.454077	outdoor street low traffic	30.05.

Table 1. The measurement point coordinates with their descriptions.



Figures 3., 4. The measurement point locations with their names.

2. Findings and Arguments

2.1. Distance Calculation

In order show the deviation between the measured point and the ground truth, the need for distance calculation based on the geographical coordinates arised. The study of available literature showed that there are two main approaches to be taken into consideration. The first one employs the so called “haversine” equation (1), which is important for navigation and enables to estimate shortest path between two points on the Earth’s surface. The differences in altitudes are not taken into consideration. Assuming the spherical shape of Earth, one neglects the ellipsoidal effects, achieving sufficient accuracy in most cases. An error does usually not exceed 0.3 % which is represented as rounding results off the to 4 significant digits (Movable Type Scripts, 2016).

$$
\begin{aligned}
a &= \sin^2\left(\frac{\Delta\varphi}{2}\right) + \cos\varphi_1 \cdot \cos\varphi_2 \cdot \sin^2\left(\frac{\Delta\lambda}{2}\right) \\
d &= 2 \cdot \mathrm{atan2}(\sqrt{a}, \sqrt{(1-a)}) \cdot R
\end{aligned}
\tag{1}
$$

The variables φ and λ denote latitude and longitude, respectively, while R stands for the mean radius of Earth. For the purpose of trigonometric functions, both coordinates need to be implemented in radians.

Nevertheless, there exist also a more straightforward method which constitutes a reasonable one-line alternative to the haversine formula for many geodetic purposes. Most of recent computers and programming languages use ‘IEEE 754’ 64-bit floating-point numbers with a precision of 15 significant digits which is enough for well-conditioned results down to distances as small as a few meters on the earth’s surface using simple spherical law of cosines formula (2). Comparing these two common formulas, it turns out that the second one may be more suitable for very small distances an equirectangular approximation (Movable Type Scripts, 2016).

$$
d = \cos^{-1}(\sin\varphi_1 \sin\varphi_2 + \cos\varphi_1 \cos\varphi_2 \cos\Delta\lambda) * \pi R/180 \tag{2}
$$

Hence, the spectral law of cosines was chosen for the analysis performed with the aid of Matlab. The calculated distances were comparable with those provided by online tool employing the more complex equation, what proved that the choice was appropriate.

2.2. Measurement Points Without Network Data

In this subsection, the locations without the information about the coordinates determined by cellular network are described.

A) grad

Looking at the Figures 6 and 8, it can be noticed that the accuracy provided by the GPS sensor is generally comparable with the deviation from the true position. It means that in the case of point of interest denoted as A, which is an open space area, the result is at the verge of reliability. It can be also observed in Figure 10 that for most of the probes the square indicating the true position is inside the circles, radius of which represents the sensor accuracy. Figures 5 and 7 indicate sufficient stability of the results.

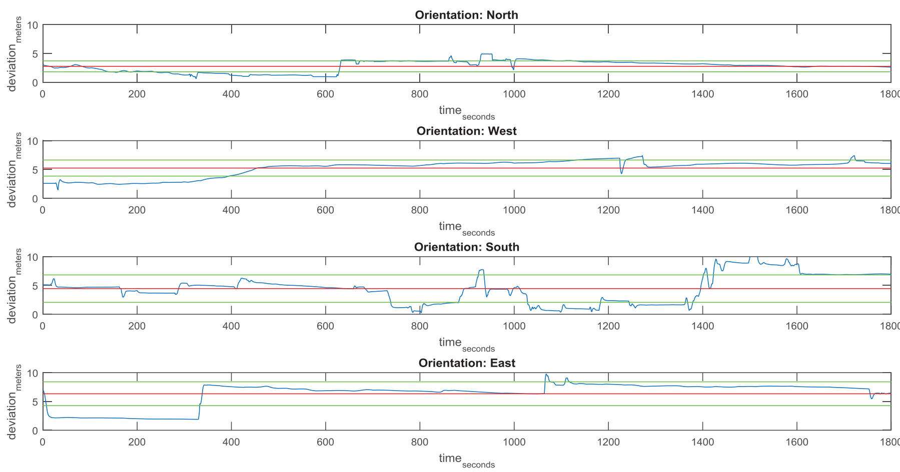


Figure 5. GPS deviation from true position - time series (blue), mean (red) +/- std (green).

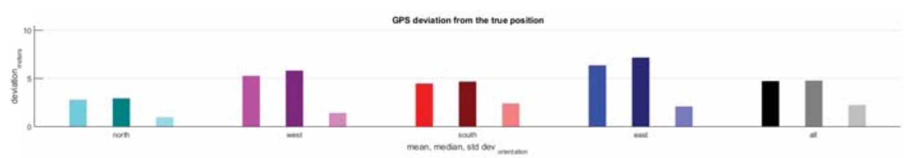


Figure 6. GPS deviation from true position per orientation – mean, median, standard dev.

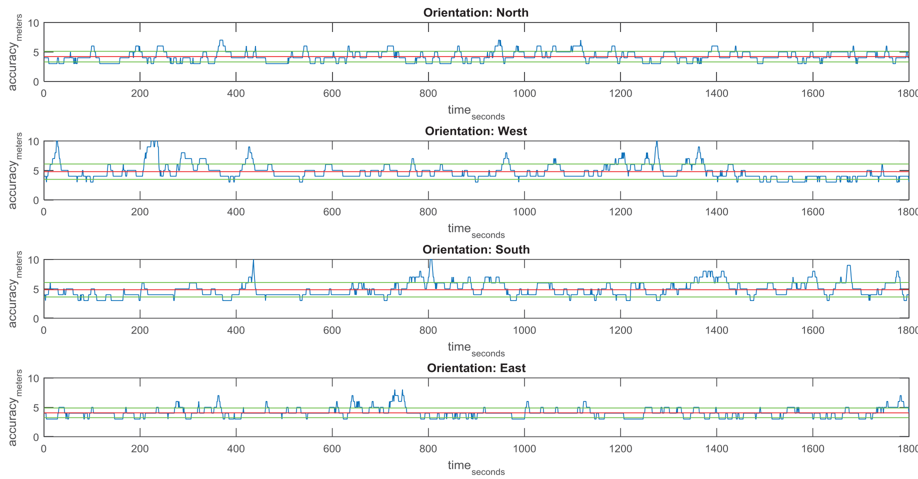


Figure 7. Accuracy of GPS per orientation - time series (blue), mean (red) +/- std (green).

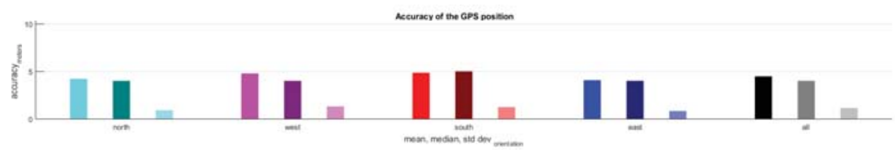


Figure 8. Accuracy of the GPS position per orientation – mean, median, standard dev.

Figure 9. a, b, c, d. GPS positions per orientation (colored) with true position (square).

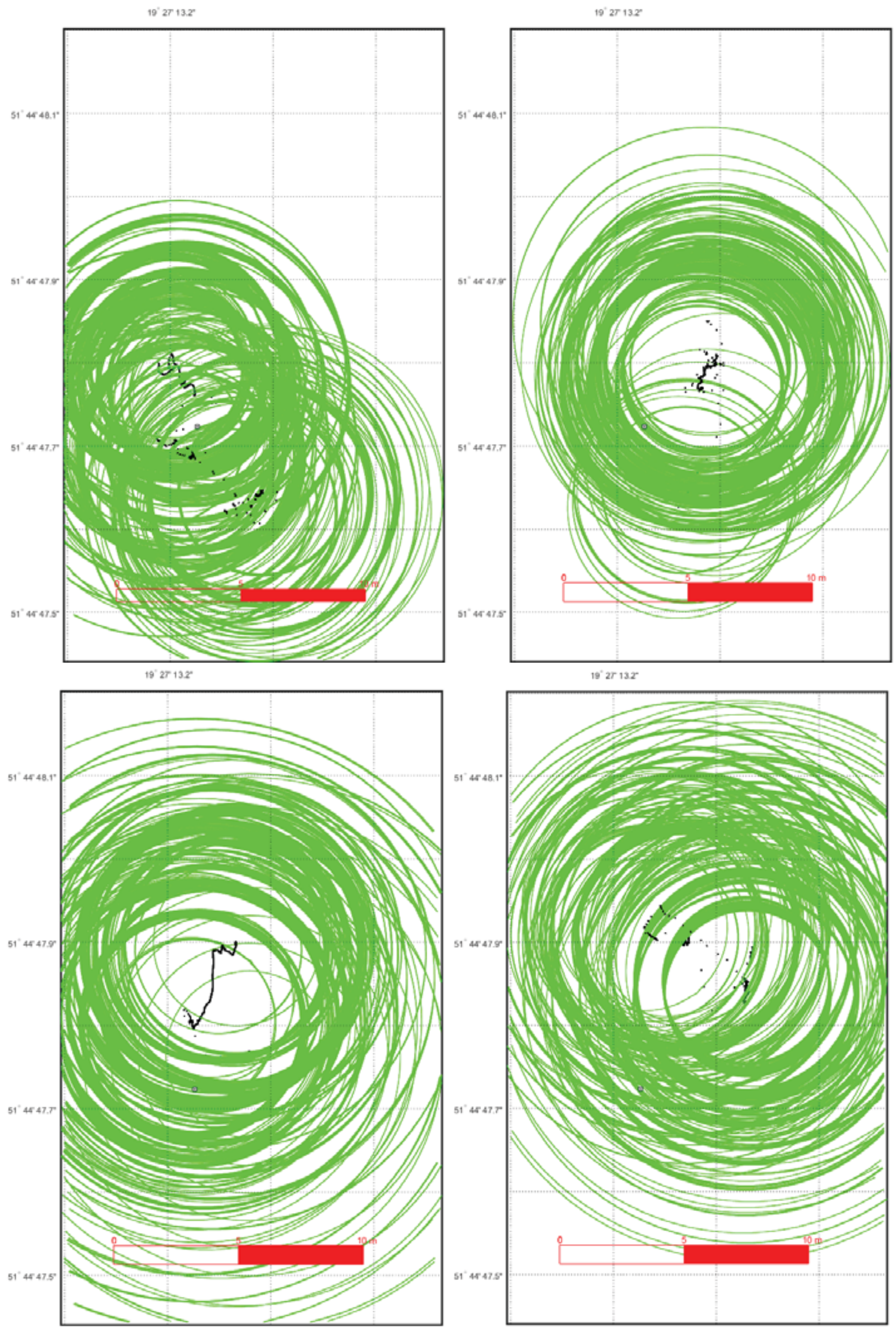


Figure 10. a, b, c, d. GPS positions (black), accuracies (green) and true position (square).

B) dwz

Example point B was located under the trees, so the Google Earth satellite screenshot is not presented here as the point is not clearly visible. Comparing the Figures 12 and 14 one may observe that the accuracy provided by the GPS sensor is, on average, a few meters smaller in value than the deviation from the true position. It means that in the green area with trees the result is less reliable than in the previous case. It can be also observed in Figure 15, that for most of the cases the square is outside the circles. Figures 11 and 13 show also more outliers, but the result can be considered as quite stable. Based on these two Figures, however, another interesting observation was made. The clear difference in curve traces and peaks between subplots, as well as largest deviation from the true position and accuracy values for the east coordinate, prove the influence of measurement setup orientation. A possible cause could be the neighborhood of a building that was about ten meters further on the western side. A more detailed investigation of the GPS sensor placement inside the smarthphone could verify this hypothesis.

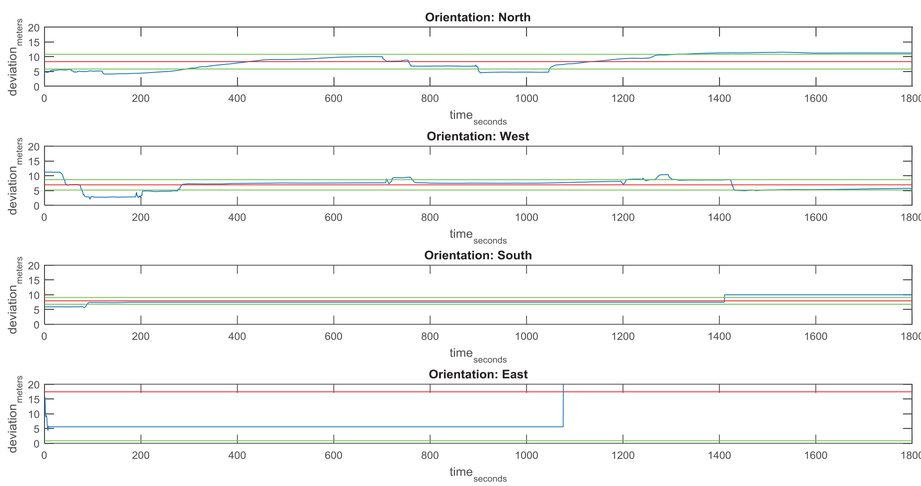


Figure 11. GPS deviation from true position - time series (blue), mean (red) +/- std (green).

Figure 12. GPS deviation from true position per orientation – mean, median, standard dev.

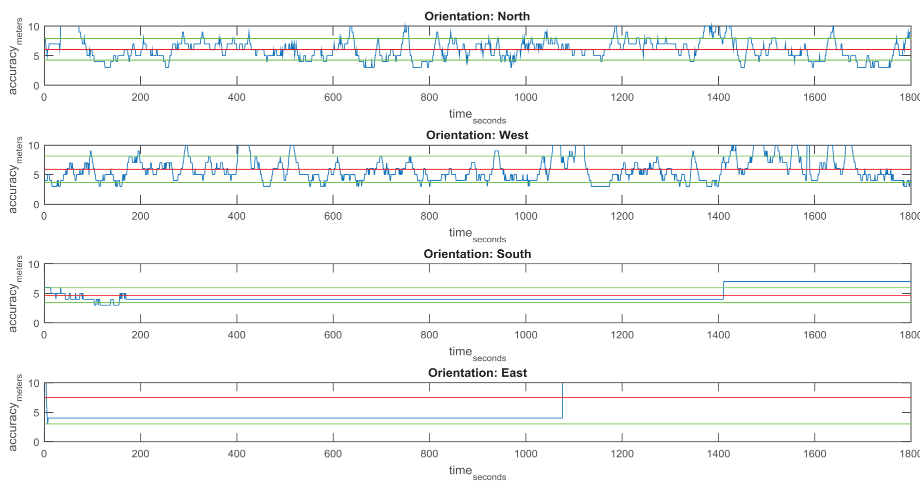


Figure 13. Accuracy of GPS per orientation - time series (blue), mean (red) +/- std (green).

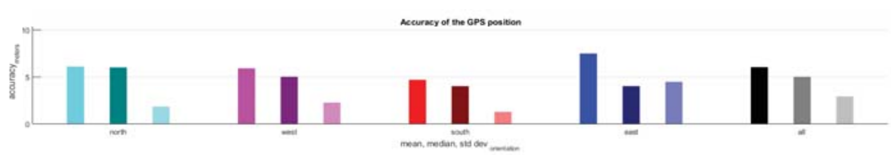


Figure 14. Accuracy of the GPS position per orientation – mean, median, standard dev.

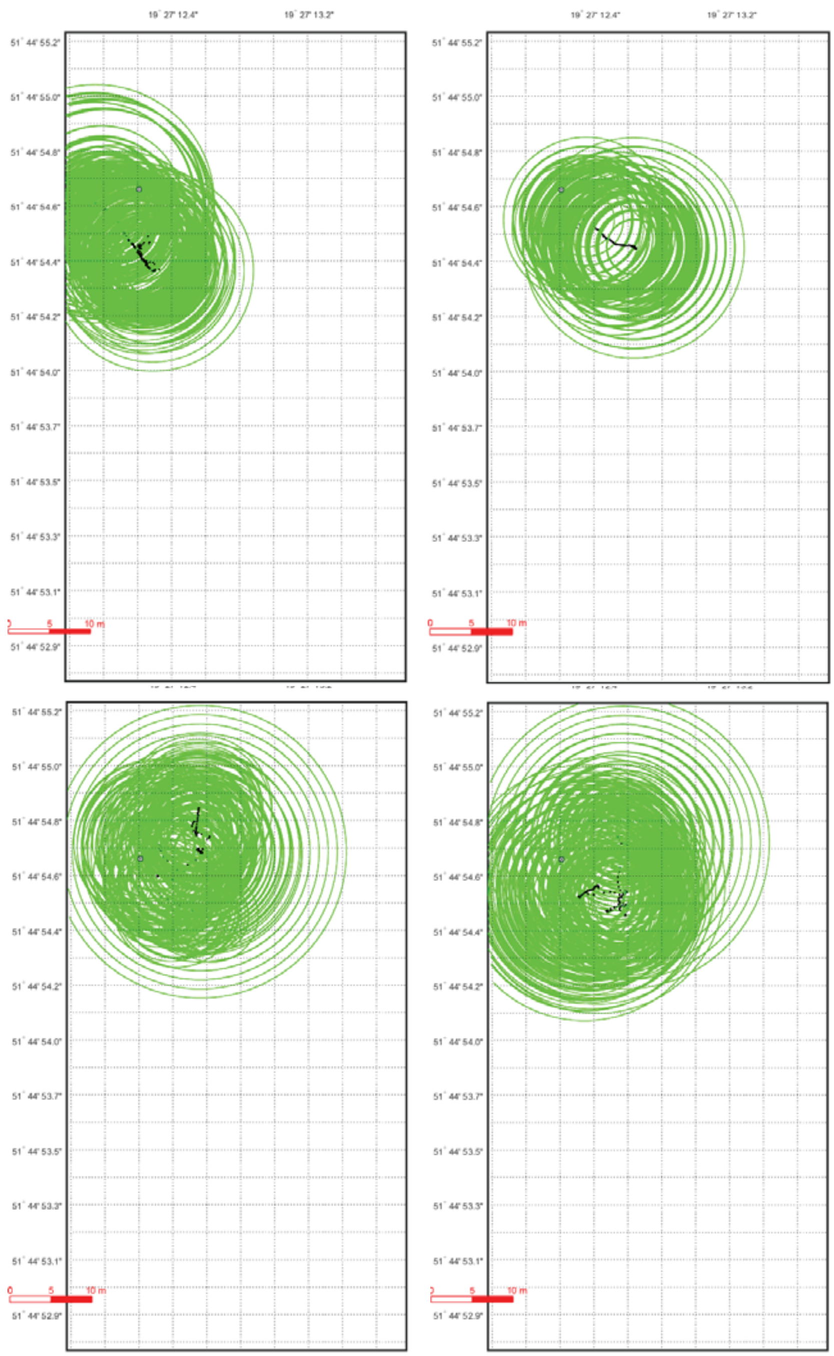


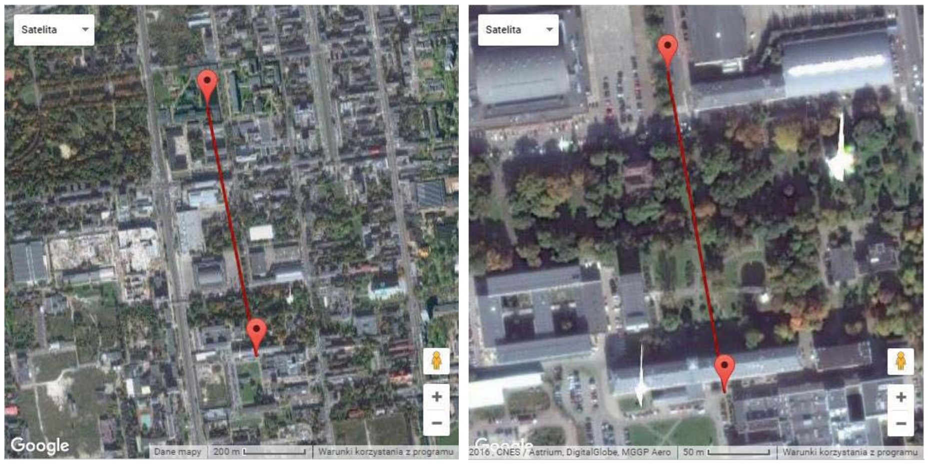
Figure 15. a, b, c, d. GPS positions (black), accuracies (green) and true position (square).

2.3. Measurement Points With Constant Network Data

Measurements taken on the following three points brought constant coordinates provided by the cellular network. They differ significantly from the true position. An online tool enabled us to illustrate the deviation on a map (Movable Type Scripts, 2016).

Figure 16. The deviation of constant coordinates provided by the cellular network from the true position of measurement hardware for the 'weeia' point of interest (distance: 151.5 m).

The next two Figures present an interesting relationship. In both cases, the positions estimated by cellular network have almost the same coordinates. Moreover, the indicated point is a close to a location of another, previous measurement series. So far it was impossible for us to find a reasonable explanation for this fact. One possibility is that the cellular network information provided for the previous point remained unchanged due to some network mistake of not updating the position on the measuring device. The answer to that phenomena might be probably found after the detailed investigation of surrounding base stations, depicted in the Figure 19, and the analysis of their signal strength. This investigation could be a starting point of future research in this area.



Figures 17., 18. The deviation of constant coordinates provided by the cellular network from the true position of measurement hardware for the ‘garaz‘ and ‘mosir‘ points of interest (distance: 792.2 m and 253.5 m, respectively).

Figure 19. Base Stations Cell IDs (arrows) with the last point ‘lodex’ true location (square).

C) weeia

In the case of point C, which was indoor, both the deviation and the accuracy was 2 up to 4 times larger than in the outdoor scenarios. Looking at the Figures 21 and 23 one may see the difference between these two and previous plots. The accuracy provided by the GPS sensor is again smaller than the deviation from the true position, which indicates the fact that it is not sufficient to rely on. It can be also observed in Figure 25, that for most of the cases the square is outside the circles. Figure 22 shows that the accuracy indicator varies significantly what makes the results totally unstable.

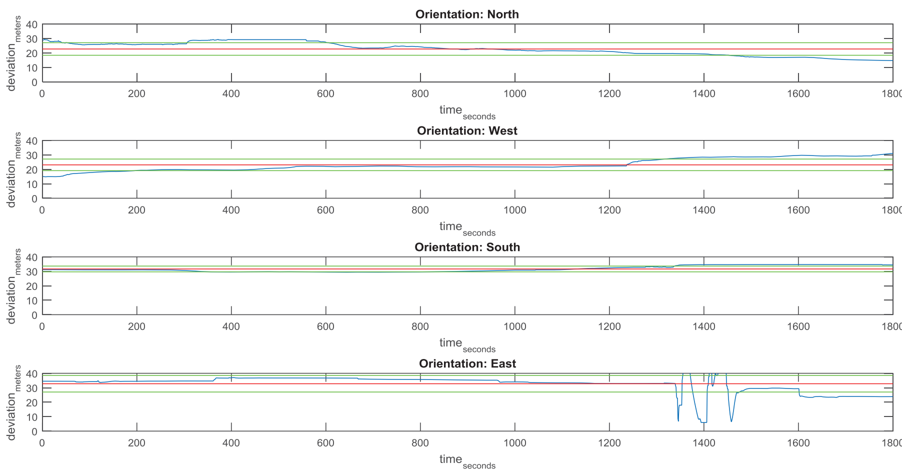


Figure 20. GPS deviation from true position - time series (blue), mean (red) +/- std (green).

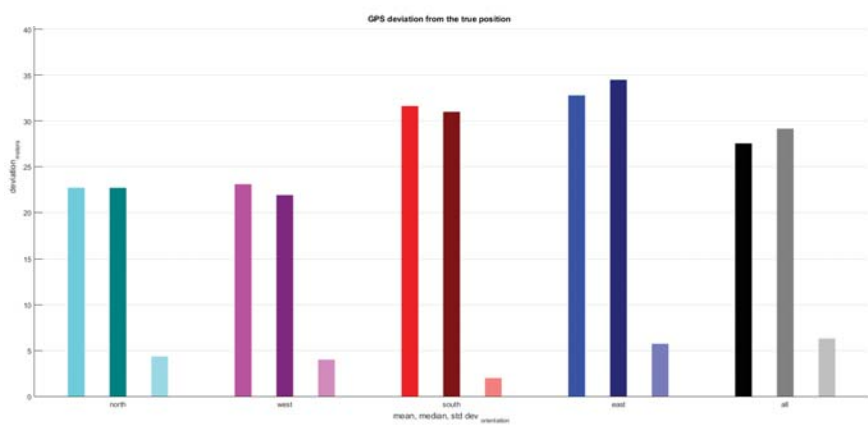


Figure 21. GPS deviation from true position per orientation – mean, median, standard dev.

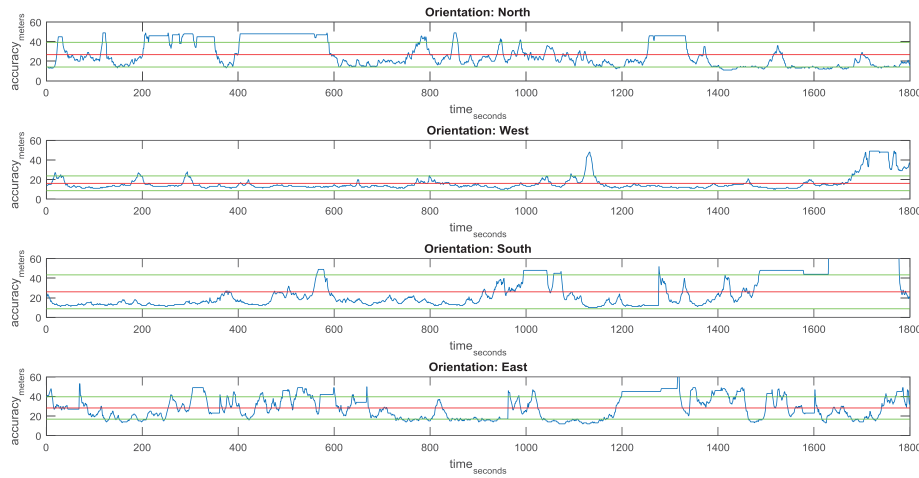


Figure 22. Accuracy of GPS per orientation - time series (blue), mean (red) +/- std (green).

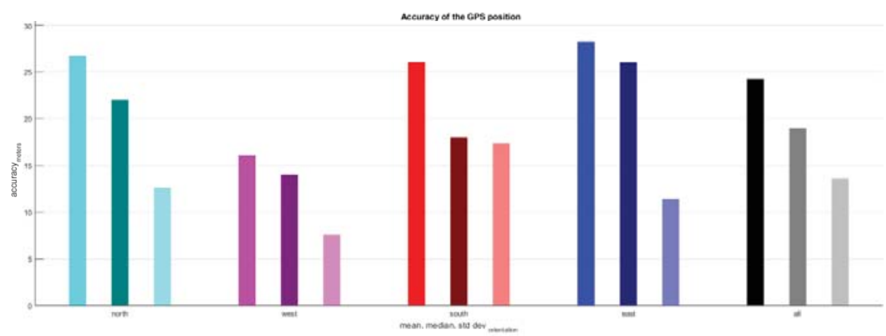


Figure 23. Accuracy of the GPS position per orientation – mean, median, standard dev.

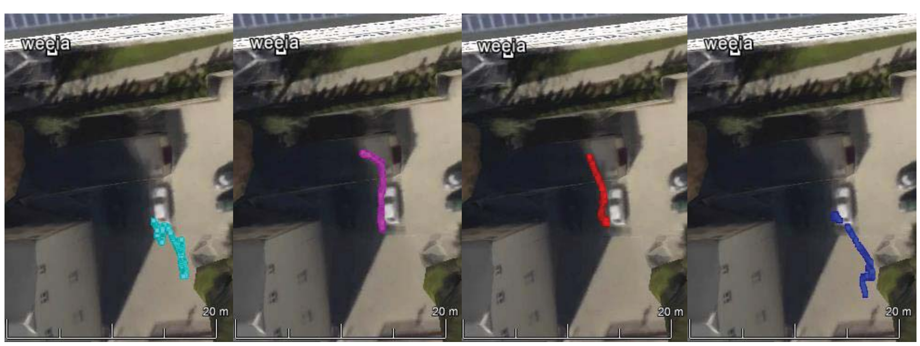


Figure 24. a, b, c, d. GPS positions per orientation (colored) with true position (square).

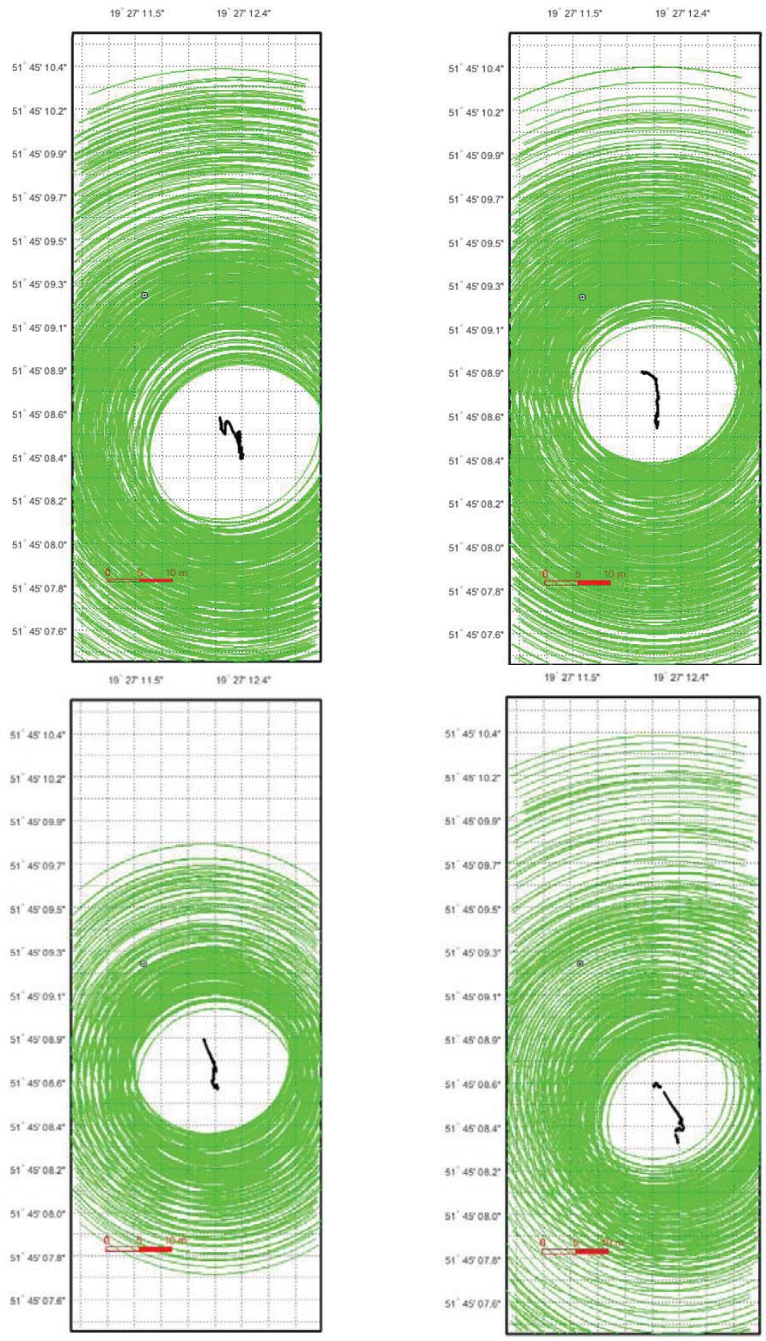


Figure 25. a, b, c, d. GPS positions (black), accuracies (green) and true position (square).

D) mosir

As for the point D, for which the measurements were collected in the street, comparing the Figures 27 and 29 it can be stated that the results are again hardly reliable since the accuracy provided by the GPS sensor is slightly smaller than the deviation from the true position. It is not clearly seen in Figure 31, however, the analysis proved that the square is outside the circles for most cases. The Figures 26 and 28 prove that the result cannot be said to be stable, no matter what the actual orientation was.

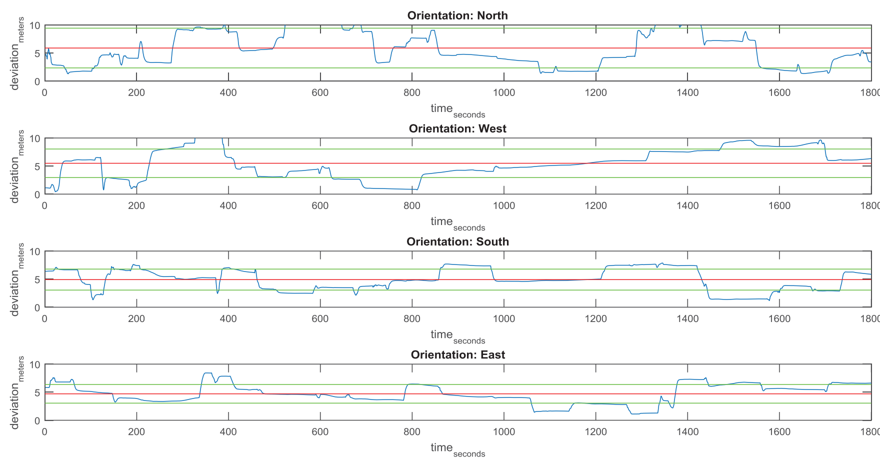


Figure 26. GPS deviation from true position - time series (blue), mean (red) +/- std (green).

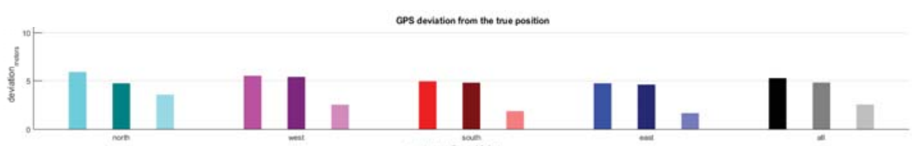


Figure 27. GPS deviation from true position per orientation – mean, median, standard dev.

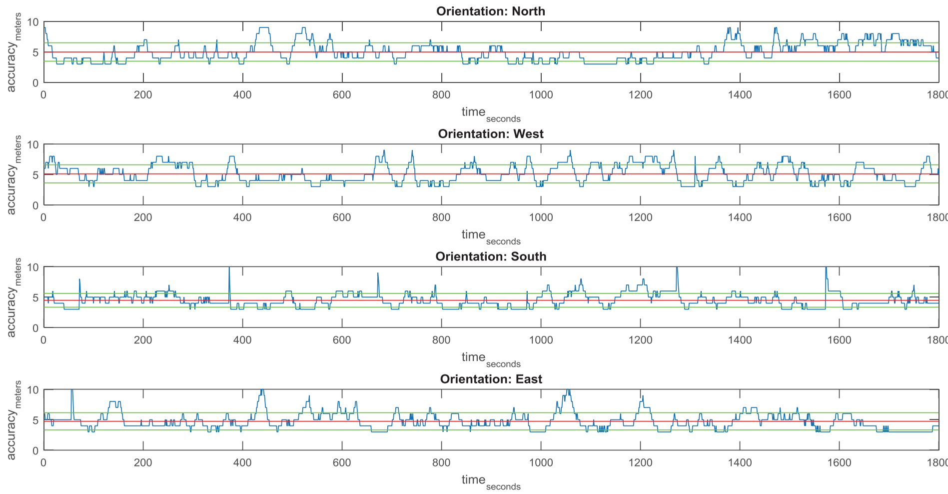


Figure 28. Accuracy of GPS per orientation - time series (blue), mean (red) +/- std (green).

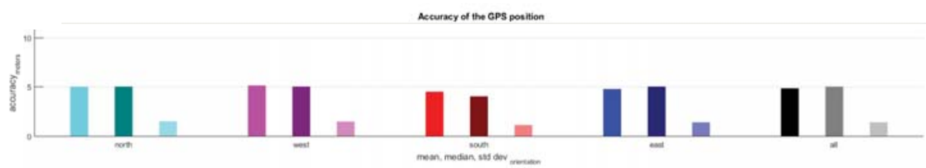


Figure 29. Accuracy of the GPS position per orientation – mean, median, standard dev.

Figure 30. a, b, c, d. GPS positions per orientation (colored) with true position (square).

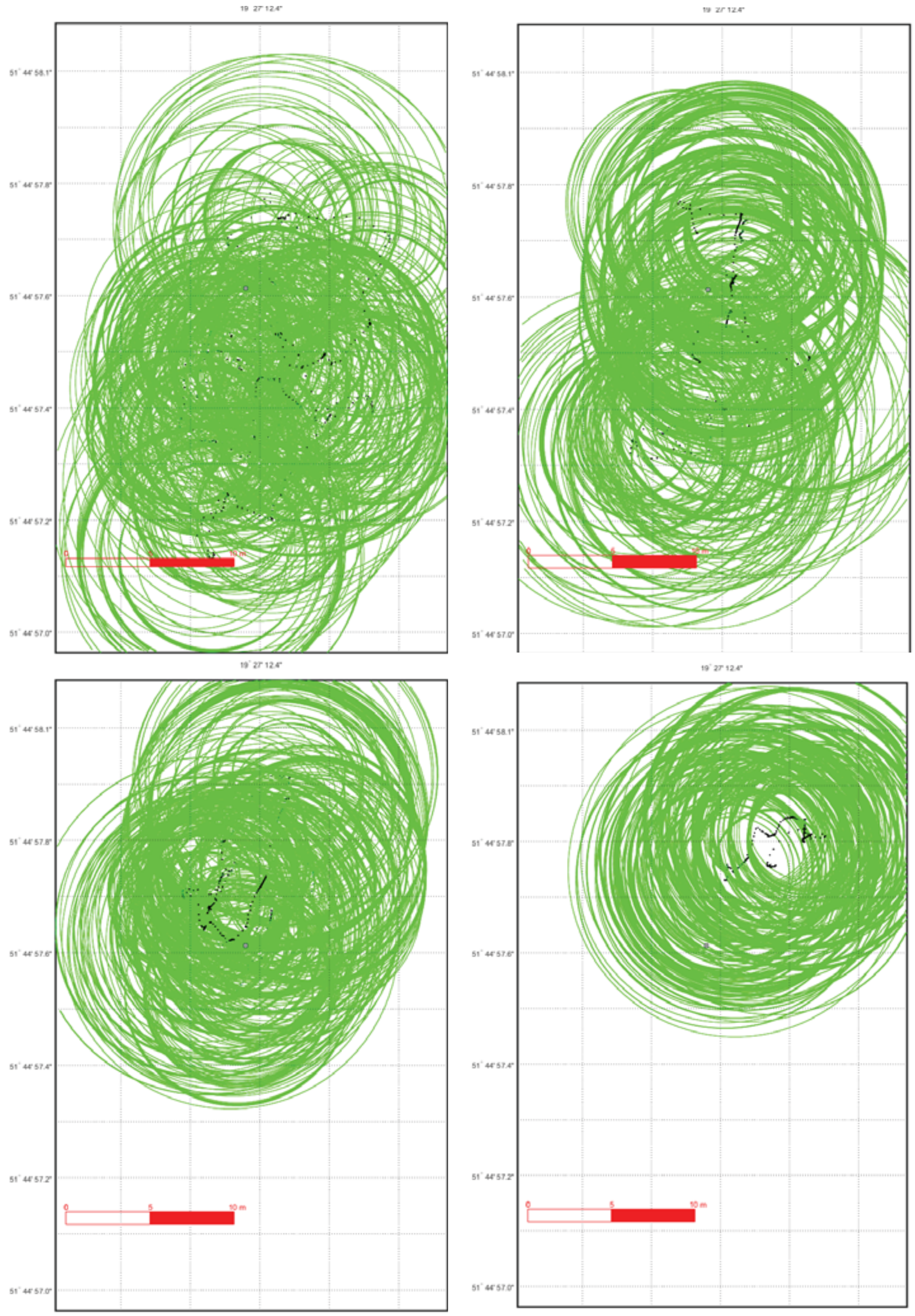


Figure 31. a, b, c, d. GPS positions (black), accuracies (green) and true position (square).

E) garaz

Comparing the Figures 33 and 35 for the location E, one observes a huge discrepancy between the GPS sensor accuracy and the deviation from the true position. That makes the results least reliable from all which were so far analyzed. It can be explained by the urban canyon scenario – an area surrounded by buildings that probably block the GPS signal and result in many secondary waves due to multipath and reflection phenomena. In Figure 37, it can be clearly seen that the square is totally outside the circles. The Figures 32 and 34 show the instability of most of the cases.

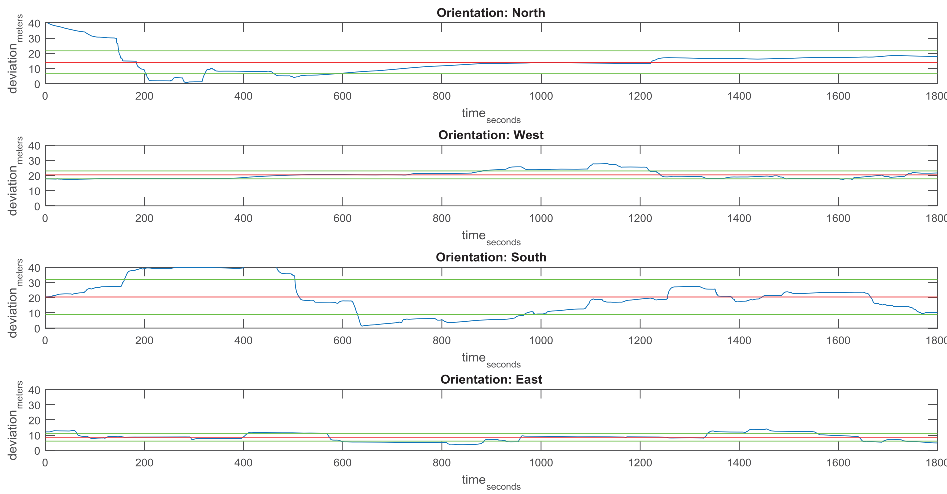


Figure 32. GPS deviation from true position - time series (blue), mean (red) +/- std (green).

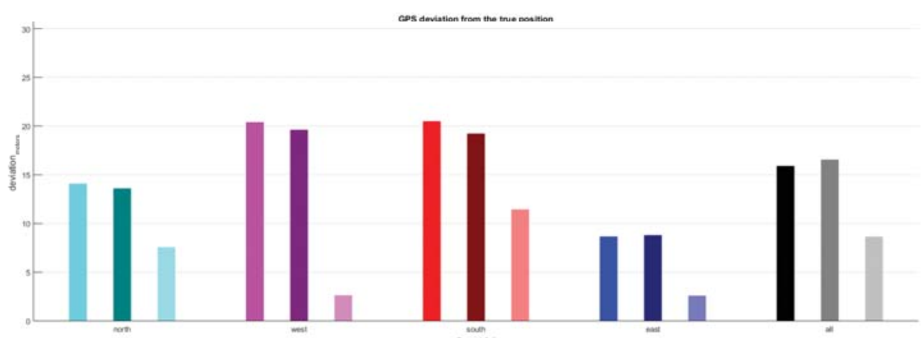


Figure 33. GPS deviation from true position per orientation – mean, median, standard dev.

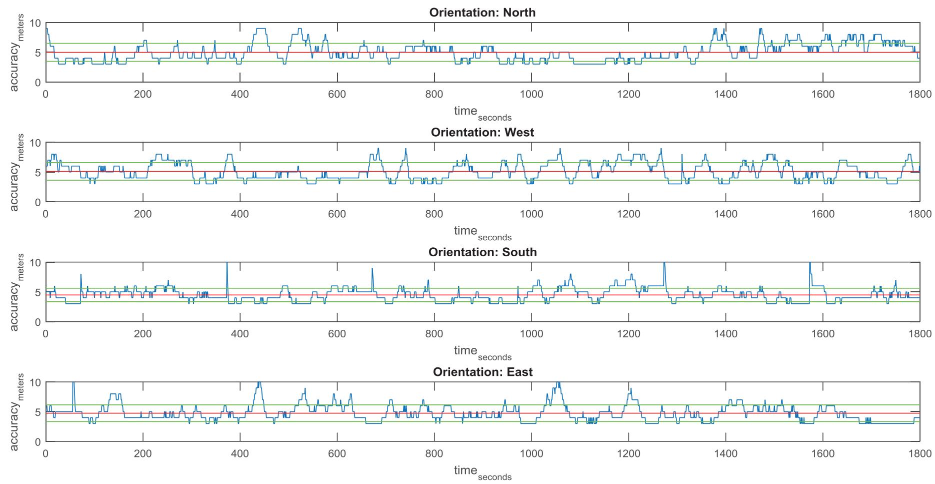


Figure 34. Accuracy of GPS per orientation - time series (blue), mean (red) +/- std (green).

Figure 35. Accuracy of the GPS position per orientation – mean, median, standard dev.

Figure 36. a, b, c, d. GPS positions per orientation (colored) with true position (square).

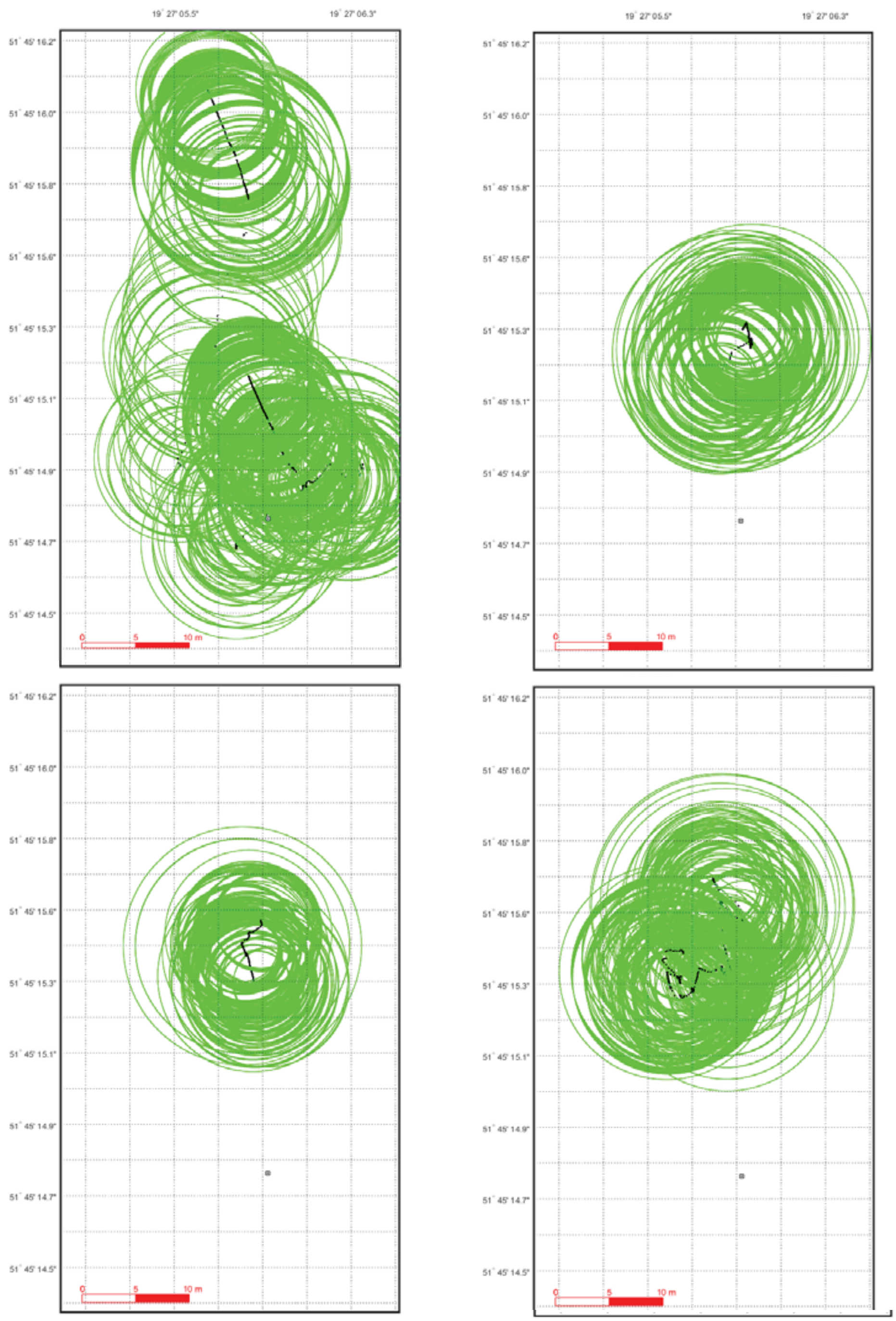
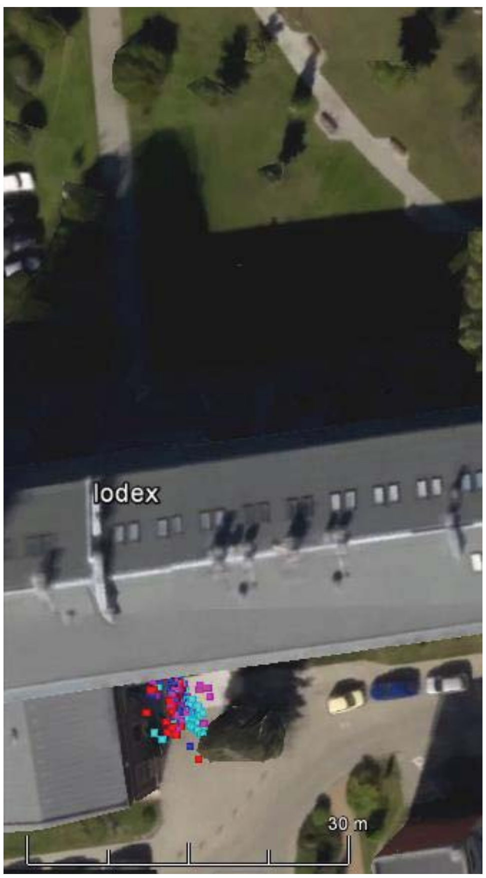


Figure 37. a, b, c, d. GPS positions (black), accuracies (green) and true position (square).

2.4. Measurement Point With Varying Network Data

F) Iodex

In this last example, one deals again with an indoor scenario. Comparing the Figures 41 and 43 it can be observed that the deviation from the true position is beyond the accuracy provided by the GPS sensor, meaning the poor reliability of the result. It is also clearly visible in the Figure 46 where the square is far outside the circles. Based on the Figures 40, 42, 44, 46 and 48 it can be stated that the results are stable with some minor outliers.



Figures 38., 39. Network positions for each orientation (colored), on the left – and points with constant network positions (yellow pins) with their true locations (white squares), right.

This point of interest was also the only one with varying coordinates information provided by the cellular network. For that reason, analysis of base stations triangulation positioning was possible. Unfortunately, again the deviations from the true position are greater than the accuracy provided by the cellular network which turned out to be more stable, but on the other hand less reliable than GPS. The discrepancies between network and GPS positions are significant, larger than the deviations from true positions. However, the network positions are more concentrated what makes it more precise than GPS positioning. This effect may be observed while comparing the Figures 50 and 51. In the Figure 50, the accuracy of the network was so large in value and significantly stable compared with the spread of the points that for the better view it was not reasonable to add this information to the same plot. In can be, however, seen from Figures 46 and 47.

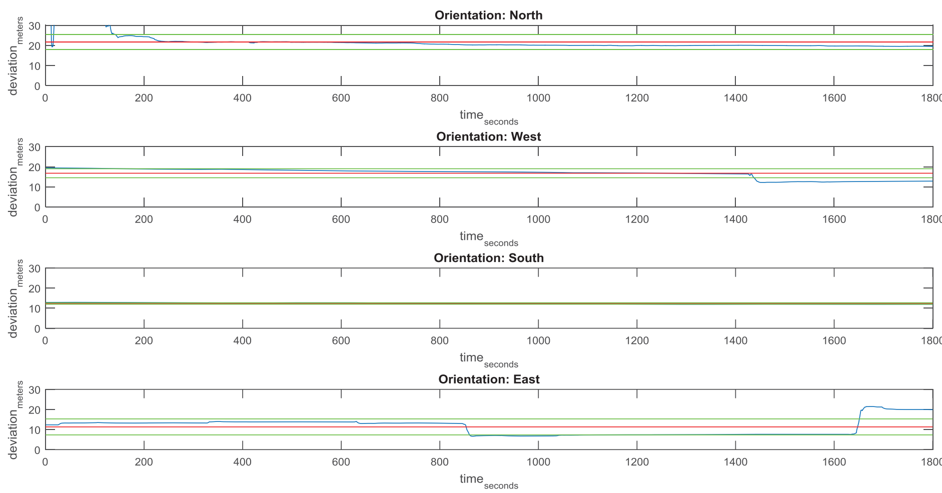


Figure 40. GPS deviation from true position - time series (blue), mean (red) +/- std (green).

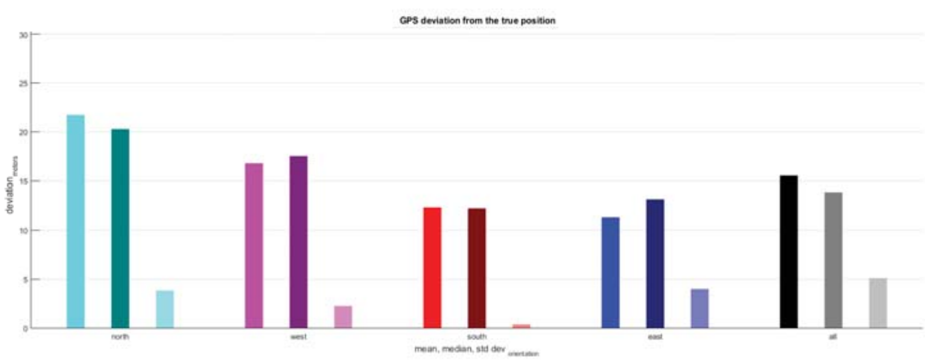


Figure 41. GPS deviation from true position per orientation – mean, median, standard dev.

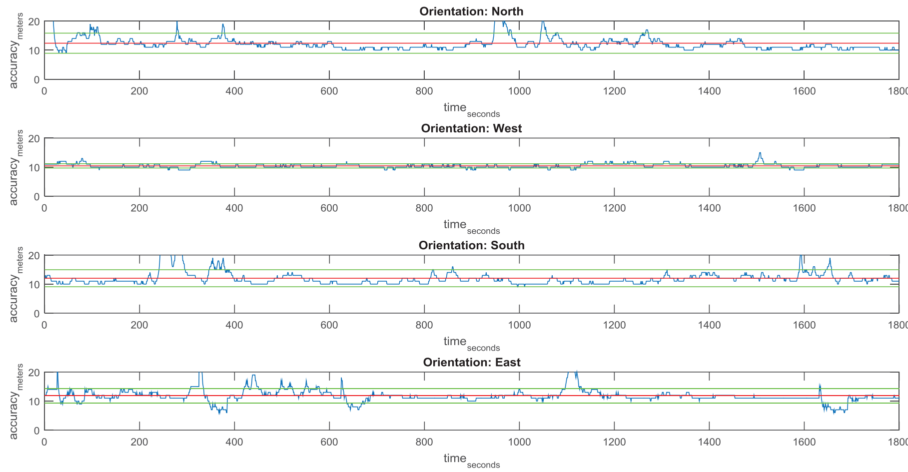


Figure 42. Accuracy of GPS per orientation - time series (blue), mean (red) +/- std (green).

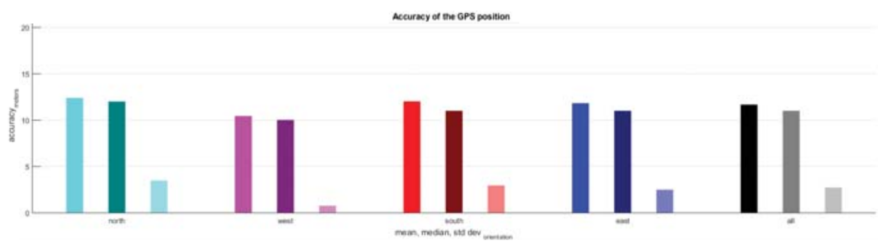


Figure 43. Accuracy of the GPS position per orientation – mean, median, standard dev.

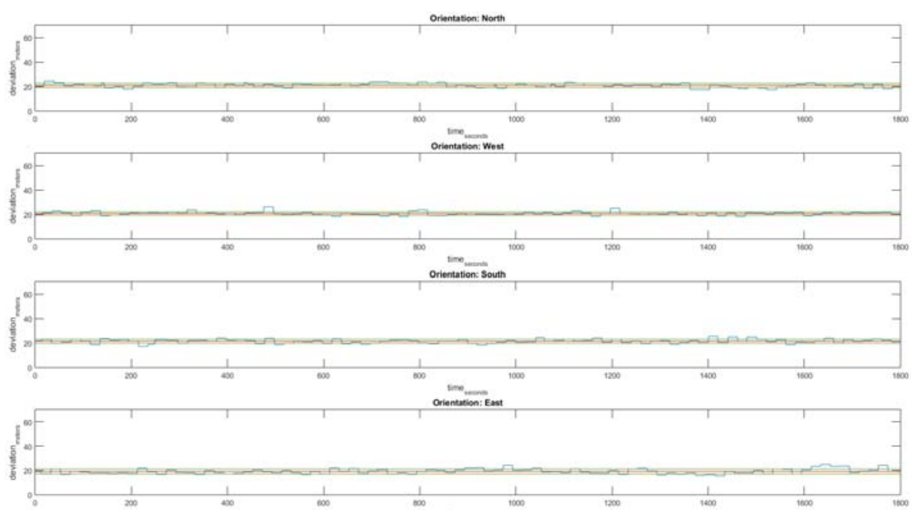


Figure 44. Deviation of coordinates provided by cellular network from the true position per orientation – plot of time series (blue) with mean (red) and +/- standard deviation (green).

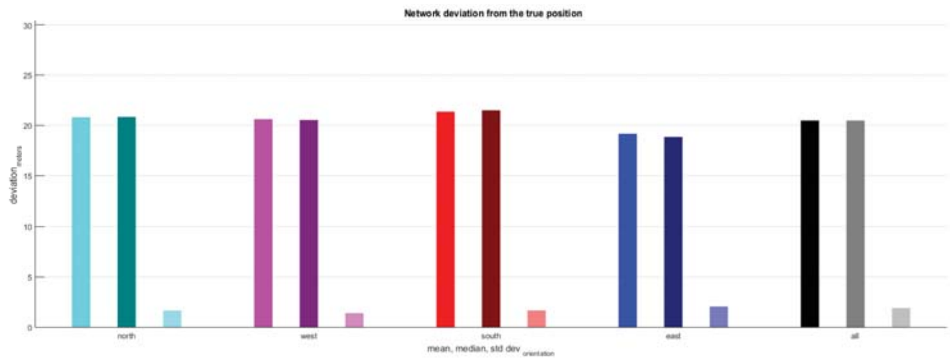


Figure 45. Deviation of coordinates provided by cellular network from the true position for each orientation – mean, median, standard deviation.

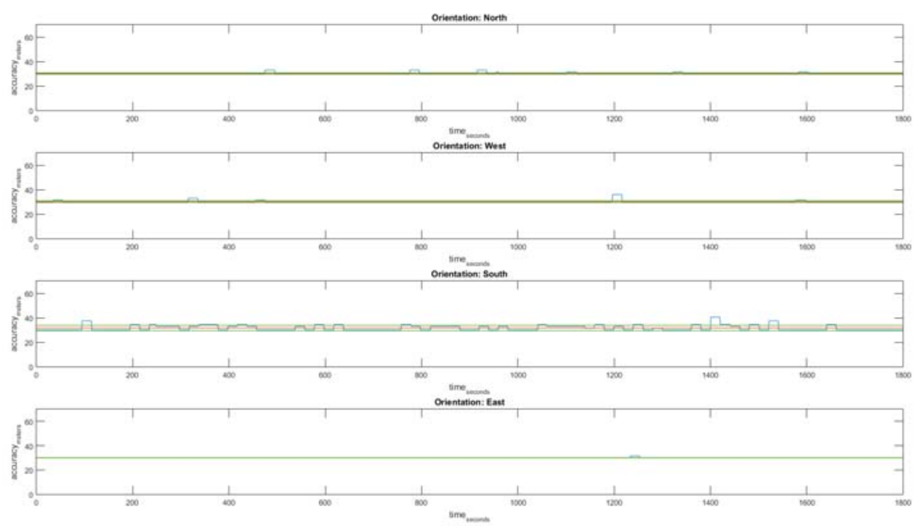


Figure 46. Accuracy of coordinates provided by cellular network per orientation – plot of time series (blue) with mean (red) and +/- standard deviation (green).

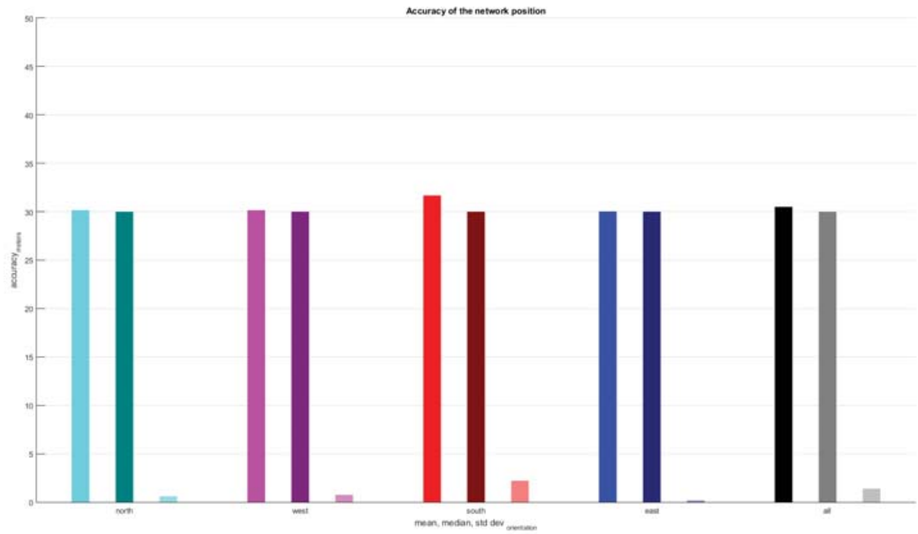


Figure 47. Accuracy of coordinates provided by cellular network for each orientation – mean, median, standard deviation.

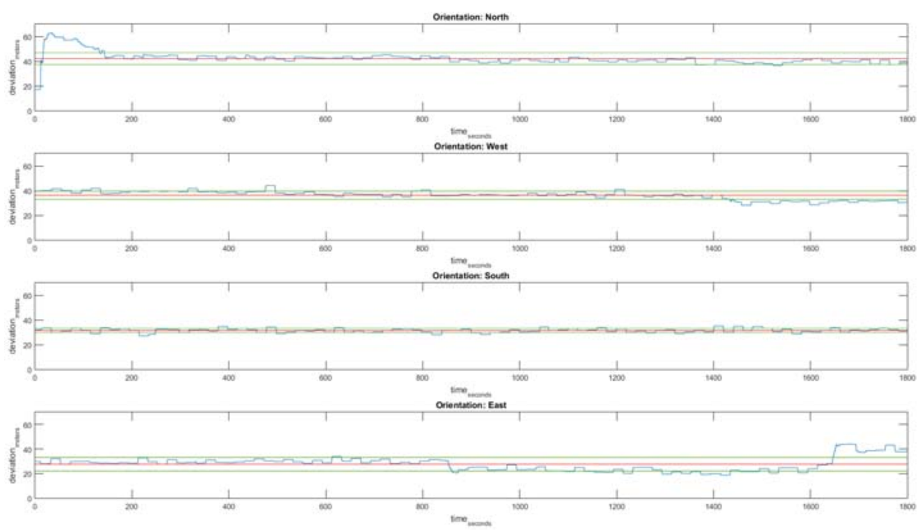


Figure 48. Deviation of coordinates provided by cellular network from GPS position per orientation – plot of time series (blue) with mean (red) and +/- standard deviation (green).

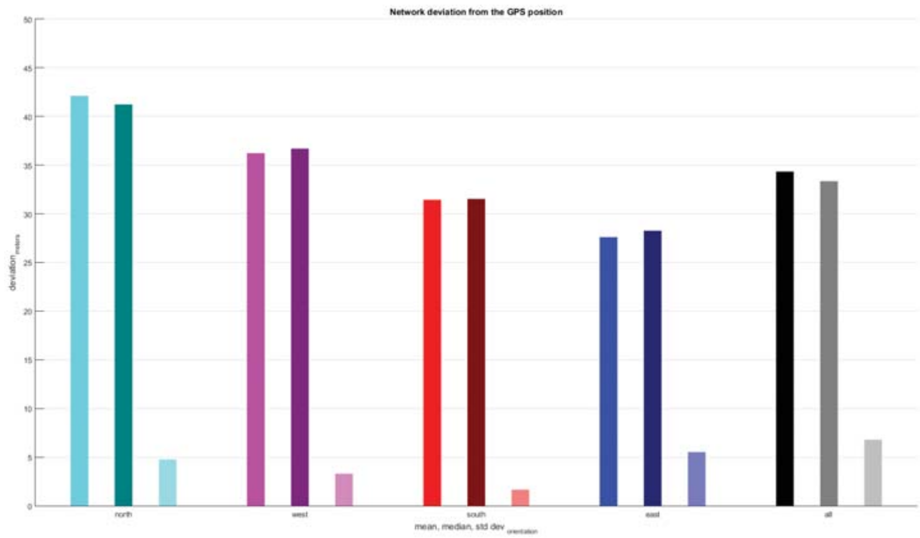


Figure 49. Deviation of coordinates provided by cellular network from GPS position for each orientation – mean, median, standard deviation.

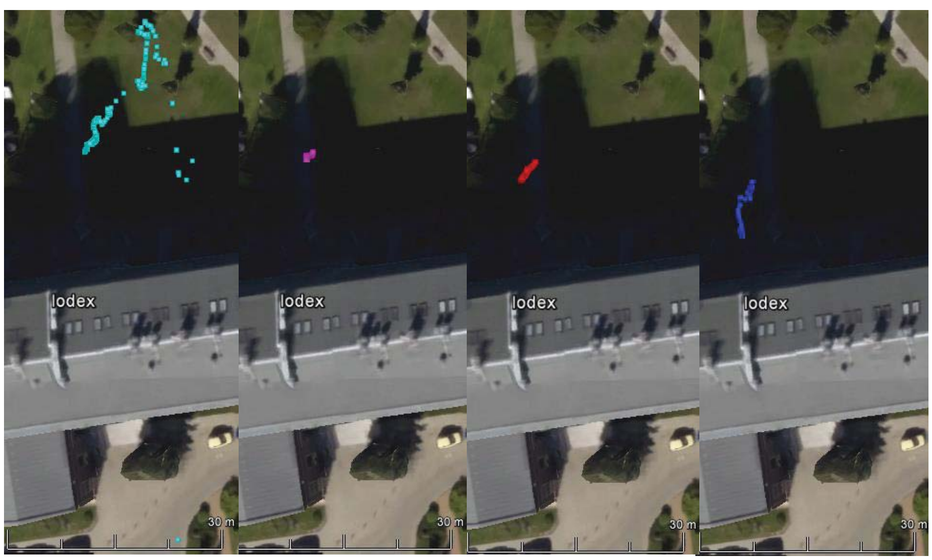


Figure 52. a, b, c, d. GPS positions per orientation (colored) with true position (square).

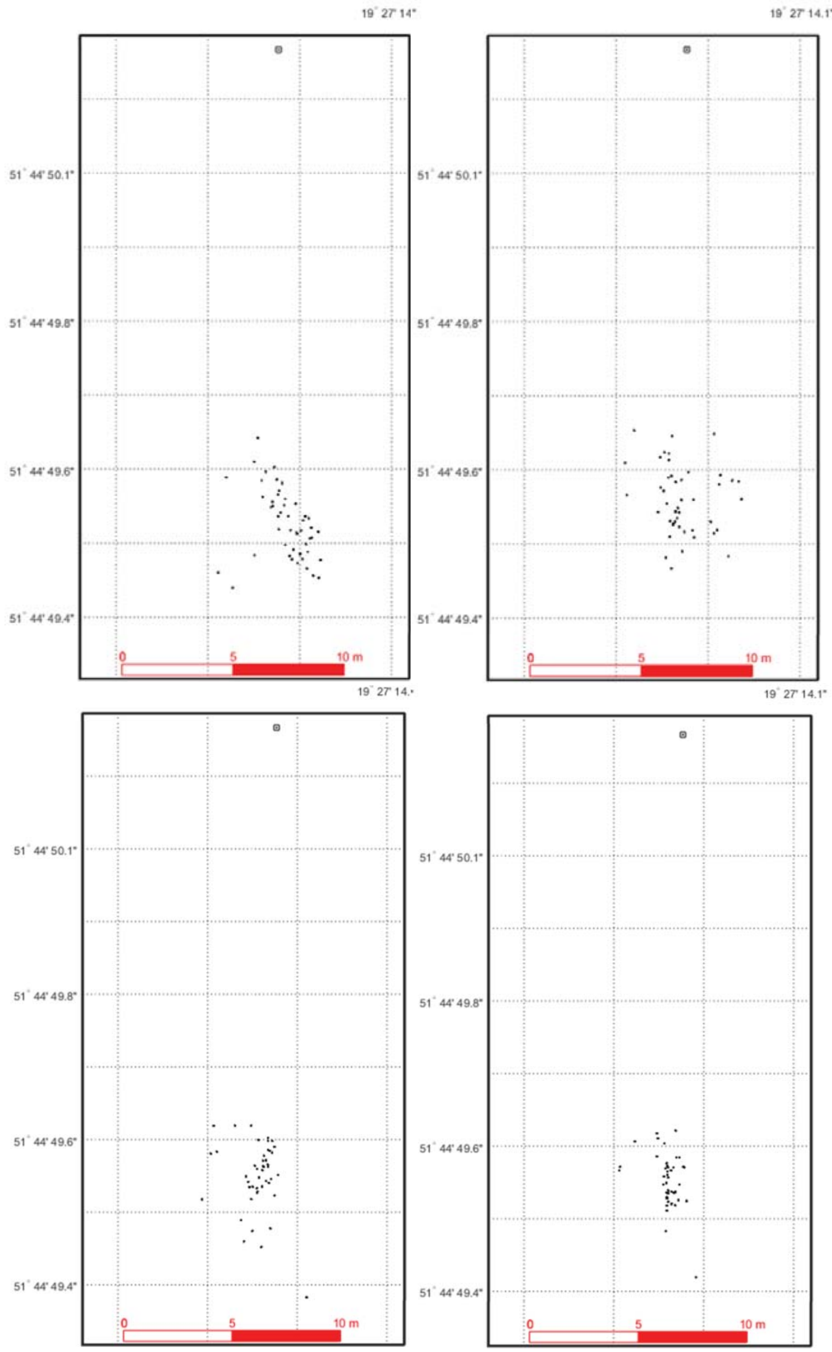


Figure 50. Network positions (points) with true position (square) per orientation.

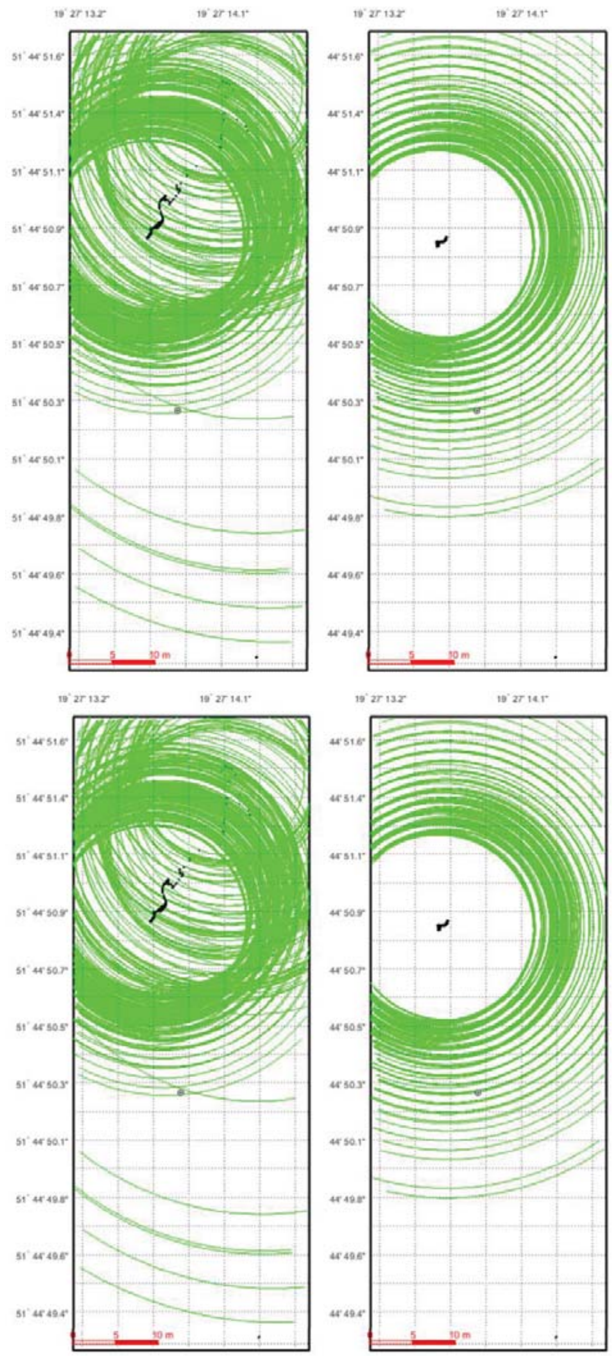


Figure 51. a, b, c, d. GPS positions (black), accuracies (green) and true position (square).

2.5. Discussion of the GPS Results

The overall results presented in the Table 2 constitute a summary of findings from the previous sections. The stability can be judged considering the ratio between the standard deviation and mean for deviation and the accuracy separately, whereas reliability might be assessed based on the relationship between the accuracy and deviation values, respectively. The reference measurements indicate the fact that outdoor locations not shaded by buildings or trees present the highest reliability, defined as spread between GPS sensor accuracy and the deviation from the true position. This study also shows that the altitude has an impact on the measurement stability, which is more significant in the indoor scenarios.

POI Name	GPS deviation [m]			GPS accuracy [m]			Description	Stability	Reliability
	Mean	Median	Std dev.	Mean	Median	Std dev.			
grad	4.70	4.76	2.21	4.47	4.00	1.14	outdoor open space	high	medium
dwz	10.15	7.45	9.45	6.03	5.00	2.91	outdoor park area	medium	low
weeia	27.55	29.15	6.31	24.27	19.00	13.58	indoor ground floor	very low	very low
mosir	5.25	4.80	2.55	4.82	5.00	1.41	outdoor in the street	low	medium
garaz	15.90	16.56	8.64	4.62	4.00	1.38	outdoor building canyon	low	very low
lodex	15.54	13.80	5.09	11.66	11.00	2.71	indoor 4th floor	medium	low

Table 2. The measurement points GPS stability and reliability.

3. Conclusions

In this work the influence of environment such as shadowing by buildings and trees was confirmed. The analysis of reference measurement data covered both static indoor and outdoor scenarios. Not only the GPS data were taken into consideration, but also the use of cellular network data was investigated. As stated before, this might be the a start point for further future work. Detailed statistical investigation was performed and some interesting correlations were found. This paper may help the everyday modern mobile phone user to understand and react to some challenges resulting from positioning tools of limited accuracy and stability. Our work might also become an impact for the cellular network providers encouraging them to further develop positioning and localization applications.

References

Movable Type Scripts (2016). Calculate distance, bearing and more between Latitude/Longitude points, http://www.movable-type.co.uk/scripts/latlong.html, accessed June 20, 2016

Ambulatory Assessment to Study Mobility and Activity Patterns in Healthy Aging Research

Pia Bereuter*, Robert Weibel **

* URPP "Dynamics of Healthy Aging" & Department of Geography, University of Zurich, Winterthurerstrasse 190, Zurich
** Department of Geography, University of Zurich, Winterthurerstrasse 190, Zurich

Keywords. CMA; Computational Movement Analysis; Healthy Ageing; Ambulatory Assessment; GPS; Accelerometer Data

1. Introduction

Research in health science and psychology is focused on particular health conditions and often conducted in controlled laboratory settings. Dynamic real-world situations show that findings from laboratory research are only partially applicable as contextual factors affect behavior (Reis 2012). Older adults, despite showing a drop in cognitive ability, handle well the challenges of every day life (Verhaeghen et al. 2012). *Ambulatory assessment*, *in situ* measurements in everyday life, has recently been advocated to study dynamic health stabilization models in their real-life context (Brose and Ebner-Priemer 2015). Ambulatory assessment includes the collection of various data over predefined periods of time, such as observed behavior and self-reports, and physiological and biological data.

2. MOASIS Study design

The *Mobility, Activity and Social Interaction Study* (MOASIS) collects individualized everyday-life health data in older adults and aims to develop computational models to measure, analyze, and improve health behaviors and health outcomes in the everyday life of aging individuals. It targets to detect and model intra-individual changes and inter-individual differences in

LBS 2016
13th Conference on Location-Based Services
Vienna, 14–16 November 2016

Published in “Proceedings of the 13th International Conference on Location-Based Services”, edited by Georg Gartner and Haosheng Huang, LBS 2016, 14-16 November 2016, Vienna, Austria.

movement trajectories and social activities of older adults, indexed by repeated measures of movement, space use and social context parameters.

The study employs the custom-built mobile sensor *uTrail* (Fig. 1), which measures the *mobility* with GPS, *physical activity* with a 3-axis accelerometer, and *social interaction* with a microphone using the electronically activated recorder (EAR) method (Mehl et al. 2001).

	Sensor	Variable
Spatial mobility	GPS	timestamp, latitude, longitude
Physical activity	IMU	timestamp, acceleration (x,y,z), step counter
Social interaction	EAR	timestamp, sound sample (30 secs)

Figure 1. Overview of the uTrail mobile sensor

Preceding to the main study, scheduled for early 2017, two pilot studies have been conducted to test the sensors and the overall study protocol. This work in progress reports on the second pilot study conducted between March and Mai 2016 with an observation period of 30 days and 27 participants (aged 65 - 80 years, fluency in German and a score above 26 in the Mini Mental State Examination MMSE; Folstein et al. 1975). The study design includes psychological baseline tests, self-reports, evening diary, complemented by the ambulatory assessment of the physical, spatial and social activity. On a daily basis the participants carry the uTrail to assess their mobility and activity, while in the evening they keep track of their activity with an evening diary.

3. Reconstructing daily spatio-temporal timelines

Due to the real-world study setup, the sensor settings and the participants' daily-life patterns and actions, the analysis must be able to cope with partial data readings. Partial data readings include lack of GPS reception, or missing data due to the device inadvertently being switched off, interrupting the continuous sampling. For all three sensors, time is used as a unique identifier (uid) to merge the different datasets. Merging enables various insights, such as how active a person is according to where they are or in which places the person is socially active. Combining accelerometer with GPS data provides more solid estimates of GPS locations when the participant moves slowly or is stationary, and helps to detect the mode of transport.

Handling different sequences based on data availability allows us to work with partial data, and build inferences to fully reconstruct timelines (Fig. 2). In this work, temporal gaps are defined by a preset temporal threshold and are used to split the segments into sub-segments that require different analysis approaches. Sub-segments with valid GPS readings can then be handled by trajectory segmentation methods (Laube and Purves 2011, Gschwend 2015) based on GPS and acceleration readings (Move-GPS, Stop-GPS). For the temporal gaps, the segment is inferred between the last and next known valid location (Move-ND, Stop-ND) based on a combined distance and acceleration criterion. Figure 2 shows conceptually for a sample day the different types of moves and stops. Given accelerometer data, inferences of activity intensities and classification provide additional hints for segments with no GPS data. No-data segments also affect data merging; here, they affect how well the audio data are mappable to the closest known GPS position (shown in Figure 2 with an audio symbol against a gray circle.)

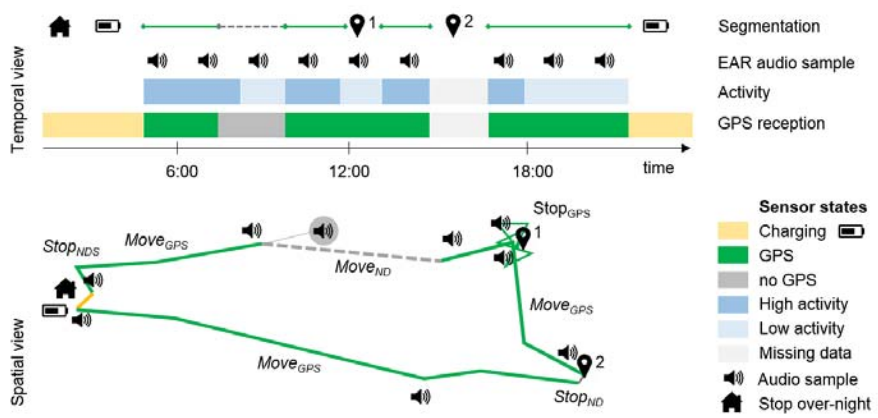


Figure 2. Conceptual illustration of a spatio-temporal trajectory considering gaps in GPS data and offline periods

4. Conclusions

Synchronizing by time allows integration with sensors that are less prone to data reception problems such as accelerometer and EAR, and thus enables (re)constructing the participants' lifelines and computing activity-related measures, while maintaining the spatial perspective (Figure 3). This is especially important as a large part of our daily life is situated indoors, where most of our social and physical interactions occur. By not knowing the semantics of mobility, these mobility patterns nevertheless often remain obscure and require good knowledge of the domain and context.

The next steps of MOASIS will first focus on further semantic annotation of moves, stops and finding further patterns and measures, by including also context data, as well as learning from, and validating with, the self-reporting and diary data. Based on the semantic annotation, we will conduct, among others sequence analysis with a variety of methods and measures.

Figure 3. Visualization of a one-day reconstruction of a participant, with sensor merging, stop and move segmentation and clustering.

Acknowledgements

This research was supported by the Velux Stiftung (project no. 917) and the University Research Priority Program (URPP) "Dynamics of Healthy Aging" at the University of Zurich. The research reported is based on the "Mobility, Activity, and Social Interactions Study" (MOASIS) conducted in cooperation between the URPP "Dynamics of Healthy Aging" and the Department of Geography, University of Zurich. The following persons are current members of the MOASIS project team and contributed to the initial research idea, the planning and implementation of the project: Mike Martin (Co-PI), Robert Weibel (Co-PI), Christina Röcke (Co-PI), Pia Bereuter, Burcu Demiray Batur, Michelle Fillekes, George Technitis. We thank Brigitte Sonderegger for the recruitment of participants, our student assistants for support in the data collection and above all, our participants for their time and willingness to take part in this research.

References

Brose A, Ebner-Priemer UW, 2015, Ambulatory Assessment in the Research on Aging: Contemporary and Future Applications. *Gerontology*. 61(4):372–380.

Folstein MF, Folstein SE, McHugh PR, 1975, “Mini-mental state”. *Journal of Psychiatric Research*. 12(3):189–198.

Mehl MR, Pennebaker JW, Crow DM, Dabbs J, Price JH, 2001, The Electronically Activated Recorder (EAR): a device for sampling naturalistic daily activities and conversations. *Behavior research methods, instruments, & computers : a journal of the Psychonomic Society, Inc*. 33(4):517–523.

Reddy S, Shilton K, Burke J, Estrin D, Hansen M, Srivastava M, 2009, Using context annotated mobility profiles to recruit data collectors in participatory sensing. *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*. 5561 LNCS52–69.

Reis HT, 2012, Why researchers should think “real-world”. In: Mehl MR, Conner TS (eds) Handbook of research methods for studying daily life. The Guilford Press, 3–21

Verhaeghen P, Martin M, Sędek G, 2012, Reconnecting cognition in the lab and cognition in real life: The role of compensatory social and motivational factors in explaining how cognition ages in the wild. *Aging, Neuropsychology, and Cognition*. 19(1-2):1–12.

Exploring Spatio-Temporal Patterns in Sport Movement Observations

Kimia Amouzandeh*, Farid karimipour*, Seyed Hossein Chavoshi*, **, Havard Tveite**

*School of Surveying and Geospatial Engineering, College of Engineering, University of Tehran
**Department of Mathematical Sciences and Technology, Norwegian University of Life Sciences

Abstract. Analysis of movement data is becoming more popular in several applications. Most of the attempts that has been made on this line of research to analyze movement sport data have focused on spatial aspects of the movement to extract some movement characteristics, such as patterns and similarities. In this research, we propose examining the behavioral movement patterns of athletes by analyzing changes in different movement attributes (e.g., speed and heart rate), which is categorized under the general term of "analysis of movement observations". An example data set of the movement observations acquired during the "orienteering" sport is presented and shortly discussed.

Keywords. Spatial movement analysis, Movement observations, Spatio-temporal patterns, Orienteering.

1. Introduction

The spatio-temporal analysis of movement data is a recent trend of research in GIScience. Recent and emerging positioning technologies have resulted in significant increases in the availability of highly accurate data on moving phenomena (Gudmundsson et al. 2011). Thus, new exploratory tools and knowledge discovery techniques are required to extract meaningful infor-

LBS 2016
13th Conference on Location-Based Services
Vienna, 14–16 November 2016

Published in "Proceedings of the 13th International Conference on Location-Based Services", edited by Georg Gartner and Haosheng Huang, LBS 2016, 14-16 November 2016, Vienna, Austria.

mation, discover interesting patterns, and explore the dynamic behavior of moving objects. Especially, analysis of movement observations, which contain information about the movement of each individual entity and the underlying mechanisms, are of great interest. These observations are key to the study and understanding of movement (Dodge et al. 2016). In this case, in addition to the positional movement data, some set of ancillary observations that describe objects behavioral and cognitive proceeds are employed to study the behavioral movement patterns and their impacts on the target object.

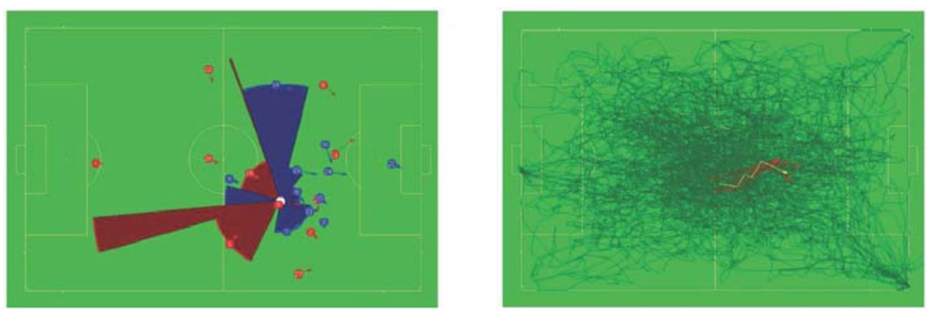
Analysis of movement data is becoming more popular in several applications. In particular, attempts have been made to analyze movements in sport scenes (Gudmundsson and Wolle 2010; Memmert and Perl 2009; Taki and Hasegawa 2000). However, they have mostly focused on spatial aspects of the movement to extract some movement characteristics, such as patterns and similarities. This research proposes examining the behavioral movement patterns of athletes by analyzing changes in different movement attributes (e.g., speed and heart rate) of each individual athlete through a competition. We believe analyzing the athletes' movement observations in terms of space (x, y, z) and time (t), through considering movement attributes of each athlete and contextual information (e.g., the environmental information such as temperature) will direct us to better understanding of behavioral movement patterns of athletes. In other words, we aim to identify the effect of athletic status (e.g., elite vs. amateur) and of surface (e.g., road vs. path vs. forest) on the movement patterns. As the first step, this paper considers movement observations of "orienteering" sport and visually analyses them to discover simple movement patterns. The initial results verify that such movement observations contain a significant level of information in order to be exploit in extracting more sophisticated behavioral movement patterns.

The rest of the paper is organized as follows: Section 2 shortly reviews the previous efforts to analyses sport movement data. In Section 3, orienteering sport is introduced and an example data set of the movement observations acquired during the orienteering task is presented and shortly discussed. Finally, Section 4 introduced the future line of the research.

2. Analyses of Sport Movement Data: A Review

Movement is a key element of many processes and activities. Understanding of the movement itself, as well as the patterns of movement is very important in many areas of science and technology (Dodge 2011). Capturing of trajectory data at fine temporal and spatial granularities has allowed representation, and concequently analysis, of detailed geospatial lifelines. Especially, coupling such data with field observations enable extraction of movement patterns that contain information about preferences regarding individual decision-making and locational choices.

Professional sports have widely been influenced by such analyses. For example, Gudmundsson and Wolle (2010) deployed trajectory clustering techniques to study frequent movements of an individual football player and groups of players (Figure 1). In the same regards, Taki and Hasegawa (2000) analyzed the movement of each player and extract the players' dominant regions, i.e., the area where a player has priority over others. They then analyzed the distribution of dominant regions. This model has been extend by Fujimura and Sugihara (2005) and by Kang et al. (2006) by including an advanced modelling of human movement. Even, some software has been developed to automatically provide basic statistical information (e.g., speed of players, player average position, number of passes performed by players), which are then used by coaches to analyze the performance of the players and choosing the best strategy.



(a) (b)

Figure 1. (a) Passable regions visualized with red (to players in the same team as the ball holder) and blue (to players in the opposite team); (b) Movement of a player, and a cluster of frequent movements highlighted in red (Gudmundsson and Wolle 2010).

As discussed, the previous efforts to analyses sport movement data have mostly focused on spatial aspects of the movement to extract some movement characteristics, such as patterns and similarities. An exception is Hollman et al. (2007), which examined the effect of age on gait velocity and stride-to-stride variability during normal and dual task walking conditions. There are also research that studies the effect of different situations on runners' biomechanics (Bert-Losier et al. 2015; Hébert-Losier et al. 2014).

3. Spatio-Temporal Patterns in Sport Movement Observations: The Case of Orienteering

This research proposes examining the behavioral movement patterns of athletes by analyzing changes in different movement attributes (e.g., speed and heart rate). Orienteering is selected as a case study. Orineterring is a family of sport that requires navigational skills using a map and compass to navigate from point to point in diverse and usually unfamiliar terrain, and normally moving at speed. There are two major forms of orienteering competition (Scouts 1995):

- *Score (- or free) orienteering:* Here, many checkpoints are placed in an area of 1 to 2 kilometers around the starting point, which is also considered as the finish line, with different scores depending on the distance to the start point or the level of difficulty to find. Competitors have a set time to find as many checkpoints as they can (in any order they wish) and earn as large a total score as possible. Therefore, they must judge the time well and evaluate their abilities to run and read orienteering map to score.
- *Cross-country (- or point-to-point) orienteering:* In this case, every competitor must visit the same checkpoints in a numerical order, and as quickly as possible. This form of orienteering is a challenge in route choice and stamina.

In the both forms of orienteering, competitors choose their route around the course. Hence, they confront many possible challenges such as terrain barriers or obstacles, artificial features, level of physical fitness and so on. For instance, if a hill sits between competitor and the control exists, a good rule of thumb is that 15 meters of climb is equal to running about 100 meters on flat ground. Hence, a 45-meter hill will be equivalent to running 300 meters; and if the competitor can contour around the hill in less than 300 meters, then he should choose around rather than over.

Figures 2 and 3 respectively illustrate the path taken by an orienteering athlete, and its corresponding movement observations, including altitude, heart rate, speed, as well as the land cover. We have divided the path into several sections based on the land cover, and computed the duration, distance, and thereby, the average speed of each section, hoping that relations can be found between these parameters in (1) an individual section, (2) sections of the same type, and (3) the whole path. This will be performed in the next steps of the research through extensive computational analyses. However, for the time being, some relations can be seen visually. For example, the heart rate has significantly increased at the very start of the path; Or in the first half of the section 3, where the land cover is forest, the altitude is ascending, which caused an increase in the heart rate although the speed is reducing. However, in the second half of this section, the altitude is descending, thus it does not influence the heart rate; instead the heart rate is in direct relation with the speed.

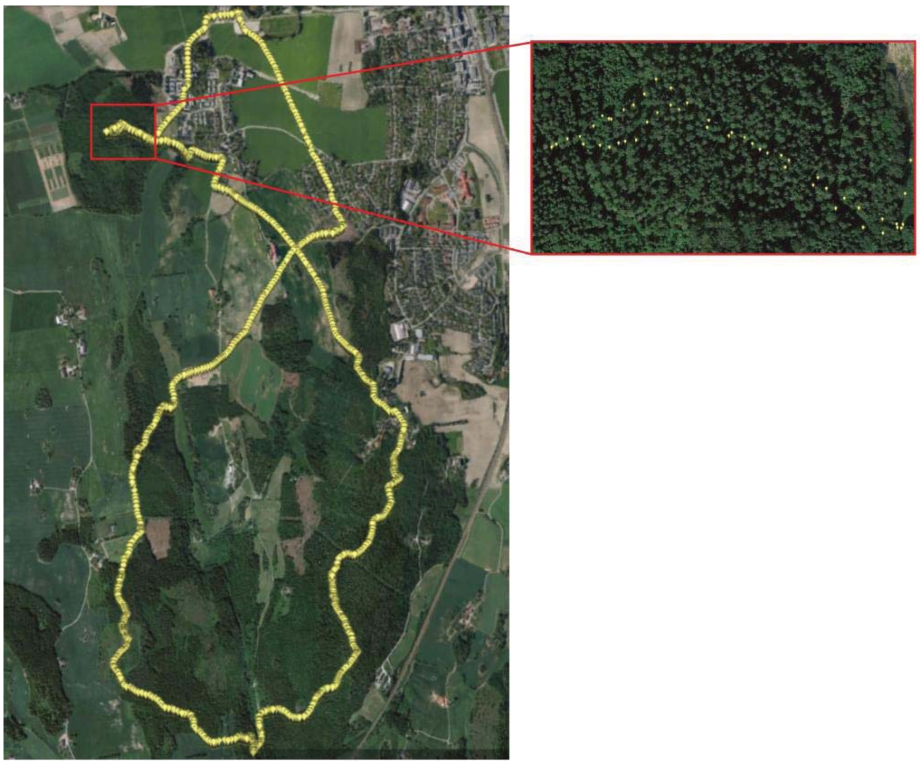


Figure 2. The path taken by an orienteering athlete. Right figure shows the path corresponded to the Section #3 in Figure 3 in more details.

4. Future Research's Direction

This paper proposed the idea of examining the behavioral movement patterns of athletes by analyzing changes in different movement attributes (e.g., speed and heart rate), which we believe leads to better understanding of behavioral movement patterns of athletes. Here, we only presented a type of such information for a path taken by an orienteering athlete, in which some patterns can be visually detected. However, complete exploration of the patterns needs sophisticated computational analyses. For example, we are going to take advantage of sequence analysis techniques to investigate and explore transformed movement data into time-dependent sequences.

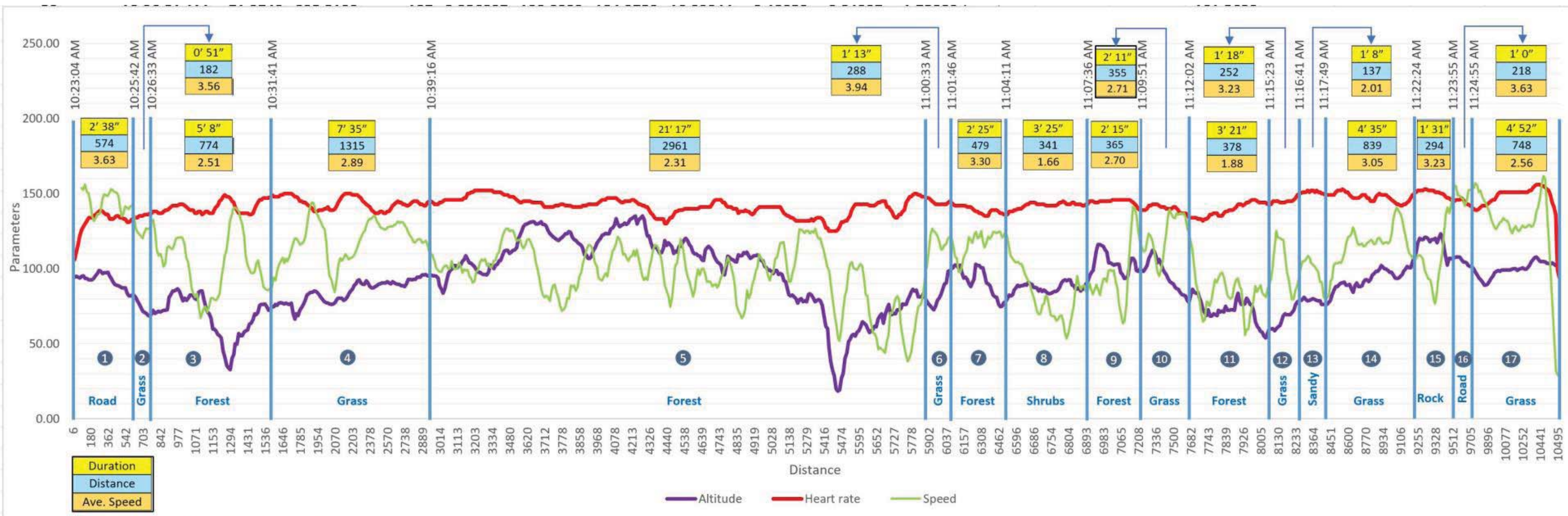


Figure 3. Movement observations corresponded to the path illustrated in Figure 2, including altitude, heart rate, speed, as well as the land cover.

References

Bert-Losier, K., L. Mourot, and H.-C. Holmberg. 2015. Elite and amateur orienteers' running biomechanics on three surfaces at three speeds.

Dodge, S. 2011. Exploring movement using similarity analysis.

Dodge, S., R. Weibel, S.C. Ahearn, M. Buchin, and J.A. Miller. 2016. Analysis of movement data. *International Journal of Geographical Information Science* 30: 825-834.

Fujimura, A., and K. Sugihara. 2005. Geometric analysis and quantitative evaluation of sport teamwork. *Systems and Computers in Japan* 36: 49-58.

Gudmundsson, J., P. Laube, and T. Wolle. 2011. Computational movement analysis. In *Springer handbook of geographic information*, 423-438: Springer.

Gudmundsson, J., and T. Wolle. 2010. Towards automated football analysis: Algorithms and data structures. *Proc. 10th Australasian Conf. on mathematics and computers in sport*.

Hébert-Losier, K., K. Jensen, L. Mourot, and H.C. Holmberg. 2014. The influence of surface on the running velocities of elite and amateur orienteer athletes. *Scandinavian journal of medicine & science in sports* 24: e448-455.

Hollman, J.H., F.M. Kovash, J.J. Kubik, and R.A. Linbo. 2007. Age-related differences in spatiotemporal markers of gait stability during dual task walking. *Gait & posture* 26: 113-119.

Kang, C.-H., J.-R. Hwang, and K.-J. Li. 2006. Trajectory analysis for soccer players. In Sixth IEEE International Conference on Data Mining-Workshops (ICDMW'06), 377-381: IEEE.

Memmert, D., and J. Perl. 2009. Game creativity analysis using neural networks. *Journal of sports sciences* 27: 139-149.

Scouts, B. 1995. Orienteering(Merit Badge). *Irving, Texas*.

Taki, T., and J.-I. Hasegawa. 2000. Visualization of dominant region in team games and its application to teamwork analysis. In Computer Graphics International, 2000. Proceedings, 227-235: IEEE.

Passive Mobile Positioning as a Way to Map the Connections Between Change of Residence and Daily Mobility

Pilleriine Kamenjuk, Anto Aasa

University of Tartu, Department of Geography

Extended Abstract

Introduction. Human mobility has commonly been studied taking into account only one side of it at a time. For example, migration or change of residence is usually defined as a movement from one area to another crossing municipal or country border, and, daily mobility has been studied to understand more short distance movements, for example, work-related mobility. In the era of mobilities as human mobility has become more diversified, for example, due to the ability to mix or substitute different movements, we need combined analyses to describe the multifaceted nature of human spatial mobility. One of these themes is the relations between place of residence and daily mobility.

A place of residence or home can be seen as Hägerstrand has termed it – the "centre of gravity" – around what all the other activities occur (Roseman 1971). To understand the effects of change of residence on daily mobility, the activity space conception can be implemented. This approach lets us inspect the associations between long-term movements, like migration or change of residence, and short-term movements, like daily mobility concerning work, leisure and home.

The study of migration is largely dependent on the data that can be used for analysis. This has somewhat limited the questions that can be asked, resulting in aspects of human spatial mobility that have not yet been examined. The development of information and communication technologies and their widespread usage are offering scientists different datasets, new methods and interpretations, making it possible to study social processes on a new level. For example, when studying the connections between change of resi-

Published in "Proceedings of the 13th International Conference on Location-Based Services", edited by Georg Gartner and Haosheng Huang, LBS 2016, 14-16 November 2016, Vienna, Austria.

dence and daily mobility, using mobile positioning data helps to overcome some constraints presented by traditional data sources like censuses or questionnaires, and allow to estimate rather long and continuous time-series of people's detailed whereabouts in time and space.

The aim of this study is to expand on the idea of migration in connection with time-geography, drawing on the longitudinal character of passive mobile positioning data and an anchor point model (Ahas et al. 2010). Derived from this, the main questions looking for answers are: 1) What affects the size of daily activity spaces? 2) How does change of residence change the size of daily activity spaces? 3) Does change of residence elicit the change in work-time location (and *vice versa*)?

Methodology. This study uses passive mobile positioning data and information from an anchor point model, developed by the Mobility Lab of University of Tartu (more information in Ahas et al. (2010)), that allow to investigate the connections between usual place of residence and daily mobility. Time-series consisting of anchor points from the anchor point model extending from January 2007 to December 2013 are used. This study deals with actual activity spaces (Dijst 1999a, 199b) of migrants who have changed their residence during the years 2008–2012 in Estonia. Activity spaces are being given area measures based on the defined anchor points and compared in the context of migration direction and settlement hierarchy, socio-economic parameters (i.e. gender, age, language) and some characteristics of activity spaces (i.e. distance between home and work location, etc.).

Activity spaces. Activity spaces in this study consist of anchor points (home, work-time and secondary anchor points) defined six months before and six months after the change of usual place of residence. Six months is quite a long time for estimating both the more regularly (for example, weekly) and more infrequently (for example, seasonally) visited places. Activity spaces are described by the size. The size of the activity space is described by activity ellipse (Newsome et al. 1998, Schönfelder & Axhausen 2003), more specifically by Standard Deviation Ellipse (95%). It is weighted by the number of days a respondent has made calls in certain anchor points. STD ellipses are calculated only for those respondents who have ≥3 unique anchor points defined, thus for respondents whose activity space consists of only two unique anchor points the areal estimate is given using buffers (5 km buffer around the line that connects two points), and for respondents whose activity space consists of only one unique anchor point the estimate is given using the size of the theoretical radio coverage area of a mobile tower (*Figure 1*).

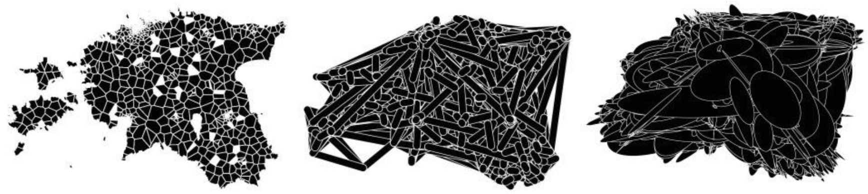


Figure 1. Possible expressions of activity spaces: one anchor point activity spaces (left), two anchor points activity spaces (middle), three and more anchor points activity spaces (right).

Sample. For the period January 2008–December 2012 it was possible to extract 99 968 changes in residence using passive mobile positioning data[1]. Migration is a selective process, meaning that some of the population (e.g. younger people that are affected by life-course events) are more prone to change residence (Bogue 1959). The structure of the sample is described in *Table 1*. Respondents can be divided by age, gender, preferred language and home location on settlement hierarchy.

Age	<=15	15-25	25-35	35-45	45-55	55-65	65-75	>75	NA	
	0.1	7.3	16.7	17.3	14.5	6.5	2.3	0.6	34.8	
Gender	Male	Female	NA							
	37.3	37.2	25.5							
Language	Estonian	Russian	English	NA						
	59.0	8.3	0.2	32.5						
Settlement hierarchy of previous place of residence	1_PrimCity	1_Hi_30%	1_Hi_15%	2_RegCntr	2_Hi_30%	2_Hi_15%	3_CoCntr	3_Hi_30%	3_Hi_15%	5_Ru
	42.3	10.5	2.1	15.3	6.6	1.4	2.3	7.2	2.7	9.8

Table 1. Division of respondents (%) by socio-demographic parameters and place of residence.

Methods. Dependent parameters are highly skewed, meaning that most of the respondents in the sample have smaller activity spaces. Thus basic statistics and non-parametric tests are used to analyse differences. For example, Wilcoxon Signed-Rank Test (alpha=0.01) for repeated measures, Kruskal-Wallis Test (alpha=0.05) and Duncan's New Multiple-Range Test (alpha=0.01) to compare different groups.

Results. *What affects the size of daily activity spaces?* To understand what can possibly affect the development of activity spaces in the context of

[1] Methodological part of extracting migrants using passive mobile positioning data is described in Kamenjuk et al. (forthcoming).

migration it is necessary to understand the difference of activity spaces in the context of different socio-demographic and environmental parameters. For this we have chosen to analyse activity spaces before the change of residence.

Men have bigger activity spaces than women (mean 1424 km², median 499 km² *vs* mean 1187 km², median 381 km²) (*Figure 2*). Estonian speaking respondents have bigger activity spaces (mean 1400 km², median 518 km²) than Russian (mean 626 km², median 104 km²) or English speaking (mean 590 km², median 55 km²). Younger migrants have bigger activity spaces than older migrants. For example, 15–25 years old have the biggest activity spaces (mean 1818 km², median 857 km²), the next groups are 25–35, 45–55 and 35–45 years old (means respectively 1313, 1381 and 1221 km², medians respectively 503, 422 and 401 km²). The average size of activity spaces for the youngest and last three age groups are below 1000 km² and medians under 250 km², the oldest and the youngest age group having the smallest size (470 km² and median 115 km², 501 km² and median 120 km² respectively).

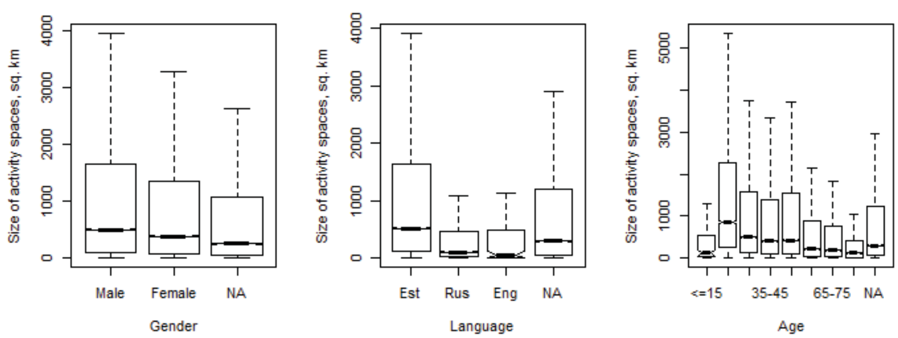


Figure 2. Size of activity spaces by socio-demographic groups.

Overall those who lived in rural areas had bigger activity spaces and those who lived in urban areas had smaller activity spaces. On urban-rural classification the average size of activity spaces for those who lived in rural areas is 1413 km² (median 532 km²) and for those who lived in urban areas is 1130 km² (median 294 km²) (*Figure 3*). On a settlement hierarchy that describes the urban-rural structure of municipalities based on daily commuting patterns (30% or 15% of people commuting to its centre representing proximate or more distant hinterland) forming the centre-hinterland structure (Tammaru 2001). People living in bigger centres (primary city and regional centres) and in their hinterland had smaller activity spaces than people living in smaller centres (like county centres), their hinterland and rural areas. For example, the average size of activity spaces of people living in the primary centre (mean 1015 km²) was 43% smaller than of people living in rural areas (mean 1776 km^2). But, for example, when looking at specific centres and their hinterland, e.g. primary city, then the average size of activity spaces of respondents living in the hinterland (15%) was bigger than of those living in the city, and, vice, versa, for county centres, the average size of activity spaces of those living in the centre was bigger than of those living in the hinterland.

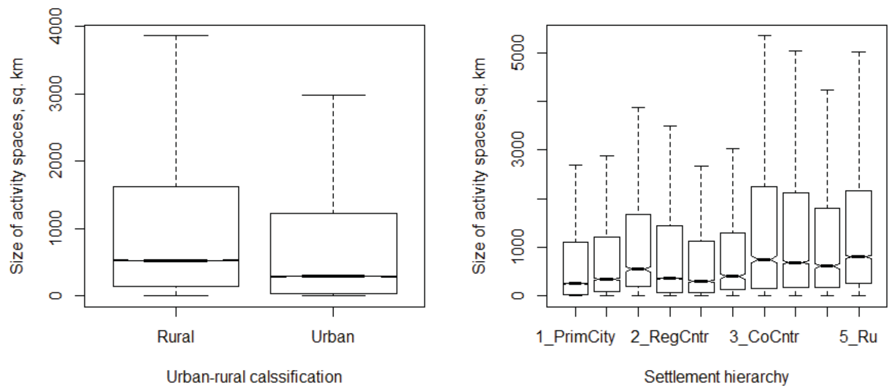


Figure 3. Size of activity spaces by urban-rural classification and settlement hierarchy.

Home and work place are both the two most important locations that affect the size of daily activity spaces. We were able to distinguish 88 266 (88.3% of the sample) respondents who besides home location had defined a work-time location (i.e. work, school, etc.) before the change of residence, and 85 403 (85.4% of the sample) respondents who had defined the work-time location after the change of residence, and 79 439 (79.5% of the sample) who had defined both. The average distance between home and work location was 12.4 km (median 2.8 km).

Overall, the distance between home and work location shows no correlation with the size of activity spaces (Spearman $r = 0.19$, $p < 0.001$). So besides home-work related movements there are other locations that contribute to the formation of the size of activity spaces. For different socio economic groups, men travel further from home for work purposes (mean 14.2 km) than women (mean 11.9 km), there were no difference between Estonian and Russian speaking respondents (*Figure 4*), although Estonian speaking respondents travelled further (13.3 km) for work purposes than English speaking (mean 8.4 km). If taking into account age, then there were not many significant differences between age groups. But how is the distance affected by home location? The distance between home and work place is smaller for those who live in cities and increases with the distance from the centre.

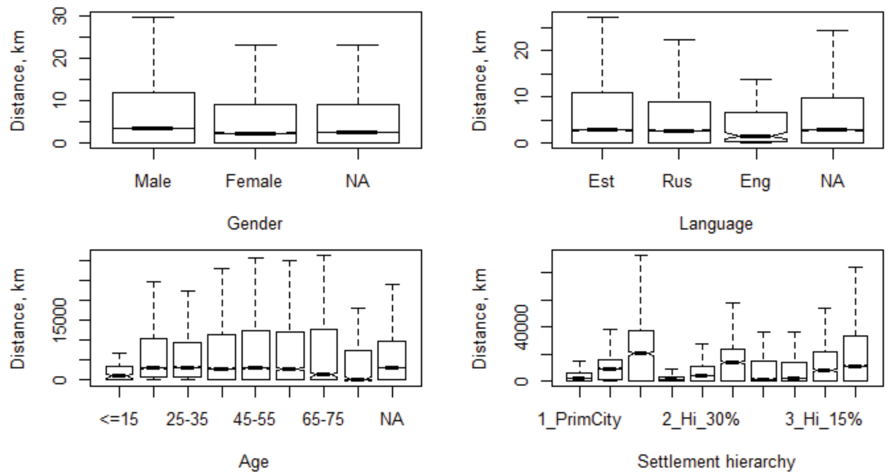


Figure 4. Distance between home and work-time location.

How does change of residence affect the parameters of daily activity spaces? According to Wilcoxon Signed-Rank Test there is a significant difference in the sizes of before and after activity spaces, the average size before being 1240 km² (median 382 km²) and after 1203 km² (median 352 km²). Although there is a difference in the direction of decrease we need to be careful if interpreting the results since the differences are very small.

18.4% of respondents migrated inside or between rural areas, 20.7% from rural to urban areas, 20.1% from urban to rural and 40.8% inside or between urban areas. If we analysed the change in activity spaces comparing the size before and after using migration direction on urban-rural scale, we can see that the change in the size of activity spaces is significant for all directions, except for rural-rural migrants. It is possible to see decrease in activity spaces for rural-urban and urban-urban moves and increase for urban-rural moves (*Table 2*).

Direction of the move	Mean		Median	
	Before	After	Before	After
Rural-Rural	1335	1329	496	488
Rural-Urban	1482	1328	573	428
Urban-Rural	1264	1367	408	460
Urban-Urban	1063	1002	242	214

Table 2. Size of activity spaces by migration direction (km²).

The change in the size of activity spaces is represented as continuous, but for understanding relative change it has been divided into five classes (*Figure 5*). The average relative change of the size of activity spaces is 21.6 (median -0.04). The average of relative change for rural-rural movers is 0.4 (median -0.01), for rural-urban movers -14.9 (median -0.20), for urban-rural movers 22.8 (median 0.12) and for urban-urban movers 49.0 (median -0.06). But the differences between groups of different migration directions according to Duncan's New Multiple-Range Test are not significant, as well as the differences are not significant for different socio-demographic groups.

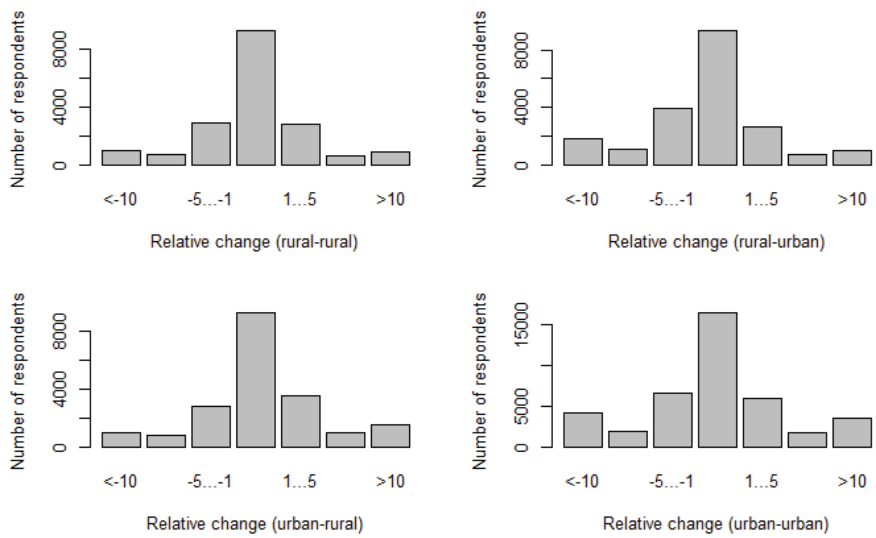


Figure 5. Distribution of relative change in the size of activity spaces by direction of the move.

According to Wilcoxon Signed-Rank Test the distance between home and work place is significantly different before and after the change of residence. The average distance between home and work location before the move is 12.4 km (median 2.8 km) and after the move is 17.3 km (median 3.9 km). If we looked at the direction of the move then the average distance has grown in all directions (*Table 3*), but for rural-urban migrants the median value has decreased. For urban-rural migrants the changes have been the most recognizable.

Direction of the move	Mean		Median	
	Before	After	Before	After
Rural-Rural	16.3	22.5	6.0	9.7
Rural-Urban	19.7	21.5	8.0	3.2
Urban-Rural	12.6	23.9	2.4	9.9
Urban-Urban	6.8	9.4	2.2	2.5

Table 3. Distance between work and home location (km).

Does change of residence elicit the change in work-time location (and vice versa*)?* This can be estimated if we collate the time series of home and work anchor points and assess the vicinity of these two events in time – whether the act of change of residence has occurred prior to the change in work-time location or vice versa – and using geographical expressions (like distance) to understand whether one of these events has motivated the other.

In total there were 20 327 different changes in home location that have been induced by change in work location and 25 840 different changes in work location that have been induced by the change in home location.

The average distance between previous and new place of residence for those whose change of residence preceded to the change of work-time location was 49 km (median 18 km). Average distance between previous and new work location was 44 km (median 14 km). Average distance between previous home and work-time location was 13 km (median 2 km) and between new home and work-time location was 12 km (median 2 km).

The average distance between previous and new place of residence for those whose change of work-time location preceded to the change of home location was 46 km (median 17 km). Average distance between previous and new work location was 44 km (median 17 km). Average distance between previous home and work-time location was 14 km (median 2 km) and between new home and work-time location was 14 km (median 2 km).

From previous we can conclude that there are cases where change of residence has also induced change in work-time location and *vice versa*. But no significant difference between both cases in the distances of previous and new meaningful locations of home and work occurs.

Discussion. Mobile positioning data has provided a methodological basis for analysing the connections of change of residence and daily activity spaces in a longitudinal perspective. From the analysis it is possible to conclude that socio-demographic parameters (gender, language, age) have an effect in determining the size of activity spaces of migrants. Also, environmental-structural conditions can increase or decrease the need for mobility. The effect of migration itself is yet debatable. The direction of the move has an effect in determining the size of activity spaces, but the relative change that also takes into account the respondents individual variability is not affected.

For calculating activity spaces, we have used all the possible anchor points. In further analysis it would be necessary to use Multiple Linkage Analysis (van Nuffel et al. 2010) to select the most important ones (for example, done in Järv et al. 2014) – this changes the perspective to the most meaningful activity locations.

In this analysis we have dealt with migrants only. Thus, comparison with stayers could provide new insight into the question whether mobility can be defined as a “lifestyle” – do migrants travel more, have bigger activity spaces, etc. Furthermore, focusing more specifically on activity locations allows us to understand whether change of residence is accompanied by total or partial displacement of daily activity spaces.

References

Ahas R, Silm S, Järv O, Saluveer E, Tiru M (2010) Using mobile positioning data to model locations meaningful to users of mobile phones. Journal of Urban Technology, 17(1):3–27.

Bogue DJ (1959) Internal migration. In: Hauser PM, Duncan OD (eds) The Study of Population: An Inventory and Appraisal. Chicago and London: The University of Chicago Press, 678–716.

Dijst M (1999a) Action space as planning concept in spatial planning. Neth. J. of Housing and the Built Environment 14(2):163–182.

Dijst M (1999b) Two-earner families and their action spaces: A case study of two Dutch communities. GeoJournal 48: 195–206.

Roseman CC (1971) Migration as a spatial and temporal process. Annals of the Association of American Geographers, 61(3):589–598.

Järv O, Ahas R, Witlox F (2014) Understanding monthly variability in human activity spaces: a twelve-month study using mobile phone call detail records. Transportation Research Part C, 38:122–135.

Kamenjuk P, Aasa A, Sellin J (forthcoming) Mapping changes of residence with passive mobile positioning data: the case for Estonia.

Newsome TH, Walcott WA, Smith PD (1998) Urban activity spaces: Illustrations and application of a conceptual model for integrating the time and space dimensions. Transportation 25:357–377.

Schönfelder S, Axhausen KW (2003) Activity spaces: Measures of social exclusion? Transport policy 10:273–286.

Tammaru T (2001) Eesti linnade mõjualad ja pendelränne. Lõpparuanne. Tartu Ülikool, Rahvastikuministri büroo.

van Nuffel N, Derudder B, Witlox F (2009) Even important connections are not always meaningful: on the use of a polarisation measure in a typology of European cities in air transport networks. Tijdschrift voor Economische en Sociale Geografie, 101:333–348.

Track-id: Activity Determination based on Wi-Fi Monitoring

S.C. van der Spek, E. Verbree, C.W. Quak, IJ.D.G. Groeneveld, R. Sulzer, E. Theocharous, M.S. Tryfona, O.T. Willems and Y. Xu

Delft University of Technology, Geomatics for the Built Environment,
Faculty of Architecture and the Built Environment,
Julianalaan 134, 2628 BL, Delft, The Netherlands

Extended Abstract

The distribution of people in buildings, the occupancy of lecture-, work- and study places and the accessibility of facilities are essential information at university campuses who have to cope with limited and even shrinking budgets and huge, rising real estate costs. Only little insight is gained in both occupancy and movement patterns with traditional counting techniques and user-based questionnaires. Management teams state that rooms and facilities are hardly used, though staff and students complain about overcrowded facilities and limited flexibility. Actual and accurate data on a 24/7 scale with high-granularity is missing.

In general Facility- and Asset Management lacks efficient methods for real-time, comprehensive and high-granularity information of location, capacity and use of tangible and intangible assets. Asset management could benefit from more detailed, more accurate and longitudinal data on assets, providing more insight into efficiency and effectiveness on different levels of scale through time.

Existing technologies could provide a platform delivering those required insights. Navigation- and communication technologies such as GNSS, Wi-Fi, Bluetooth, RFID can be used to 'locate' users, estimate intensities and reveal patterns of movement and patterns of use. For Asset management indoor localisation is essential.

Technology

Wi-Fi is a widespread communication technology used by electronic devices to connect to a Wireless Local Area Network (WLAN) base station or to connect ad-hoc directly between devices. Wi-Fi may be used to obtain

LBS 2016
13th Conference on Location-Based Services
Vienna, 14–16 November 2016

Published in "Proceedings of the 13th International Conference on Location-Based Services", edited by Georg Gartner and Haosheng Huang, LBS 2016, 14-16 November 2016, Vienna, Austria.

internet access, to exchange data, to access an intranet or for sending data to devices like a printer. Today a large range of electronic devices is capable of using Wi-Fi including computers, laptops, smart-phones, tablets, digital cameras, audio players, printers, (video-)game consoles and sensors. Wi-Fi networks are offered in companies, private homes, cities and (semi) public spaces and also at university campuses. Eduroam is a worldwide standard for University Campus WLAN networks.

Wi-Fi cannot only be used as a technology to transfer digital data wirelessly, but also as a tool for Facility and Asset management or as a platform for location-based services (LBS): Wi-Fi Access Points (AP's) can be used as sensors to collect information of connecting devices, delivering dashboards with temporal data on intensity of devices based on the number of unique devices detected and patterns of movement based on detections of the same device at different access points.

Wi-Fi 'user' data can be obtained in two ways: (a) by scanners or (b) by the network.

ad. (a) Wi-Fi scanners register connection attempts from devices within range. Every enabled Wi-Fi device is continuously searching for Wi-Fi access points and therefore broadcasting its unique media access control (MAC) address. No connection between device and scanner is made and no data is exchanged. Scanners can be other Wi-Fi devices as well as (modified) Access Points.

ad. (b) When using the network Access Points the real -established-connections are used. Either the connection start- and endtime is logged, or the system regularly scans for connected devices. At TU Delft a dump of devices connected to Eduroam Access Points is made every five minutes for the whole campus for network management purposes. Personal information such as MAC address and network ID are immediately encrypted (hashed). The research projects described in this abstract use this anonymised data from the Eduroam network for spatio-temporal analysis. Only staff and students from the university connecting to the eduroam Wi-Fi network are incorporated in this research.

In the Geomatics Synthesis Project Wi-Fi is used in a campus-wide experiment to monitor flows and occupation patterns at the TU Delft Campus. Students worked for two months on three parallel projects :

(1) extracting presence of people at specific places;

(2) unravelling patterns of movement within buildings and between buildings on the campus; and

(3) identifying activities and irregular use based on Wi-Fi data.

In all projects, the same dataset is used. All project also had to cover four cross-cutting topics: Privacy, Validity and Accuracy, Representativeness and reflection on the system of Access points (data collection).

Project 3: Track-id: Activity Determination based on Wi-Fi Monitoring

The aim of this project is to recognise the activity of different users in an area through Wi-Fi monitoring. First of all, the estimation of the user's occupation is calculated by the use of a Markov model with the information derived from the Wi-Fi dataset. Their identity is used in order to estimate the activity that a user is probably doing.

The main question of this research is:

To what extent and how reliable is it possible to determine the activities of individuals through the users' characteristics that can be derived from a Wi-Fi network?

This project focuses more on the use of the facilities of the research area during irregular hours. The irregular hours are specified as the hours outside the opening hours of the buildings, not including exceptions like extended opening hours or events. The use of the buildings is examined during irregular hours, to allow efficient real estate management and provide security. The Information Communication Technology (ICT) department of Delft University of Technology (TU Delft) provided a database dump of the Wi-Fi network of TU Delft. These data are analysed, in order to get useful and valuable information about the usage of buildings and the activities in buildings.

Dataset Limitations

The dataset has been provided by a third party source, hence it is not possible to select the tracking technologies and methodologies. In this chapter, the infrastructure that the third party utilised to gather along with the validation, the accuracy and the representativeness of the tracking system is discussed. Finally, an insight about the data protection that is relevant with the data and methodologies that are used, is presented.

Validity and accuracy

Due to the design of the tracking infrastructure, if a user is only passing by an access point and gets scanned, the user gets a minimum connection time of five minutes. Furthermore, the system is designed in a way that a device can only maintain a single connection at a time, thus, if a user moves inside the five-minute period of his last access, he will not be tracked to the new position.

Due to the nature of Wi-Fi tracking, a user that is detected in a certain access point, is not necessary located around that access point. For example, a user might be passing outside a building and he might be scanned by an access point inside it when actually he is not there. Moreover, false location of scanned users can also happen between floors of a building.

Representativeness

The representativeness of the data collection reflects what categories of users can the implemented Wi-Fi tracking system identify, or what categories of users it cannot.

The first big category is the users that were not connected to the Wi-Fi network. It consists of smaller categories, a) users that use old technology, b) users that are not part of the academic network that has access to the Wi-Fi network, c) users who consciously turned off their Wi-Fi devices, d) users connected to the network through a wired connection.

The second category refers to places that there are no available data in the given database. The missing data accounts for, either buildings that are excluded for security reason, e.g. Nuclear reactor, or for places that are not covered by access points, hence no information is collected.

System of access points

With the implemented system of access points, every device is usually detected in only one access point. Thus, the processes of fingerprinting and trilateration, that would allow the determination of the position of a device, cannot be carried out. Therefore, it is assumed that the detected devices are located to the specific access points that they are detected.

Data protection

According to the Data Protection Directive (DPD) (Directive 95/46/EC) ‘Personal data is any information relating to an identified or identifiable natural person’. The data collected from the Wi-Fi network are considered personal data, even if the username and MAC address of each user and device are hashed, hence the data must be treated accordingly. Currently, DPD secures the data privacy of individuals against unlawful use. According to DPD, to process private data, one has to have a valid ground to do so. In the current project, scientific purposes are sufficient reason, yet data must be processed with respect to the Principles mentioned in the DPD and with respect of the Data subject rights.

Research

In order to distinguish the activity of a user, an occupation profile is assigned to each user. According to their occupation profile, their main building and the type of the building that they are located in, the activity of the specific session is determined. However, the main building of each user is determined as the building where that particular user spent his most time at.

The profile of the users is determined by using a Markov model. A Markov model is a stochastic model that is used to model randomly changing systems, where it is assumed that future states depend only on the current state and not on the events that occurred before it. The stated property is characterised as 'memorylessness' or Markov property. Generally, this assumption enables reasoning and computation with the model that would otherwise be intractable. There are different Markov models used in different situations.

According to the Markov model, some training sets are defined considering the different profiles that need to be assigned to the users (student, academic staff, support staff or other). Those training sets are compared with the user's information that are derived from the dataset and the probability of each user to belong to each occupation profile is determined. Further, the user is assigned with an occupation randomly, based on the different probabilities (Petrushin 2000, Luhr et al. 2003, Mühlenbrock et al. 2004, Stamp 2015). The activities of each individual, during irregular hours, is determined through a deterministic model, which takes into consideration the assigned user occupation, the user main faculty and the type of building the user is located each time.

For determining the activity of each user, his main building, his occupation and his scanned location are taken into consideration. To make an accurate statement, independent of the occupation classification of a user, the total numbers of faculty staff and students are compared to the numbers of the dataset. The guests of the university have to be filtered out since official statistics do not contain guests of the university. After this procedure, the main building of a user is determined, as his main faculty, but only if he spent more than one hour there.

The results of the use of the TU Delft campus are visualised on different spatial levels and on different representations. The spatial levels that are used, are related to the campus, building and floor ("maploc") levels. Tables and graphs, a dynamic visualisation and a GIS and Web application are created during this project.

Conclusions

The overall accuracy of the determination of the number of users per building is 94%. Regarding the determination of the users' occupation using the Markov model the accuracy of the process is 50%. Considering the above results, the pre-process and the analyses conducted to detect distinct users in a complex of buildings, are regarded of good quality and can be used further. On the other hand, the determination of user occupation is not accurate enough and further research is required. Additionally, the identification of specific events and exceptions on the opening hour of buildings can be identified by detecting irregularities of user connections. Finally, it is clear that through Wi-Fi tracking it is possible to extract information that will allow efficient real estate management and provide security solutions.

Acknowledgement

This project is part of the Geomatics Synthesis Project (GEO1101) 'Rhythm of the Campus' which was carried out in Spring 2016. The data is collected by ICT of TU Delft and made available for the project. In a later stage – if no obstructions are encountered – the data will be made open-source.

The course was initiated and coordinated by Stefan van der Spek, director Geomatics for the Built Environment and Edward Verbree, section GIS-technology. Edward Verbree, Martijn Meijers and Wilko Quak mentored the three project teams. Bart Valks and Iljoesja Berdowski represented Facility Management of TU Delft. Alexandra den Heijer and Ruud Binnenkamp (Management in the Built Environment) assisted to the overall scope of the project.

References

DIRECTIVE 95/46/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL, 1995, Official Journal L 281 , 23/11/1995 P. 0031 - 0050

Mautz R (2012) Indoor Positioning Technologies. ETH Zurich, Department of Civil, Environmental and Geomatic Engineering, Institute of Geodesy and Photogrammetry

Mühlenbrock M, Brdiczka O, Snowdon D, Meunier JL (2004) Learning to Detect User Activity and Availability from a Variety of Sensor Data, Xerox Research Centre Europe, Meylan, France

Petrushin V A (2000) Hidden Markov Models: Fundamentals and Applications Part 1: Markov Chains and Mixture Models

Petrushin V A (2000) Hidden Markov Models: Fundamentals and Applications Part 2: Discrete and Continuous Hidden Markov Models

Stamp M (2015) A Revealing Introduction to Hidden Markov Models

In_sight: Using Existing Wi-Fi networks to Provide Information on Occupancy and Exploitation of Educational Facilities using at Delft University of Technology.

S.C. van der Spek, E. Verbree, B.M. Meijers, F.J. Bot, H.H. Braaksma, R.C. Braggaar, B.R. Ligtvoet & B.R. Staats

Delft University of Technology, Geomatics for the Built Environment,
Faculty of Architecture and the Built Environment,
Julianalaan 134, 2628 BL, Delft, The Netherlands

Extended Abstract

The distribution of people in buildings, the occupancy of lecture-, work- and study places and the accessibility of facilities are essential information at university campuses who have to cope with limited and even shrinking budgets and huge, rising real estate costs. Only little insight is gained in both occupancy and movement patterns with traditional counting techniques and user-based questionnaires. Management teams state that rooms and facilities are hardly used, though staff and students complain about overcrowded facilities and limited flexibility. Actual and accurate data on a 24/7 scale with high-granularity is missing.

In general Facility- and Asset Management lacks efficient methods for real-time, comprehensive and high-granularity information of location, capacity and use of tangible and intangible assets. Asset management could benefit from more detailed, more accurate and longitudinal data on assets, providing more insight into efficiency and effectiveness on different levels of scale through time.

Existing technologies could provide a platform delivering those required insights. Navigation- and communication technologies such as GNSS, Wi-Fi, Bluetooth, RFID can be used to ‘locate’ users, estimate intensities and reveal patterns of movement and patterns of use. For Asset management indoor localisation is essential.

Published in “Proceedings of the 13th International Conference on Location-Based Services”, edited by Georg Gartner and Haosheng Huang, LBS 2016, 14-16 November 2016, Vienna, Austria.

Technology

Wi-Fi is a widespread communication technology used by electronic devices to connect to a Wireless Local Area Network (WLAN) base station or to connect ad-hoc directly between devices. Wi-Fi may be used to obtain internet access, to exchange data, to access an intranet or for sending data to devices like a printer. Today a large range of electronic devices is capable of using Wi-Fi including computers, laptops, smart-phones, tablets, digital cameras, audio players, printers, (video-)game consoles and sensors. Wi-Fi networks are offered in companies, private homes, cities and (semi) public spaces and also at university campuses. Eduroam is a worldwide standard for University Campus WLAN networks.

Wi-Fi cannot only be used as a technology to transfer digital data wirelessly, but also as a tool for Facility and Asset management or as a platform for location-based services (LBS): Wi-Fi Access Points (AP's) can be used as sensors to collect information of connecting devices, delivering dashboards with temporal data on intensity of devices based on the number of unique devices detected and patterns of movement based on detections of the same device at different access points.

Wi-Fi 'user' data can be obtained in two ways: (a) by scanners or (b) by the network.

ad. (a) Wi-Fi scanners register connection attempts from devices within range. Every enabled Wi-Fi device is continuously searching for Wi-Fi access points and therefore broadcasting its unique media access control (MAC) address. No connection between device and scanner is made and no data is exchanged. Scanners can be other Wi-Fi devices as well as (modified) Access Points.

ad. (b) When using the network Access Points the real -established- connections are used. Either the connection start- and endtime is logged, or the system regularly scans for connected devices. At TU Delft a dump of devices connected to Eduroam Access Points is made every five minutes for the whole campus for network management purposes. Personal information such as MAC address and network ID are immediately encrypted (hashed). The research projects described in this abstract use this anonymised data from the Eduroam network for spatio-temporal analysis. Only staff and students from the university connecting to the eduroam Wi-Fi network are incorporated in this research.

In the Geomatics Synthesis Project Wi-Fi is used in a campus-wide experiment to monitor flows and occupation patterns at the TU Delft Campus. Students worked for two months on three parallel projects :

(1) extracting presence of people at specific places;

(2) unravelling patterns of movement within buildings and between buildings on the campus; and

(3) identifying activities and irregular use based on Wi-Fi data.

In all projects, the same dataset is used. All project also had to cover four cross-cutting topics: Privacy, Validity and Accuracy, Representativeness and reflection on the system of Access points (data collection).

Project 1: In_sight: Using existing WiFi networks to provide information on occupancy and exploitation of educational facilities using at Delft University of Technology.

The goal of the first project is to estimate the occupation at a location at a certain time. The research question for this team was: *To what extent can the alignment of occupation and exploitation of educational facilities on different scales be indicated through Wi-Fi monitoring?*

Hypothesis.

The hypothesis is that every person has a certain number of devices and that only a limited number of devices is connected to the Wi-Fi. The location should be defined according to the map. This potentially interferes with the distribution and coverage of the Wi-Fi Access Points. The group, therefore, formulated the following hypothesis:

Hypothesis: The alignment of occupation and exploitation of educational facilities can be indicated through Wi-Fi monitoring on all Spatial Levels with adequate reliability.

The approach is to understand the way the Wi-Fi collects and stores information. Wi-Fi does not measure the number of people but the number of connected devices which relates to a connected device per person factor to the number of people. The number of devices represents the presence of people at that place at that time for a certain duration based on an average number of devices per person. This factor needs to be calculated and calibrated. According to earlier research, this factor will vary depending to the kind of activity (use).

Methodology

In general, the methodology used for the project was based on Lemmens (1991): This method distinguishes between data capture, storage, analysis and communication. The data is captured by ICT of TU Delft. After that, the data is transferred to a specific server for the project and stored. Contents wise, the first step in the project was to make a distinction between static and dynamic devices. Static devices such as printers and Wi-Fi extenders should be identified, as well as devices (moving) outside the building. A next challenge is the validation of the logs: Wi-Fi does not automatically connect to the nearest or strongest Access Point. Measurements have to be done and algorithms have to be developed to correct the 'location'. Theoretical research, tests and multiple case studies were carried out to monitor the quality of the data and validate the data. For example, for a specific area counting cameras and manual counting were issued to validate the results.

Five different scales were defined for the project: (SL0) whole campus, (SL1) building-level or facility, (SL2) floor and (SL3) Access Point and (SL4) room.

Research

The data was provided by ICT of TU Delft to the project on a daily basis (post-processing only). The data was then processed and a dashboard was made for visualisation and interaction at the different scales. A limitation is that only data is included of devices of staff and students connected to Eduroam, no devices of guest, devices connected to other network or devices not connected at all.

Conclusions

Validity and Accuracy: Based on the outcomes the hypothesis could not be confirmed and was rejected. Only on SL0 and SL1 the outcomes were reliable. For SL2 (floor), SL3 (AP) and SL4 (room) the system was not reliable enough.

System of AP's: The AP's cover multiple rooms and deliver differences in propagation, which makes scaling to more detailed levels inaccurate. The conclusion is that better algorithms need to be developed to control the number of devices in a room or on a specific floor, i.e. to locally estimate the occupancy rate.

Representativeness: A limitation for the research is the way the data is collected and the data provided by ICT. This limits the representativeness of the data. Besides eduroam users might switch off Wi-Fi or opt out.

Privacy: No direct issues for privacy were detected. Nevertheless, people should be able to opt-out and if specific information, i.e. a schedule is know, 'devices' are retraceable. This conflicts with EU regulations.

Recommendation

Improve the AP system - more consistent naming and addressing of AP's; The suggestions is also to keep the broadcasting level steady to improve the reliability of the collected data.

Improve representativeness by extending beyond Eduroam not only covering connected staff and students;

Advised is to include the visitor network as well.

Extend with Wi-Fi with LAN usage to map position of Wi-Fi devices based on LAN access and include people who switch to LAN.

Acknowledgement

This project is part of the Geomatics Synthesis Project (GEO1101) 'Rhythm of the Campus' which was carried out in Spring 2016. The data is collected by ICT of TU Delft and made available for the project. In a later stage – if no obstructions are encountered – the data will be made open-source.

The course was initiated and coordinated by Stefan van der Spek, director Geomatics for the Built Environment and Edward Verbree, section GIS-technology. Edward Verbree, Martijn Meijers and Wilko Quak mentored the three project teams. Bart Valks and Iljoesja Berdowski represented Facility Management of TU Delft. Alexandra den Heijer and Ruud Binnenkamp (Management in the Built Environment) assisted to the overall scope of the project.

References

Ackoff, R. L. (1989). From Data to Wisdom. Journal of Applied Systems Analysis, 16, p. 3-9.

Agouris, P., A. Croitoru, A. Stefanidis (2008) FEATURE INTEGRATION FOR GEOSPATIAL INFORMATION A Review and Outlook, Chapter 18 in Digital Government Volume 17 of the series Integrated Series In Information Systems, pp 353-376

Binnekamp, R. (2014, 18-04) Aligning Real Estate Demand & Supply. Manegerial Problem Solving in the Built Environment, TU Delft.

den Heijer, A. (2011). Managin the university campus; Information to support real estate decisions. Dleft: Eburon.

European Union. (1995). Directive 95/46/EC of the European Parliament and of the Council of 24 October 1995 on the protection of individuals with regard to the processing of personal data and on the free movement of such data. Official Journal of the European Union L281 (pp. 31-50). Brussels: European Union.

G. Bellinger, D. Castro, & Mills, A. (2004). Data, Information, Knowledge, Wisdom. Retrieved from http://www.systems-thinking.org/dikw/dikw.html

Graux, H. (2011). Open government data: reconciling PSI re-- use rights and privacy concerns. European Public Sector Information Platform Topic Report No. 2011 / 3.

Hillson, D., & Simon, P. (2007). Practical Project Risk Management: The ATOM Methodology: Management Concepts.

Kotaru, M., Joshi, K., Bharadia, D., & Katti, S. (2015). SpotFi: Decimeter Level Localization Using WiFi. Paper presented at the Proceedings of the 2015 ACM Conference on Special Interest Group on Data Communication, London, United Kingdom.

Kulk, S., B. van Loenen (2012), Brave New Open Data World? International Journal of Spatial Data Infrastructure Research, Vol.7, 196-206 (link)

Lemmens, M. J. P. M. (1991). GIS: the data problem.

Lemmens, M. J. P. M. (2011). Geo-information;Technologies, Applications and the Environment (5 ed.). Dordrecht: Springer.

Lendino, J. (2015). How to boost your Wi-Fi speed by choosing the right channel. Retrieved from http://www.extremetech.com/computing/179344-how-to-boost-your-wifi-speed-bychoosing- the-right-channel

Loenen, B. van, J. de Jong, J.A. Zevenbergen (2008), Locating mobile devices; balancing privacy and national security, NWO Research report. (link)

Mahmuda, A., S. Karagiorgou, D. Pfoser, · C. Wenk (2015) A comparison and evaluation of map construction algorithms using vehicle tracking data, Geoinformatica, 19:601–632, DOI 10.1007/s10707-014-0222-6

Marcaletti, A., Rea, M., Giustiniano, D., Lenders, V., & Fakhreddine, A. (2014). Filtering Noisy 802.11 Time-of-Flight Ranging Measurements. Paper presented at the The 10th ACM International Conference on emerging Networking EXperiments and Technologies, Sydney, Australia. http://conferences2.sigcomm.org/conext/ 2014/CoNEXT_papers/p13.pdf

Mautz, R. (2012) Indoor Positioning Technologies. Chapter 8: "WLAN / Wi-Fi" ETH Zurich, Department of Civil, Environmental and Geomatic Engineering, Institute of Geodesy and Photogrammetry.

Merriam-Webster. (Ed.) (2016) (Online ed.). Merriam-Webster

Orellana, D., A.K. Bregt, A. Ligtenberg, M. Wachowicz, (2012) Exploring visitor movement patterns in natural recreational areas, in: Tourism Management, 33(3):672–682 DOI 10.1016/j.tourman.2011.07.010

Petrenko, A., Sizo, A., Qian, W., Knowles, A. D., Tavassolian, A., Stanley, K. and Bell, S. (2014), Exploring Mobility Indoors: an Application of Sensor-based and GIS Systems. Transactions in GIS, 18: 351–369. doi:10.1111/tgis.12102

Pruitt, J., & Grudin, J. (2003). Personas: Practice and Theory (pp. 15).

Scassa, T. (2010). Geographical information as ‘personal information’ Oxford University Commonwealth Law Journal, 10(2), 185-214.

Statista. (2014). Average number of connected devices used per person in selected countries in 2014 (Statistic). Retrieved 14-06-2016 http://www.statista.com/statistics/333861/connecteddevices-per-person-in-selected-countries/

Valks, B. (2016a, 18-04-2016). Campus Development TU Delft - Facilities Management & Real Estate, Technische Universiteit Delft.

Yang, J., & Chen, Y. (2009, Nov. 30 2009-Dec. 4 2009). Indoor Localization Using Improved RSS-Based Lateration Methods. Paper presented at the Global Telecommunications Conference, 2009. GLOBECOM 2009. IEEE.,

A2B: Identifying movement patterns from large-scale Wi-Fi based location data.

S.C. van der Spek, E. Verbree, M. Bon, X.A. den Duijn, B. Dukai, S.J. Griffioen, Y. Kang and M. Vermeer

Delft University of Technology, Geomatics for the Built Environment,
Faculty of Architecture and the Built Environment,
Julianalaan 134, 2628 BL, Delft, The Netherlands

Extended Abstract

The distribution of people in buildings, the occupancy of lecture-, work- and study places and the accessibility of facilities are essential information at university campuses who have to cope with limited and even shrinking budgets and huge, rising real estate costs. Only little insight is gained in both occupancy and movement patterns with traditional counting techniques and user-based questionnaires. Management teams state that rooms and facilities are hardly used, though staff and students complain about overcrowded facilities and limited flexibility. Actual and accurate data on a 24/7 scale with high-granularity is missing.

In general Facility- and Asset Management lacks efficient methods for real-time, comprehensive and high-granularity information of location, capacity and use of tangible and intangible assets. Asset management could benefit from more detailed, more accurate and longitudinal data on assets, providing more insight into efficiency and effectiveness on different levels of scale through time.

Existing technologies could provide a platform delivering those required insights. Navigation- and communication technologies such as GNSS, Wi-Fi, Bluetooth, RFID can be used to 'locate' users, estimate intensities and reveal patterns of movement and patterns of use. For Asset management indoor localisation is essential.

Technology

Wi-Fi is a widespread communication technology used by electronic devices to connect to a Wireless Local Area Network (WLAN) base station or to connect ad-hoc directly between devices. Wi-Fi may be used to obtain

LBS 2016
13th Conference on Location-Based Services
Vienna, 14–16 November 2016

Published in "Proceedings of the 13th International Conference on Location-Based Services", edited by Georg Gartner and Haosheng Huang, LBS 2016, 14-16 November 2016, Vienna, Austria.

internet access, to exchange data, to access an intranet or for sending data to devices like a printer. Today a large range of electronic devices is capable of using Wi-Fi including computers, laptops, smart-phones, tablets, digital cameras, audio players, printers, (video-)game consoles and sensors. Wi-Fi networks are offered in companies, private homes, cities and (semi) public spaces and also at university campuses. Eduroam is a worldwide standard for University Campus WLAN networks.

Wi-Fi cannot only be used as a technology to transfer digital data wirelessly, but also as a tool for Facility and Asset management or as a platform for location-based services (LBS): Wi-Fi Access Points (AP's) can be used as sensors to collect information of connecting devices, delivering dashboards with temporal data on intensity of devices based on the number of unique devices detected and patterns of movement based on detections of the same device at different access points.

Wi-Fi 'user' data can be obtained in two ways: (a) by scanners or (b) by the network.

ad. (a) Wi-Fi scanners register connection attempts from devices within range. Every enabled Wi-Fi device is continuously searching for Wi-Fi access points and therefore broadcasting its unique media access control (MAC) address. No connection between device and scanner is made and no data is exchanged. Scanners can be other Wi-Fi devices as well as (modified) Access Points.

ad. (b) When using the network Access Points the real -established-connections are used. Either the connection start- and endtime is logged, or the system regularly scans for connected devices. At TU Delft a dump of devices connected to Eduroam Access Points is made every five minutes for the whole campus for network management purposes. Personal information such as MAC address and network ID are immediately encrypted (hashed). The research projects described in this abstract use this anonymised data from the Eduroam network for spatio-temporal analysis. Only staff and students from the university connecting to the eduroam Wi-Fi network are incorporated in this research.

In the Geomatics Synthesis Project Wi-Fi is used in a campus-wide experiment to monitor flows and occupation patterns at the TU Delft Campus. Students worked for two months on three parallel projects :

(1) extracting presence of people at specific places;

(2) unravelling patterns of movement within buildings and between buildings on the campus; and

(3) identifying activities and irregular use based on Wi-Fi data.

In all projects, the same dataset is used. All project also had to cover four cross-cutting topics: Privacy, Validity and Accuracy, Representativeness and reflection on the system of Access points (data collection).

Project 2: A2B : Identifying Movement patterns from large-scale Wi-Fi based location data.

A company Wi-Fi network works as a company-broad roaming service for Wi-Fi enabled devices. This enables to collect data of connection to this system and based on that aggregate to flows of devices through the system. This assists both Asset management by providing insight on actual movements between facilities and users by potentially offering tools to facilitating their movement behaviour. The second project specifically focusses on analysis of movement within and between facilities. In several corporate situations, Wi-Fi is already used for measuring movement, i.e. IKEA, Airports such as Copenhagen and Schiphol and the University campus of the National University of Singapore. Research has been carried out by Meneses and Moreire (2012) but also at TU Delft (Kalogianni et al. 2015).

The aim of this research is to use location data based on Wi-Fi logs to conduct a mobility analysis producing knowledge about the use and interaction on the Delft University Campus level.

Methodology

The TU Delft campus is equipped with over 1700 Wi-Fi Access Points (AP's) distributed over 30 buildings. The AP's mainly cover the indoor space. All students and staff have free access to this system. The system scans and stores all connections every 5 minutes for every AP. All data is encrypted. The data includes a timestamp, encrypted user information and AP name. The AP is located in a specific building at a specific place.

The analysis of movement focusses on two levels: between buildings and between building parts. The latter research has been carried out at the Faculty of Architecture as this was the only place where the exact location of access points was provided.

For the analysis of the data, a distinction is made between static devices, laptops and mobile devices like Smartphones. The hypothesis is that Smartphones are more representative for analysing movement behaviour than laptops and tablets. The latter are usually offline while moving through or between buildings and therefore not observed by the system.

The methodology for processing the data is based on the sequence and duration of the connection to specific AP's. The less AP's the more likely a device is static. The more AP's the more likely a device is mobile. Also being 'invisible' is taken into account by defining being 'away' for at least an hour is called 'world'. Connections to the same AP with short intervals are grouped in blocks. This way the status and sequence of every device can be defined as either world (outside), moving (between AP's) or present (within the range of AP).

The next step of the research was to derive movement patterns from the data. The movement was analysed on building-part level by grouping AP's to specific regions.

Research

The dataset comprised two months of data. Within this dataset this team discovered almost 45.000 different users and more than 85.000 different devices. Only around 24.000 of these devices were classified as mobile, the other devices were either static or had insufficient sessions connected to the Wi-Fi to deliver movement patterns.

The movement patterns were visualised in general and delivered a clear relation between the lecturing schedule and movement: main peaks at the 1st hour (08:45), during start and end of lunch (12:45 and 13:45) and at the end of the 8th hour (17:45); Small peaks can be observed at the intermediate breaks around 10:45 (after 2nd hour) and 15:45 (after 6th hour).

The former results were, of course, expected based on the academic schedule. More interesting are the observations of movement behaviour between facilities and the indoor movement patterns in the building of the Faculty of Architecture and the Built Environment. In general, the main movement is from most faculties in direction of the Aula for lunch, but even bigger is the flow to the library. In Architecture the pressure on the central street, especially from the East-Wing is visible.

Conclusion

On campus level, the Rhythm between buildings can be shown rather clearly based on the Wi-Fi data. Specifically, relations between Faculties can be illustrated. At building level, the same methodology can be introduced by using an indoor network graph based on the floorplan. This successfully illustrated movement in the building, however clearly issues with overlap between AP's can be observed.

Recommendation

On building level, the range of AP's needs to be investigated and translated into algorithms to identify the correct movement patterns. The performance of the tool is depending on building form. Architecture has a specific, ideal form with three main distinguishable parts. This will not always be the case.

For this research, especially the description of the outdoor space of TU Delft was missing. It is advised to add AP's in the public domain of the University Campus to make a distinction between people leaving the premises of TU

Delft and people using the outdoor facilities of TU Delft, like the centrally located Mekelpark area.

Acknowledgement

This project is part of the Geomatics Synthesis Project (GEO1101) 'Rhythm of the Campus' which was carried out in Spring 2016. The data is collected by ICT of TU Delft and made available for the project. In a later stage – if no obstructions are encountered – the data will be made open-source.

The course was initiated and coordinated by Stefan van der Spek, director Geomatics for the Built Environment and Edward Verbree, section GIS-technology. Edward Verbree, Martijn Meijers and Wilko Quak mentored the three project teams. Bart Valks and Iljoesja Berdowski represented Facility Management of TU Delft. Alexandra den Heijer and Ruud Binnenkamp (Management in the Built Environment) assisted to the overall scope of the project.

References

Agouris, P., A. Croitoru, A. Stefanidis (2008) FEATURE INTEGRATION FOR GEOSPATIAL INFORMATION A Review and Outlook, Chapter 18 in Digital Government Volume 17 of the series Integrated Series In Information Systems, pp 353-376

Agrawal, Rakesh and Ramakrishnan Srikant (1994). "Fast algorithms for mining association rules". In: Proc. 20th int. conf. very large data bases, VLDB. Vol. 1215, pp. 487–499. URL: https://www.it.uu.se/edu/ course/homepage/infoutv/ht08/vldb94_rj.pdf (visited on 04/09/2015).

Agrawal, Rakesh, Tomasz Imieli ´ nski, and Arun Swami (1993). "Mining association rules between sets of items in large databases". In: ACM SIGMOD Record. Vol. 22. ACM, pp. 207–216. (Visited on 04/09/2015).

Anbukkarasy, G. and N. Sairam (2013). "Interesting Metrics Based Adaptive Prediction Technique for Knowledge Discovery". In: International Journal of Engineering and Technology 5.3, pp. 2069–2076. (Visited on 05/16/2016).

Conference on Business Intelligence and Financial Engineering, 2009. BIFE '09. International Conference on Business Intelligence and Financial Engineering, 2009. BIFE '09. IEEE, pp. 460–463. DOI: 10.1109/ BIFE.2009.110.

Dodge, Somayeh, Robert Weibel, and Anna-Katharina Lautenschütz (2008). "Towards a taxonomy of movement patterns". In: Information visualization 7.3-4, pp. 240–252.

Graux, H. (2011). Open government data: reconciling PSI re-- use rights and privacy concerns. European Public Sector Information Platform Topic Report No. 2011 / 3.

Heijer den, Alexandra (2012). "Managing the University Campus: Exploring models for the future and supporting today's decisions". In:

Hunter, J. D. (2007). "Matplotlib: A 2D graphics environment". In: Computing In Science & Engineering 9.3, pp. 90–95.

Kalogianni, E et al. (2015). “Passive WiFi Monitoring of the Rhythm of the Campus”. In: Proceedings of The 18th AGILE International Conference on Geographic Information Science. AGILE, pp. 1–4.

Kulk, S., B. van Loenen (2012), Brave New Open Data World? International Journal of Spatial Data Infrastructure Research, Vol.7, 196-206 (link)

Loenen, B. van, J. de Jong, J.A. Zevenbergen (2008), Locating mobile devices; balancing privacy and national security, NWO Research report. (link)

Mahmuda, A., S. Karagiorgou, D. Pfoser, · C. Wenk (2015) A comparison and evaluation of map construction algorithms using vehicle tracking data, Geoinformatica, 19:601–632, DOI 10.1007/s10707-014-0222-6

Mautz, R. (2012) Indoor Positioning Technologies. Chapter 8: "WLAN / Wi-Fi" ETH Zurich, Department of Civil, Environmental and Geomatic Engineering, Institute of Geodesy and Photogrammetry.

Mautz, Rainer (2012). “Indoor positioning technologies”. PhD thesis. Habilitationsschrift ETH Zürich, 2012.

Meneses, Filipe and Alberto Moreira (2012). “Large scale movement analysis from WiFi based location data”. In: Indoor Positioning and Indoor Navigation (IPIN), 2012 International Conference on. IEEE, pp. 1–9.

Orellana, D., A.K. Bregt, A. Ligtenberg, M. Wachowicz, (2012) Exploring visitor movement patterns in natural recreational areas, in: Tourism Management, 33(3):672–682 DOI 10.1016/j.tourman.2011.07.010

Parliament and Council of European Union (1995). Directive (EC) 95/46/EC. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:31995L0046:en:HTML.

Pei, Jian et al. (2004). “Mining sequential patterns by pattern-growth: The prefix span approach”. In: Knowledge and Data Engineering, IEEE Transactions on 16.11, pp. 1424–1440.

Petrenko, A., Sizo, A., Qian, W., Knowles, A. D., Tavassolian, A., Stanley, K. and Bell, S. (2014), Exploring Mobility Indoors: an Application of Sensor-based and GIS Systems. Transactions in GIS, 18: 351–369. doi:10.1111/tgis.12102

Radaelli, Laura et al. (2013). “Identifying Typical Movements among Indoor Objects–Concepts and Empirical Study”. In: Mobile Data Management (MDM), 2013 IEEE 14th International Conference on. Vol. 1. IEEE, pp. 197–206.

Scassa, T. (2010). Geographical information as ‘personal information’ Oxford University Commonwealth Law Journal, 10(2), 185-214.

Spek, SC van der (2008). “Mapping Pedestrian Movement: Using Tracking Technologies in Koblenz”. In: Lecture Notes in Geoinformation and Cartography, pp. 95–118.

Zhang, Yuejin et al. (2009). “A Survey of Interestingness Measures for Association Rules”. In: International

Zhao, Shao et al. (2014). “Discovering People’s Life Patterns from Anonymized WiFi Scanlists”. In: Ubiquitous Intelligence and Computing, 2014 IEEE 11th Intl Conf on and IEEE 11th Intl Conf on and Autonomic and Trusted Computing, and IEEE 14th Intl Conf on Scalable Computing and Communications and Its Associated Workshops (UTC-ATC-ScalCom). IEEE, pp. 276–283.

Smart Survey – A Turnkey Solution for Automatically Identifying Travel Modes and Trip Purposes of People with Smartphones[1]

Norbert Brändle, Peter Widhalm, Markus Ray, Magnus Åhlander

Dynamic Transportation Systems
Austrian Institute of Technology
email: norbert.braendle@ait.ac.at

Extended Abstract

In many societies personal trips of people usually involve multiple travel modes, including passenger cars, buses, subway, walking, bicycle riding, etc. Different travel modes vary with respect to speed, acceleration patterns and other characteristics. Recognizing travel modes and trip purposes is critical to understand people's travel behavior and is vital for improving transportation planning, management and operations. The ever growing sensing capabilities of smartphones combined with their easy programmability, large market penetration rate, and effective distribution channels for third party applications have resulted in smartphones maturing into an effective tool for unobtrusive monitoring of human travel behavior. Identifying travel modes on smartphones allows interesting applications: smartphone-based mobility surveys, for example, automatically detect trip segments and document travel modes of respondents, allowing compilation of mobility profiles including carbon footprint. In addition, inferring activities of people, i.e. trip purposes further supports replacement of tedious manual writing of travel diaries at a new level. With knowledge of a person's travel mode, also targeted real-time information may be provided to the traveler, crowd-sourced real-time traffic information for travel modes is possible in which traffic speeds are aggregated from probes. Integrated e-ticketing apps for public transport

[1] We gratefully thank the company Neue Urbane Mobility GmbH, a subsidiary of the Wiener Stadtwerke Holding AG for their fruitful cooperation in performing real-world mobility surveys.

Published in "Proceedings of the 13th International Conference on Location-Based Services", edited by Georg Gartner and Haosheng Huang, LBS 2016, 14-16 November 2016, Vienna, Austria.

in a city or region would allow identification of times a user travels on public transport and charge fees accordingly.

Travel mode identification with smartphone sensor data is an active research field, see e.g. (Hemminki et al. 2013), (Shin et al. 2014), (Su et al. 2016), (Shafique & Hato, 2016). What is striking is that the development and validation datasets used for the publications are often rather limited. For example, the recent approach presented by Su et al. (2016) recognizes six modes, and their development dataset was obtained from five volunteers asked to travel in different modes, with durations ranging between 26 minutes and 46 minutes. Shafique & Hato (2016) also distinguish between six modes (but do not perform trip segmentation), where performance is based on 50 participants, some of which provided only a single day of travel. The approach in (Hemminki et al. 2013) distinguishes between four transport modes based on accelerometer data, and was developed on 150 hours of transportation data from 16 individuals. The work in (Montoya et al. 2015) requires a transport network infrastructure (OpenStreetMap) and General Transit Feed Specification (GTFS) data to distinguish six modes. Their validation data for the 87 journeys in Paris was not self-reported by the unknown number of travelers, but annotated by a single person "familiar with the Paris transportation system". The complexity of their algorithm is stated as 0.1 CPU seconds per journey second, which is prohibitive for practical applications.

We present and demonstrate smart survey, a readily available software solution for smartphone-based multi-modal trip reconstruction distinguishing eight travel modes (walking, bicycling, driving a car, driving a motorbike, taking a bus, tramway, subway, train). The principle is as follows: a software app continuously runs on a smartphone in the background and analyzes and records smartphone sensor data for trip starts, and collects and records network location data during trips. The client software frequently transfers the recorded data from the smartphone to the server via available wireless data standards. The server software analyzes the transferred sensor data of the smartphone for trip segments and classifies transport modes into eight classes (Widhalm et al. 2012), (Nitsche et al. 2014). A web application allows editing and correcting the trips (travel mode, activities) by the user (*Figure 1)*.

The solution has the following distinguished features:

- The system automatically recognizes *eight travel modes* – walking, bicycling, driving a car, driving a motorbike, taking a bus, tram, subway, train.
- The concept captures *activity based mobility by identifying trip purposes semi-automatically* (the related system *modalyzer* (https://www.innoz.de/en/node/88 does not represent the activity concept)

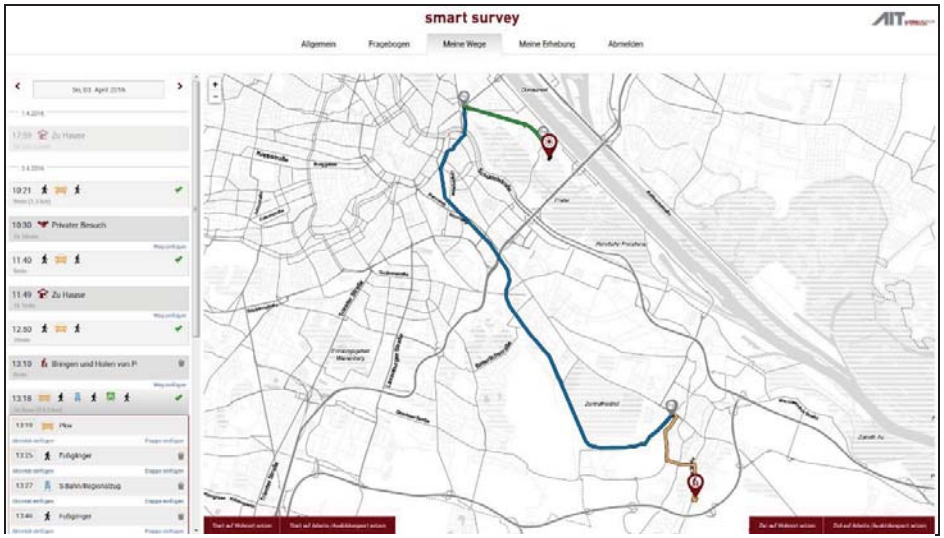


Figure 1. Screenshot of the web application allowing correction and validation of the inferred trip data

- The performance was evaluated on comprehensive real-world trip data captured by more than 300 respondents participating in mobility surveys, self-reporting the correctness of the automatic trip reconstruction on the smart survey web application during several weeks. The solution was extensively tested between June and August 2016 by 123 customers of the public transport provider in Vienna recording their daily multimodal travel behavior. The survey produced more than 7800 trips with a total length of more than 75.000 km and 7875 hours. 82% of the trips were confirmed by the respondents.
- The best results for trip reconstruction can be achieved by exploiting transport network data such as OpenStreetMap or General Transit Feed Specification (GTFS), yet the solution also runs without supplementary GIS data (e.g. in regions without extended underground lines).

The showcase at the LBS conference venue demonstrates the easy setup with QR-Codes and provides demonstration of the smart survey web application.

References

Hemminki S, Nurmi P, Tarkoma S (2013) Accelerometer-Based Transport Mode Detection on Smartphones. Proceedings 11th ACM Conference on Embedded Networked Sensor Systems

Montoya D, Abiteboul S, Senellart P (2015) Hup-me: inferring and reconciling a timeline of user activity from rich smartphone data. Proceedings 23rd SIGSPATIAL International Conference on Advances in Geographic Information Systems. Seattle, WA, USA

Nitsche P, Widhalm P, Breuss S, Brändle N, Maurer P (2012) Supporting large-scale travel surveys with smartphones – A practical approach. Transportation Research Part C - Emerging Technologies 43(2):212 - 221

Shafique M A, Hato E (2016) Travel Mode Detection with Varying Smartphone Data Collection Frequencies. Sensors 16(5)

Shin D, Aliaga D, Tuncer B, Müller Arisona S, Kim S, Zünd D, Schmitt G (2014) Urban sensing: Using smartphones for transportation mode classification. Computers, Environment and Urban Systems, in press.

Su S, Caceres H, Tong H, He Q (2016). Online Travel Mode Identification Using Smartphones With Battery Saving Considerations, IEEE Transactions on Intelligent Transportation Systems, in press.

Widhalm P, Nitsche P, Brändle N (2012) Transport Mode Detection with Realistic Smartphone Sensor Data; Proceedings of the 21st International Conference on Pattern Recognition (ICPR), Tsukuba, Japan

Exploring Human Mobility Characteristics Based on Floating Car Data and Mobile Phone Records

Yaofei Chang[*], Chun Liu[* **], De Wang[***]

[*] College of Surveying and Geo-informatics, Tongji University, Shanghai, China
[**] Key Laboratory of Advanced Engineering Surveying of NASMG, Shanghai, China
[***] College of Architecture and Urban Plannning, Tongji University, Shanghai, China

Abstract. Along with the promotion of Information and Communication Technology, floating car data and mobile phone records have been extensively used in capturing individuals' movements. In this paper, we discuss corresponding trajectory extraction methods and conduct a spatio-temporal analysis based on two datasets. Conclusively, we discover that the two datasets are both adequate for reflecting human mobility characteristics. Meanwhile, data qualities and inherent properties make them distinguished in depicting human mobility patterns.

Keywords. Floating Car Data, Smartphone-based Positioning, Human Activities, Spatio-temporal Analysis

1. Introduction

Human mobility characteristics have aroused significant interests recently with rapid development of mobile positioning technology and big data methods. What lies behind spatio-temporal activities of metropolitan residents contributes a lot to interpret urban structures (Liu X et al. 2013), intelligent transportation (Ma et al. 2015), land utilization (Pei et al. 2014), tourism management (Zheng et al. 2011), and environment problems (Zheng et al. 2013). Looking back upon those days when tracking of human activities relied on questionnaires and travel diaries, we are fortunate

LBS 2016
13th Conference on Location-Based Services
Vienna, 14–16 November 2016

Published in "Proceedings of the 13th International Conference on Location-Based Services", edited by Georg Gartner and Haosheng Huang, LBS 2016, 14-16 November 2016, Vienna, Austria.

enough to enjoy newly developed methods in big data era, which outperform the traditional ones both in velocity and volume. Commonly used approaches include vehicle-mounted GPS (Liu Y et al. 2012a), smartphone-based positioning (Diao et al. 2015), smart cards (Kim et al. 2014) and check-ins (Cheng et al. 2011).

Born with distinctive advantages, different techniques reflect human mobility characteristics from different aspects. For instance, mobile phone records cover the entire population, which makes it persuasive to depict human mobility rules of the whole city. Vehicle-based GPS is less universal but of high spatial resolution, and thus enables specific hotspots extraction of human activities.

On the other hand, inconsistent data qualities of different techniques bring challenges on modelling and visualization. No matter actively or passively the data is collected, spatio-temporal information is stored with a certain time interval. Therefore, it's necessary to build suitable models to illustrate trajectory patterns concealed in inconsecutive data. Kang (2013) points out that commonly used origin and destination (OD) in trajectory analysis of floating car data (FCD) is a representative of the trip-based method, while mobile phone records follow the sampling-based framework.

In this paper, we focus on revealing human mobility characteristics using FCD and mobile phone records. We are trying to answer two questions: (1) are FCD and mobile phone records adequate for reflecting human mobility characteristics; (2) are there any similarity and divergence between processing methods of these two kinds of data. This paper is organized as follows. *Section 2* introduces the two datasets and related trajectory extraction methods. *Section 3* gives detailed results of temporal and spatial analysis. Then, *Section 4* discusses several issues along with potential applications of the two datasets in human mobility exploration. At last, *Section 5* summarizes the contribution of this paper and offers an outlook of the future work.

2. Data Preprocessing

2.1. Data Description

In this paper, we use two datasets D1 and D2, both gathered in Shanghai, China. D1 is a trajectory dataset collected by 8,000 taxis (equipped with GPS) on seven consecutive days with a time interval of 10 seconds theoretically, adding up to 40 million pieces of data. Each piece of data records the taxi's id, speed, longitude, latitude, height, state, and time. To be specific, "id" identifies a taxi exclusively, location information is based on WGS1984, and “state” indicates the taxi’s occupancy condition, where “0” means available while “1” means occupied.

Since that the full dataset of mobile phone records is excessively big, we extract a uniform sample from one day’s dataset as D2, which contains about 20 million pieces of records and covers approximately seven million residents, accounting for 30% of the permanent population. D2 logs correspondences between base stations and mobile phones, whose time interval is determined by the operating and moving frequency of phone subscribers. Similarly, each record includes an anonymous id related to the particular mobile phone, thus protecting subscribers’ privacy. And location information is present in latitude and longitude as well.

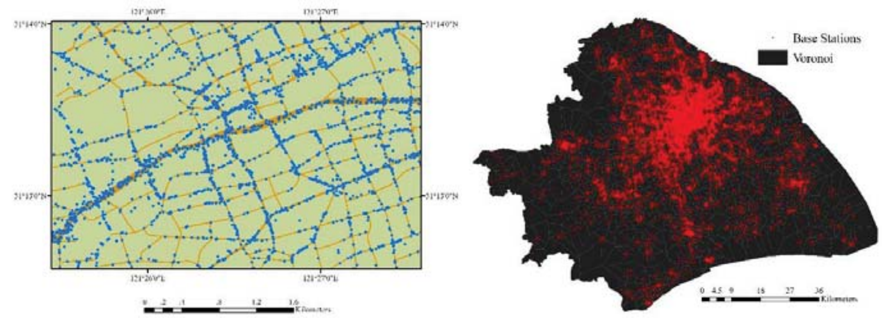


Figure 1. FCD (left) and mobile phone record (right) have different spatial resolution. The former is located on streets while the latter is limited to the range of base stations.

It should be noted that spatial resolution of FCD and mobile phone records are prominently different due to their positioning methods. As *Figure 1* indicates, GPS limits the positioning accuracy to road level, while that of mobile phone records is up to the distribution density of base stations which complies with a diminishing pattern from the urban centers to the surrounding areas.

2.2. Trajectory Extraction

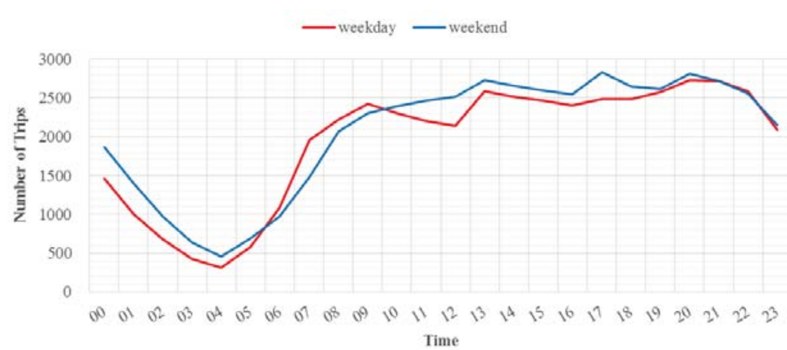
Each record in D1 and D2 can be abstracted by a 3D point feature (x_i, y_i, t_i), where x_i and y_i denote the location, and t_i denotes the time. As for D1, field “state” is a good marker in extracting trajectories. State transformation between “available” and “occupied” helps identifying displacements of metropolitan residents, providing a better understanding of human activity characteristics in the flow space as a result.

When it comes to D2, things are different. Indicators of human activity trajectories seem ambiguous here because mobile phones are not designed to record spatial movements. Hence, sampling-based trajectory extraction is applied to D2 in practical situation, where datasets of one day and peak hours are commonly used exemplars. It's reasonable that most trajectories are closed because home is a stagnation point in ordinary people's daily routine. And we can tell different human activities such as working and staying in with the help of POIs.

3. Human Mobility Characteristics

3.1. Temporal Distributions

It's apparent that time serves as a contributory factor in human mobility. To make a specific understanding, we fetch valid trips (no less than 500 meters) from D1 and display the hourly statistical result in *Figure 2a*. It can be concluded that temporal characteristics of weekends are different from that of weekdays. The morning peak disappears on weekends when most people are free from commuting restrictions. In addition, there is a summit lasting from 17:00 to 18:00 on weekends, which may result from the prologue of night activities. In general, human activities are put off on weekends along with an extended duration, and the traffic volume based on taxis surpasses that on weekdays. Similar patterns have been discovered by Liu (2012b) using FCD in Shanghai collected in 2009, and we are about to investigate the temporal distribution characteristics even more elaborately by shortening the time interval to half an hour or ten minutes.



(a)

(b)

Figure 2. Temporal distribution patterns of (a) FCD and (b) mobile phone records. Three conspicuous peaks of human mobility are shown in (a), both on weekday and on weekends. While (b) indicates that 10:00-11:00 is the busiest period of human activities.

The temporal distribution pattern we draw from D2 exhibits a parallel tendency with that of D1. Nevertheless, it should be pointed out that no midday peak exists in *Figure 2b*. A possible explanation to this phenomenon is that communication acts tend to happen in equal probability during daytime, which makes subscribers' movements the primary factor influencing temporal distribution characteristics of D2. Since that trips within the range of one base station will not be recorded, it's conspicuous why the noon, when most people take a rest or wander around, turns out less active during daytime.

3.2. Spatial Distributions

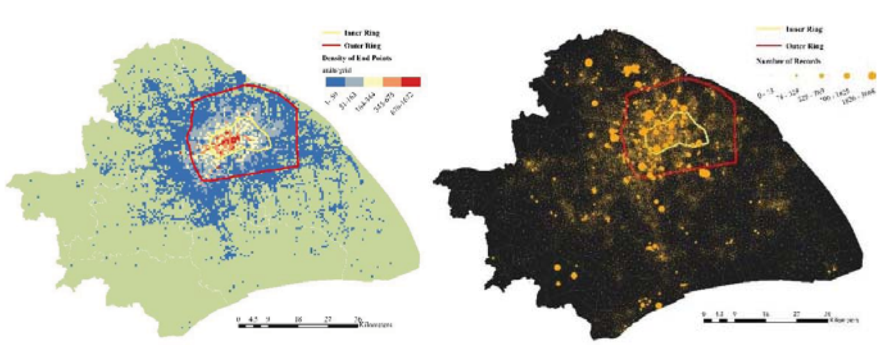


Figure 3. Spatial distribution patterns of FCD (left) and mobile phone records (right). Most frequently visited spots detected by FCD cluster inside the inner ring, while hot spots inferred by mobile phone usages are comparatively discrete in space.

As a peculiar transportation means, taxi usages have strong relationship with the latent urban structure. Apart from particular functional regions like airports and railway stations, taxi usages are most likely to gather in urban areas, especially commercial districts and tourist attractions. What we distinguish from *Figure 3a*, which depicts the spatial distribution of all the get-off points in D1, highly coincides with the hypothesis. Areas in red, which indicates a higher density of get-off points, are clustering within the inner ring of Shanghai, except for Hongqiao International Airport and South Railway Station.

Remarkably, *Figure 3b* demonstrates another spatial pattern of human mobility revealed by mobile phone usages. Noticing that mobile phone usages reflect residents' daily activities instead of certain travel purposes, hotspots detected from D2 are comparatively decentralized in geographical space. Regions with diverse functions may get involved in daily movements, not limited to home, offices, and entertainment places. Therefore, several residential districts resting between the inner and outer rings become hotspots, but typical commercial districts such as People's Square and Lujiazui are not included. And those base stations outside the outer ring with strong connection intensity may either be suburban centers or result from the edge effect.

4. Discussions

Big data, as a newly developed sensor of the real world, enables us to perceive spatial distributions as well as spatial interactions. What we have discussed above demonstrates the merits of FCD and mobile phone records on quantifying spatial distributions of human mobility. Likewise, check-in data from social media also contributes to solve urban issues, such as discovering unreasonable distribution of traffic arteries or detecting highly urbanized regions nationwide. Furthermore, thanks to the capability of revealing interpersonal connections, big data makes it possible to quantify interdependence and interactive intensity of geographical units. To be specific, researches on interdependence excel at deriving regions with particular attributes on a rough scale, thus commonly employed in land use classification. While detecting detailed urban structures is the expertise of interactive intensity, where the community discovery algorithm is generally used.

Before the advent of big data, small data collected by conversations and questionnaires occupied an indispensable position in geographical researches. Small data is rich in individual information, like age, sex, family relationships and penchants. However, big data shows drawbacks in what small data is good at. Poor in property information restricts big data to designated themes. For example, FCD only reflects a part of individuals' movements and fails to distinguish their travel purposes, so it will be regarded less valuable in researches of travel requirements of urban residents. On the other hand, quantity of big data may become the stumbling block to the quality of output. In other words, abundant data does not necessarily lead to accurate conclusions, which has been discussed thoroughly by Zhao (2016). Therefore, the emergence of big data brings about a people-oriented approach into geographical researches along with potential challenges on data processing and discrimination. What we should pay attention to when excavating into big data is that the balance between quality and quantity is always a vital point. Only appropriate data can result in convincing discoveries.

5. Conclusions

In this paper, we generate a comparative analysis of human mobility characteristics in Shanghai based on floating car data and mobile phone records. In general, we find the two datasets both adequate for reflecting human mobility characteristics. However, it should be noted that FCD, as a frequently used means of transportation, is better at detailed trajectory illustration. And it follows a concentrated distribution pattern in geographical space and is sensitive to changes temporally. As for mobile phone records, where the sampling-based method is applied to extract trajectories, bring an unparalleled performance in detecting workplaces and residences.

Still, many potential works relied on FCD and smartphone-based positioning can be promoted in the future. An integrated excavation into various datasets will broaden our understanding of geographical interactions and heterogeneity in human mobility patterns. Thus, dynamic monitor and prediction of human activities across various scales will become a promising direction as well as uncovering connections among different functional regions.

Acknowledgement

Yaofei Chang would like to thank Professor De Wang for his constructive suggestions and support.

References

Cheng Z, Caverlee J, Lee K, et al. Exploring Millions of Footprints in Location Sharing Services[C]. International Conference on Weblogs and Social Media, 2011.

Kang C, Sobolevsky S, Liu Y, et al. Exploring human movements in Singapore (a comparative analysis based on mobile phone and taxicab usages)[J]., 2013.

Kim K, Oh K, Lee Y K, et al. An analysis on movement patterns between zones using smart card data in subway networks[J]. International Journal of Geographical Information Science, 2014, 28(9): 1781-1801.

Liu X, Gong L, Gong Y, et al. Revealing daily travel patterns and city structure with taxi trip data[J]. Journal of Transport Geography, 2013, 43(0).

Liu Y, Wang F, Xiao Y, et al. Urban land uses and traffic 'source-sink areas': Evidence from GPS-enabled taxi data in Shanghai[J]. Landscape and Urban Planning, 2012a, 106(1): 73-87.

Liu Y, Kang C, Gao S, et al. Understanding intra-urban trip patterns from taxi trajectory data[J]. Journal of Geographical Systems, 2012b, 14(4): 463-483.

Ma S, Zheng Y, Wolfson O, et al. Real-Time City-Scale Taxi Ridesharing[J]. IEEE Transactions on Knowledge and Data Engineering, 2015, 27(7): 1782-1795.

Diao M, Zhu Y, Ferreira J, et al. Inferring individual daily activities from mobile phone traces: A Boston example[J]. Environment and Planning B-planning & Design, 2015.

Pei T, Sobolevsky S, Ratti C, et al. A new insight into land use classification based on aggregated mobile phone data[J]. International Journal of Geographical Information Science, 2014, 28(9): 1988-2007.

Zhao Z, Shaw S L, Xu Y, et al. Understanding the bias of call detail records in human mobility research[J]. International Journal of Geographical Information Science, 2016: 1-25.

Zheng Y, Zhang L, Ma Z, et al. Recommending friends and locations based on individual location history[J]. ACM Transactions on The Web, 2011, 5(1).

Zheng Y, Liu F, Hsieh H, et al. U-Air: when urban air quality inference meets big data[C]. Knowledge Discovery and Data Mining, 2013.

Understanding Spatiotemporal Mobility Patterns related to Transport Hubs from Floating Car Data

Linfang Ding[1, 2], Mathias Jahnke[1], Shirui Wang[1], Katre Karja[1]

[1] Chair of Cartography, Technical University of Munich
[2] Group of Applied Geoinformatics, University of Augsburg

Abstract. Transport hubs such as airports and railway stations are places where plenty of passengers are exchanged between vehicles or between transport modes. Analyzing their mobility patterns, for instance traffic flows in/out of the transport hubs, helps better understanding passengers travel behaviors and improving the transportation planning. In this paper, we aim to visually present the spatiotemporal mobility patterns related to transport hubs using floating car data. Following a visual analysis workflow, which consists of computational algorithms, data mining approaches, and visualization techniques, we preprocess the raw data related to the transport hubs, derive relevant pick-up and drop-off events, cluster and aggregate those events, and visually analyze their spatiotemporal distributions using mainly proportional symbol mapping and pie-chart mapping techniques. We use one-week Floating Car Data (FCD) in Shanghai as our test dataset and select Hongqiao international airport as the test transport hub. The preliminary experiment results show that there are obvious temporal mobility patterns as well as significant hotspot places related to Hongqiao airport.

Keywords. Travel mobility, Spatial clustering, Spatial aggregation, Visual analysis, Floating car data

1 Introduction

With the advances in location positioning and communication technologies, there is an increasing trend collecting floating car data (FCD) or spatial trajectory data from moving vehicles (e.g. private cars, taxis, buses) for understanding urban motilities. Extensive work has been done to investigate general urban mobility patterns using FCD. For instance, (Liu et al. 2012) examined large amounts of floating car data to understand intra-urban human mobility patterns from taxi trajectory data. (Ding, Fan and Meng 2015a) investigated different mobility patterns of taxi drivers at two income levels and analyzed their distinct behaviors especially when there are no passengers.

In urban areas, transport hubs such as airports and railway stations, where plenty of passengers are exchanged between vehicles or between transport modes, are of particular importance and have great influence on urban traffics. Understanding spatiotemporal travel/mobility patterns related to (e.g. traffic flows in/out) transport hubs may help urban planners and traffic managers to better learn passenger behaviors and to improve transportation planning.

However, analyzing movement data is very challenging due to their large data volume, implicit spatiotemporal relationship, and uncertain semantics. To tackle the challenges, a wide range of researches have been conducted to extract geographic

Published in "Proceedings of the 13th International Conference on Location-Based Services", edited by Georg Gartner and Haosheng Huang, LBS 2016, 14-16 November 2016, Vienna, Austria.

knowledge from movement data. Zheng and Zhou (2011) systematically investigated spatial trajectories from a wide spectrum of perspectives and disciplines, e.g. spatial database, mobile computing and data mining. They specifically pointed out the importance as well as the challenges in applying visualization methods for understanding the uncertainties in the spatial trajectories, exploring original data to inspire new ideas, and presenting the computing results to help a decision making.

A straightforward way for visualizing the floating car GPS points is by dot mapping. For instance, (Stanica, Fiore and Malandrino 2013) used dot maps to show the velocities of the road traffic in Cologne. One problem related to dot mapping of the raw data (often numerous points) is the unavoidable point overlapping effect. Another popular visualization technique is 3-D spatiotemporal mapping by making use of the height component for the representation of certain attribute. For instance, (Grant et al. 2011) used the extrusion of lines or areas to show the transportation delay in the Salt Lake City region; (Keler, Ding and Krisp 2016) proposed a selection circle visualization method using the 3-D representations of both average speed and average density derived from floating car data to investigate the traffic congestion in Shanghai. At a more aggregated level, proportional symbol mapping techniques are popular to show the overview of movement patterns. For example, (Andrienko et al. 2013) partition the space to irregular polygons based on clustering results to show aggregated movement flows. In addition, density mapping is a highly effective way to show density differences in geographic distributions across a landscape. (Prasannakumar et al. 2011) used density maps to show the hot spots of road accidents based on spatiotemporal clustering of road accidents and furthermore to investigate whether spatial or temporal factors, such as the proximity to the school or the season, have influences to the road accidents. Interactive mapping techniques are also popular in supporting visual exploration and analysis of dynamic movement patterns, e.g. NYC Taxi Holiday Visualization System[1] allows users to explore traffic from JFK and LGA airports during the holiday season (Nov 15th to December 31st), and HubCab[2] system developed by MIT Senseable city lab allows users to get insight into the taxi mobility patterns at a fine granularity and supports future taxi sharing based on a model named 'shareability networks' (Szell and Groß 2014).

For visually exploring traffic flow patterns related to transport hubs, (Ding, Yang and Meng 2015b) proposed a visual analytics workflow and developed a web-based visual interface for the visual exploration of movement data at both an aggregated and an individual level. In their work, they revealed the significant places as well as their semantics (e.g. residential, commercial, industrial, public) related to the transport hubs. However, there is a lack of in-depth investigation of the temporal patterns related to transport hubs.

In this paper, following a similar visual analysis workflow in (Ding et al. 2015b), which incorporates computational algorithms, data mining approaches, and visualization techniques, we go one step further with the aim to visually analyze the spatial and temporal traffic flow patterns related to transport hubs using floating car data. More specifically, we firstly preprocess a large amount of movement data, reconstruct trajectories and extract the starting and ending points related to the transport hubs. Secondly, we apply hierarchical clustering methods to derive significant clusters related to transport hubs and aggregate them to significant places. Finally, we design appropriate spatial and temporal visualization techniques, e.g. dot maps, proportional symbol maps, pie chart maps, to visually analyze those significant places. We use one-week FCD in Shanghai as our test dataset and select Hongqiao international airport as the test transport hub. The experiment results reveal significant spatiotemporal traffic flow patterns related to Hongqiao airport.

---

[1] http://taxi.imagework.com/

[2] http://hubcab.org/#13.00/40.7219/-73.9484

2 The visual analysis workflow

In this section, we introduce the general workflow of visualizing spatiotemporal distributions of transport hub related traffics, which consists of mainly traffic-hub related trajectory reconstruction, data preprocessing, point clustering and aggregation, and visualization and analysis.

2.1 Data preprocessing and trajectory reconstruction

This paper focuses on the investigation of the taxi trajectories with passengers travelling from and to the transport hubs. We firstly filter out erroneous GPS points for instance, inappropriate GPS points with locations outside Shanghai and timestamps beyond the study time slots. Since the raw data are individual GPS points, we reconstruct from the FCD geospatial database the occupied trajectories (with passengers) by connecting the temporal sequences of GPS points with the “car status” attribute value of 1. After filtering out erroneous trajectories, we then extract occupied trajectories related to (i.e. from/to) the transport hubs, and their starting (pick-ups) and ending points (drop-offs).

2.2 Point Clustering and aggregation

In this work, we use spatial clusters to identify pick-up/drop-off hotspots. Spatial clustering can be used to gain insight into the distribution of data, to observe the characteristics of each cluster, and to focus on a particular set of clusters for further analysis (Han, Kamber and Tung 2001). Specifically, we use a hierarchical agglomerative clustering method (Kaufman and Rousseeuw 1990) to detect the significant areas or places where most of the pickup/drop-off events happen. The given set of data objects is hierarchically decomposed, forming a dendrogram - a tree that splits the database recursively into small subsets. The dendrogram can be formed either “bottom-up” or “top-down”. This work adopts the “bottom-up” way. The “bottom-up” approach, also called “agglomerative” approach, starts with each object forming a separate group. It successively merges the objects or groups according to some measures like the distance between the two group centers and this is done until a termination condition holds.

To perform agglomerative hierarchical cluster analysis on a data set, the following procedure is required: 1) Find the similarity or dissimilarity between every pair of objects in the data set. 2) Group the objects into a binary, hierarchical cluster tree. 3) Determine the threshold to cut the hierarchical tree into clusters.

In this work, the input of the clustering method is the extracted pickup/drop-off events. The parameters of the methods are normally a distance function and a linkage criterion. The parameter setting is largely dependent on the applications. The output is the clustered events indicating which cluster the event belongs to. To filter out the significant places, we set a significant threshold value for the minimum number of the cluster elements. If a cluster has a number of elements larger than the significant threshold value, then this cluster is considered as a significant cluster.

Based on the clustering results, a variety of aggregated values can be derived for the significant clusters, for instance, the occurrences of pick-up events, the occurrences of the drop-off events, or the total number of the pick-up and drop-off events. The cluster centroids will be calculated to represent the location of the aggregates, which are regarded as the hot pick-up/drop-off places related to the corresponding transport hubs.

2.3 Visual analysis

In our work, we mainly focus on presenting significant spatiotemporal travel patterns related to the transport hubs. To visualize the aggregated significant events, proportional symbol mapping and pie-chart mapping are mainly used to show the one-variate (e.g. the total number of the pick-up and drop-off events) and two-variate (e.g. pick-up and drop-off events) spatial distributions respectively. For showing especially temporal information, for instance distributions of events at different time slots during one day or different days, small multiples of proportional symbol maps and pie chart maps will also be applied.

3 Experiment

3.1 Test data

The test dataset are raw GPS points collected from about 2000 GPS-enabled taxis within 47 days from 10th May to 30th June 2010, in Shanghai. The temporal resolution of the dataset is 10 seconds. Each position record has nine attributes, i.e. car identification number, company name, current timestamp, current location (longitude, latitude), instantaneous velocity, and car-status (meaning taxi occupied or empty). The detailed description of the fields is shown in Table 1. The data are stored in a MongoDB database.

Field	Example field value	Field description
Date	20100517	8-digit number, yyyymmdd
Time	235903	6-digit number, HHMMSS
Company name	QS	2-digit letter
Car identifier	10003	5-digit number
Longitude	121.472038	Accurate to 6 decimal places, in degrees
Latitude	31.236135	Accurate to 6 decimal places, in degrees
Velocity	16.1	In km/h
Car status	1/0	1-occupied; 0-unoccupied

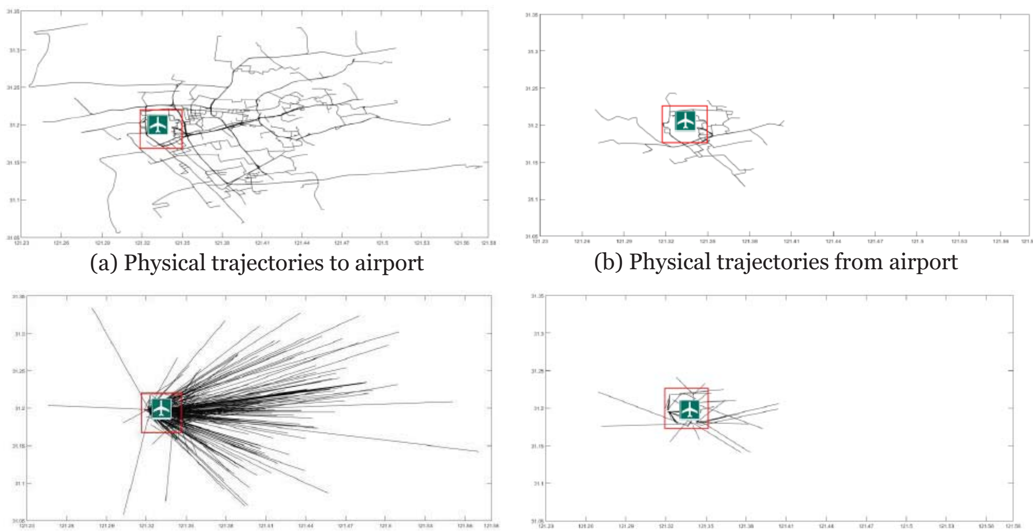
Table 1. The properties of the test data.

Figure 1 Shanghai Hongqiao airport area as study transport hub

In this work, Hongqiao international airport is chosen as our study area. Figure 1 shows the location and extent of the Hongqiao international airport.

3.2 Data extraction and temporal division

For illustration purpose, we extract one hour data at 6-7h (on 17th May 2010) from the database and reconstructed the GPS traces by connecting a temporal sequence of GPS points. Focusing on the occupied trajectories during this hour, we extract about 13,300 trajectories in the whole Shanghai area, of which around 300 trajectories are related to Hongqiao airport. Figure 2 shows the reconstructed occupied trajectories to/from Hongqiao airport (Figure 2(a) and 2(b)) and their origin-destination (O-D) trajectories (Figure 2(c) and 2(d)). Obviously, at 6-7 hour there are more taxis driving to Hongqiao airport than leaving the airport, which may indicate that many passengers take flight in the early morning at 6-7h.



(a) Physical trajectories to airport

(b) Physical trajectories from airport

(c) O-D trajectories to airport

(d) O-D trajectories from airport

Figure 2 Spatial distribution of the occupied trajectories (a,b) and the corresponding origin-to-destinations (c,d) to and from airport at 6-7h.

To investigate hourly temporal mobility activities, we derive one-day trajectories to/from Hongqiao airport and divide the data to each hour. Figure 3 shows the hourly distribution of the number of trajectories from/to the airport using the bar charts. Red and blue represent trajectories to and from the airport respectively. The bar chart shows that: (1) there are temporal patterns like peaks and valleys for the traveling activities related to the airport during a day. For instance during the early morning (2-4h), there are much fewer trajectories related to the airport than other time periods, while at 6-7h, 11-12h, 23-24h there are more trajectories; (2) there are more trajectories to the airport at 4-10h than from the airport, approximately similar amount of trajectories from and to the airport at 11-16h, and increasing trajectories from the airport than to the airport at 17h-24h and 1-2h. This indicates that there are more passengers taking taxis in the morning to the airport, while in the late afternoon or during night there are more passengers taking taxis to the city centre.

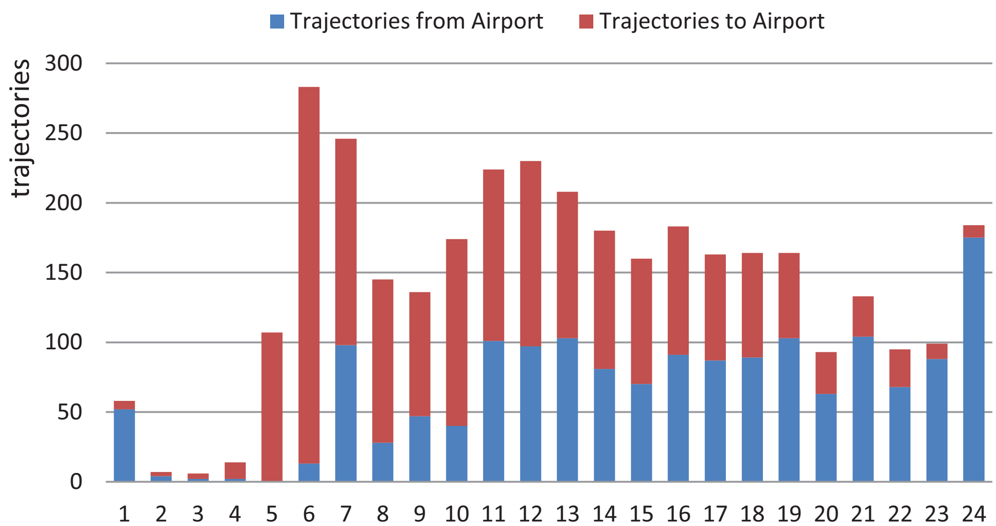
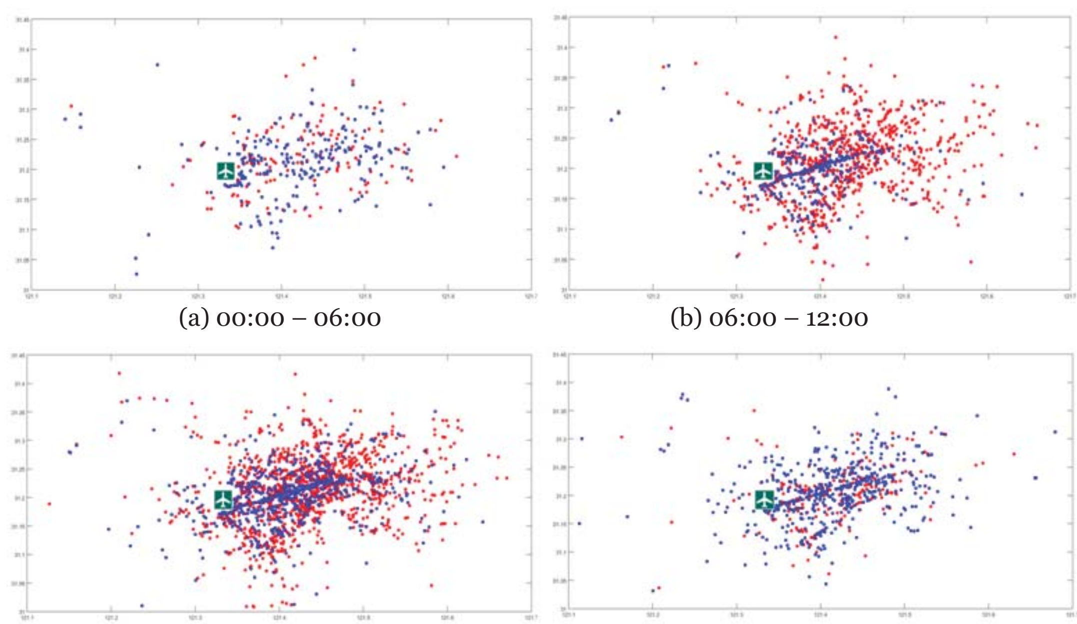


Figure 3 Hourly patterns of trajectories from and to the Hongqiao airport

Furthermore, we focus on analysing only the spatiotemporal distribution of the pick-up and drop-off points. We investigate the pick-ups and drop-offs distributions during four typical time-slots, i.e. 00:00-06:00, 06:00-12:00, 12:00-18:00, and 18:00-24:00. Figure 4 shows their spatial distributions at each time slot. Obviously, there are general distribution patterns can be observed, for instance, denser pick-up/drop-off activities at 06-12 in Figure 4(b) and at 12-18 in 4(c), and less events at 18-24 in Figure 4(d), especially at 00-06 shown in 4(a). In addition, we can also observe distinct patterns of pick-ups and drop-offs in each subfigure. For example, it seems that at 6-12 there are more drop-offs than pick-ups. However, due to the dot over-plotting problem, it is hard to detect hot spots of the two kinds of events.



(a) 00:00 – 06:00 (b) 06:00 – 12:00

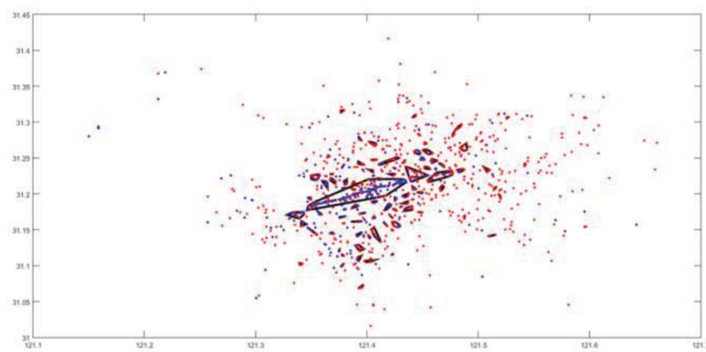
(c) 12:00 – 18:00 (d) 18:00 – 24:00

Figure 4 Pick-up and drop-off events in four time slots. Red represent pick-up events and blue drop-off events.

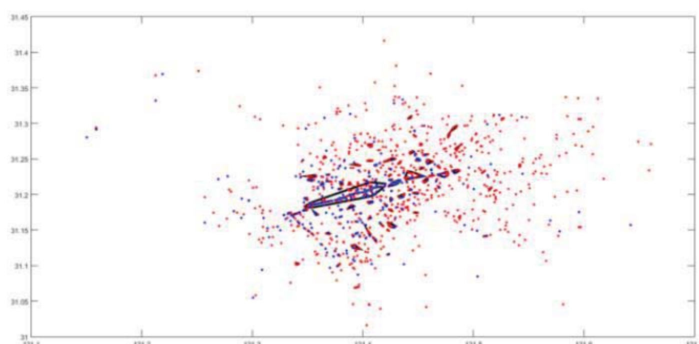
3.3 Pick-up/Drop-off clustering and aggregation

To solve the dot over-plotting issues and detect pick-up and drop-off hotspots, we use clustering methods to find dense pick-up and drop-off areas and aggregate the events to significant places, which has more mobility activities related to the airport.

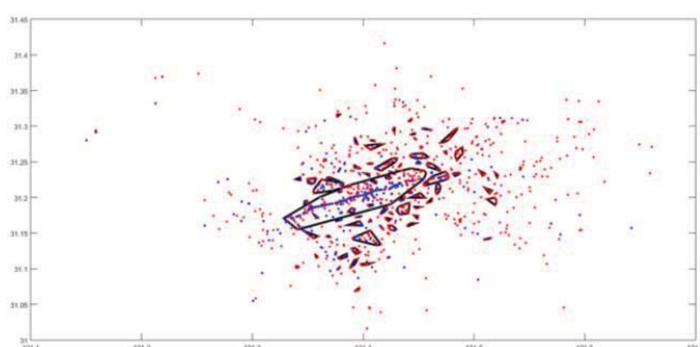
In our experiment, we use the agglomerative hierarchical clustering method to find dense areas. In order to define the significant places, we set a significant threshold value for the minimum number of the cluster elements. If a cluster has a number of elements larger than the significant threshold value, then this cluster is a significant cluster. Since the clustering method will assign each point to a cluster and here we are interested only in clusters with a higher density or a larger number of cluster elements, we select clusters with more than 5 points as significant clusters. Instead of trying different distance and linkage parameters, we used the hierarchical clustering methods provided by Matlab and specify arbitrary clusters using a parameter "maxclust". To find appropriate "maxclust", we try different values and the resulted clusters are illustrated in Figure 5.



(a)



(b)



(c)

Figure 5 Hierarchical clustering results of pick-up and drop-off events at 6-12 with different "maxcluster" parameter (a) 500 (b) 600 (c) 400. The convex hull shows significant clusters.

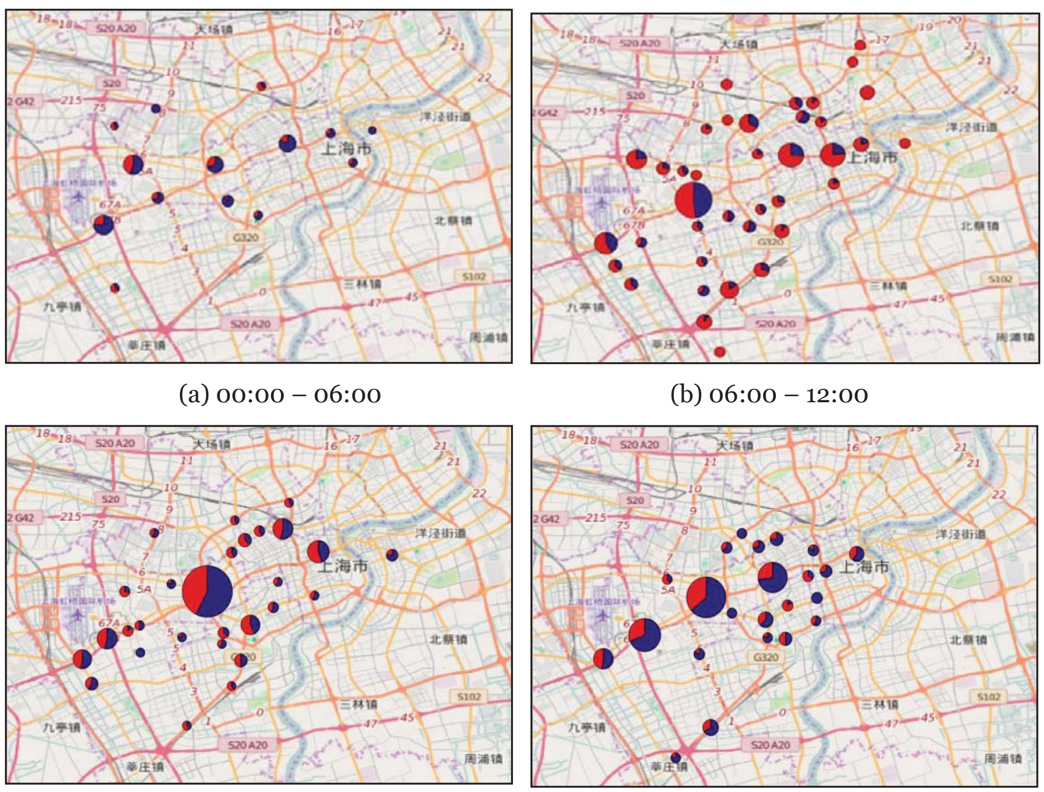
For each time slot, we select different parameter values for the clustering since the temporal distribution of the pick-up and drop-off events are different.

After we get the significant clusters, we aggregate the cluster elements and use the cluster centroids as the spatial locations of the aggregates. Each cluster has corresponding aggregated values, for instance, the number of pick-up events, the number of drop-off events, and the total number of pick-up and drop-off events. Those summarized values at the cluster centroids reflect pick-up and drop-off activity hot spots.

3.4 Visual analysis

To show the pick-up and drop-off hotspots related to the transport hub, we apply pie chart mapping and proportional symbol mapping techniques, which respectively represent the pick-up and drop-off distribution and the total number of the pick-ups/drop-offs.

To get an overview of the temporal hotspots of the pick-ups and drop-offs respectively, we use multiple pie-chart maps at four time slots. Figure 6 shows the results of the pie-chart mapping results. The sizes of the pie charts are proportional to the total number of the pick-up and drop-off events. The red and blue pie sectors represent pick-up and drop-off events.



(a) 00:00 – 06:00

(b) 06:00 – 12:00

(c) 12:00 – 18:00

(d) 18:00 – 24:00

Figure 6 Multiple pie chart maps showing the pick-up and drop-off patterns. Red represents pick-up events and blue drop-off events.

From Figure 6, we can easily observe the spatial distribution of the hotspots of pick-up and drop-off events at the four time slots during a day. Most of the host spots are distributed to the east of the airport, which towards the city center area. Compared with the other time slots, at 00-06 (Figure 6(a)) there are obviously fewer and smaller hot spots. At 06-12, pick-up events are dominant, which indicates in the morning there are more passengers taking taxis at the hot spots (shown Figure 6(b)) and traveling to Hongqiao airport. Beside the hot spots eastwards of the airport, at this time slot there are also several hotspots southeast of the airport. While at 12-18 (Figure 6(c)) and 18-24 (Figure 6(d)), there is an increasing trend more passengers travel from the airport to the hotspots in the city center.

To visualize the temporal distribution of the total amount of travel activities (pick-ups and drop-offs) related to the airport during a day, we present a pie cart map in Figure 7. Different colors (black, white, light gray, and dark gray) represent different time slots (00-06, 06-12, 12-18, and 18-24). The size of each sector are proportional to the total number of pick-up and drop-off events at this time slot. The biggest pies represent the most active areas that traveling to/from the airport. The proportions of the pies reveal the temporal distribution of the travelling activities. There are a few black or white pies which indicate the corresponding hotspots are significantly active at early morning (00-06) or in the morning (06-12). There is a big dark gray circle in the center of the map and another one right on the south of the airport, which represent two hotspots that especially active in the evening (18-24) travelling to/from the airport. The pie charts with even temporal distributions indicate hotspots that are active for the whole day or most of the day.

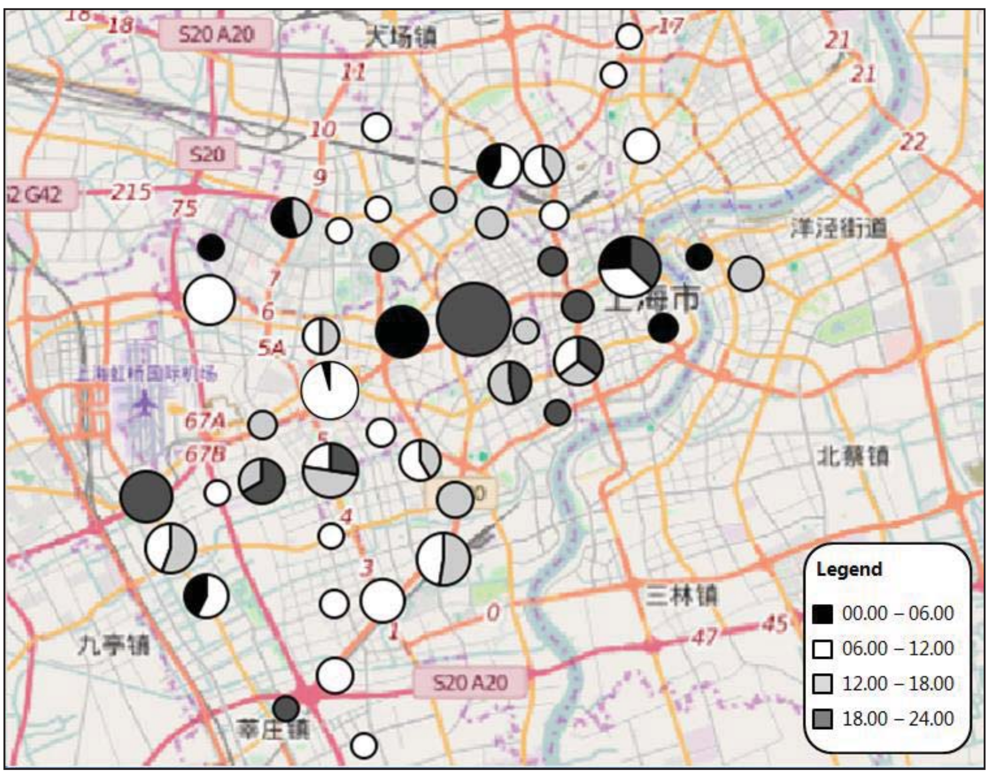


Figure 7 Temporal pie-chart mapping of the pick-up and drop-off events.

Moreover, we investigate one-week FCD data related to Hongqiao airport. The bar chart in Figure 8 shows a daily pattern in one week for trajectories to and from airport. In general, there are relatively more activities related to the airport from Monday to Thursday than on Friday and at weekend. In terms of the hourly pattern, similar to Figure 3, it shows active travels to the airport in the morning and afterwards an increasing amount of passengers traveling from airport to the city center.

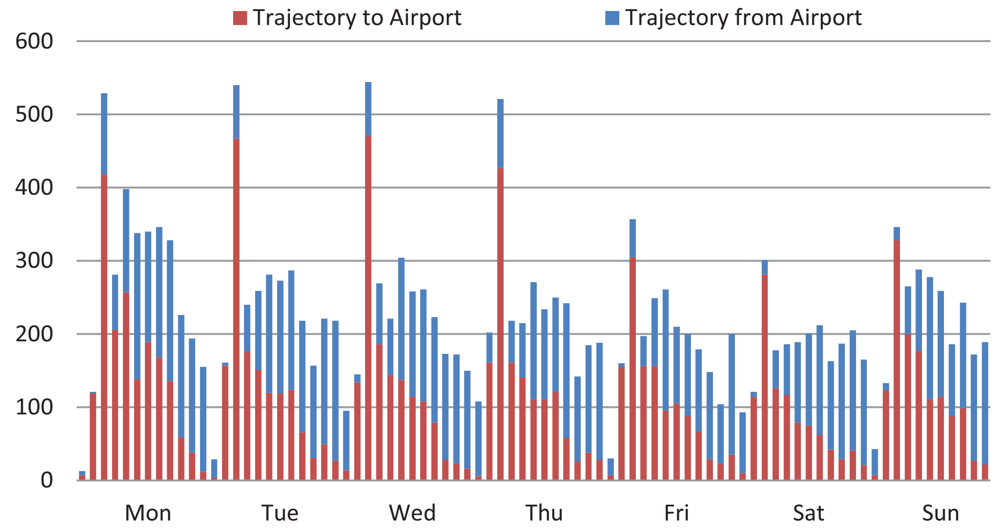


Figure 8 Daily-patterns of trajectories from and to the Hongqiao airport

In order to present the weekly data in one map, we firstly calculate for each day the significant clusters and for the whole week we aggregate the overlapped clusters into one big cluster with a recalculated centroid. Then we create a pie chart over each cluster to show the distribution of the number of events from Monday to Sunday in each significant place. As shown in Figure 9, red, orange, yellow, green, cyan, blue and purple color represent the sum of the pick-up and drop-off events on Monday, Tuesday, Wednesday, Thursday, Friday, Saturday and Sunday respectively. The area of each pie sector are proportional to the total number of pick-ups and drop-offs at the corresponding day.

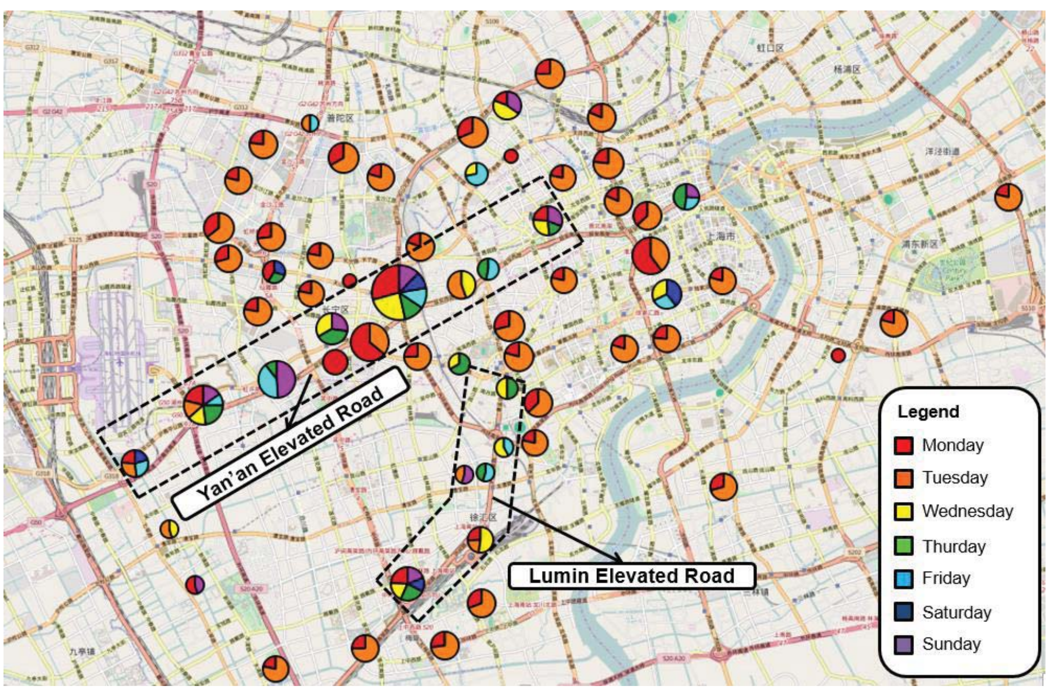


Figure 9 Pie chart map of Hongqiao airport related significant places from Monday to Sunday

It is evident from Figure 9 that the majority of the significant places based on the clustering and aggregation results have large portions of activities on Monday and Tuesday (red and orange), especially Tuesday (orange). In addition, we could see that a large amount of significant places located along several major roads. Along the

"Yan'an Elevated Road" and "Luming Elevated Road" the time distribution of significant places from Monday to Sunday appears to be more even, which indicate these two road are popular road where taxis pick up passengers to Hongqiao airport or drop off passengers from Hongqiao airport.

4 Conclusion & Outlook

This paper aims to analyze and visualize the spatiotemporal mobility patterns related to transport hubs using floating car data. By following a visual analysis workflow incorporating computational algorithms, data mining approaches, and visualization techniques, we investigated the spatiotemporal patterns of one-week FCD data. The experiment results show that there are obvious hourly and daily temporal mobility patterns and as well significant spatial hotspots related to transport hubs.

In the future, we plan to improve our work in the following aspects. Firstly, we would like to investigate the appropriate clustering parameter in an interactive manner, for instance, by implementing a slider bar for selecting different parameter values. Secondly, we will integrate this work to the web-based visualization system proposed in (Ding et al. 2015b) and improve the graphic user interface with powerful interactive functions to allow users explore the visualization results.

References

Andrienko, G. L., N. V. Andrienko, P. Bak, D. A. Keim & S. Wrobel. 2013. *Visual Analytics of Movement*. Springer.

Ding, L., H. Fan & L. Meng. 2015a. Understanding taxi driving behaviors from movement data. In *AGILE Conference on Geographic Information Science*. Lisbon.

Ding, L., J. Yang & L. Meng. 2015b. Visual Analytics for Understanding Traffic Flows of Transportation Hub from Movement Data. In *International Cartographic Conference 2015*. Rio de Janeiro, Brazil.

Grant, M., M. Day, R. Winick, A. Chavis, S. Trainor & J. Bauer. 2011. Showcasing Visualization Tools in Congestion Management. Federal Highway Administration (FHWA), U.S. Department of Transportation

Han, J., M. Kamber & A. K. H. Tung. 2001. Spatial Clustering Methods in Data Mining: A Survey. In *Geographic Data Mining and Knowledge Discovery, Research Monographs in GIS,* eds. H. J. Miller & J. Han. Taylor and Francis.

Kaufman, L. & P. Rousseeuw. 1990. *Finding Groups in Data*. Wiley & Sons, Inc., New York.

Keler, A., L. Ding & M. J. Krisp (2016) Visualization of traffic congestion based on Floating Taxi Data. *Kartographische Nachrichten (KN)*, 2-13.

Liu, Y., C. Kang, S. Gao, Y. Xiao & Y. Tian (2012) Understanding intra-urban trip patterns from taxi trajectory data. *Journal of Geographical Systems,* 14, 463-483.

Prasannakumar, V., H. Vijith, R. Charutha & N. Geetha (2011) International Conference: Spatial Thinking and Geographic Information Sciences 2011Spatio-Temporal Clustering of Road Accidents: GIS Based Analysis and Assessment. *Procedia - Social and Behavioral Sciences,* 21, 317-325.

Stanica, R., M. Fiore & F. Malandrino. 2013. Offloading Floating Car Data. In *World of Wireless, Mobile and Multimedia Networks (WoWMoM), 2013 IEEE 14th International Symposium and Workshops on a*, 1-9.

Szell, M. & B. Groß. 2014. Hubcab – Exploring the Benefits of Shared Taxi Services. In *Decoding the City How Big Data Can Change Urbanism*.

Is there a relationship between complicated crossings and frequently visited locations? – A case study with boro taxis and OSM in NYC

Andreas Keler*, Jukka M. Krisp*

* University of Augsburg, Institute of Geography, Applied Geoinformatics, Alter Postweg 118, 86159 Augsburg, Germany

Extended Abstract

Introduction

Extracted positions of taxi trajectories, where customers enter or leave the vehicle are useful information for a big variety of applications (Castro et al. 2013). They are useful for estimating cruising miles, which is the taxi mileage without a fare, and helpful for its reduction as tested with the pCruise algorithm (Zhang & He 2012). Additionally, the inspection of taxi pick-up points might be helpful for providing taxi service quality assessments (Zhang et al. 2014) and analyzing the taxi drivers behavior, for example if the driver is hunting or waiting for new customers (Li et al. 2011). For the inspection of the spatial distributions of taxi pick-up and drop-off points, Pan et al. (2013) are using besides “heatmaps”, which are 2-D histograms in the Euclidean space, as well the density-based clustering algorithm DBSCAN (Ester et al. 1996), which was successfully tested with geodatabases (Sander et al. 1998). In contrast to this, Krisp et al. (2012) propose partitioning-based clustering (k-means) for getting in and out of a taxi. When taxi pick-up and drop-off points in Euclidean space form density- or distance-connected clusters of certain spatial extent, we can associate those areas with additional geographic information on land-use (Pan et al. 2013) or on region function (Li et al. 2011). Density-based clustering is applicable for whole vehicle trajectories as shown by Rinzivillo et al. (2011) with the use of the OPTICS algorithm, which was introduced by Ankerst et al. (1999). The big advantage of OPTICS is the possibility to create reachability plots that allow estimations for beneficial search distances (Epsilon) for a selected minimum number of points (MinPts).

Published in “Proceedings of the 13th International Conference on Location-Based Services”, edited by Georg Gartner and Haosheng Huang, LBS 2016, 14-16 November 2016, Vienna, Austria.

In our approach we use OPTICS for extracted taxi drop-off points for the derivation of density-based clusters in one selected investigation area on one selected day of observation. These resulting clusters are then related with complicated crossings.

Description of the test data sets

In this work we inspect the vehicle traffic dynamics and the transportation infrastructure of New York City (NYC). Therefore, we make use of time-based extracts from green taxi trip data and of road network data within the administrative boundaries of NYC coming from the OpenStreetMap (OSM) project.

Trip data of green taxi cabs in New York

New York City, especially Manhattan, has a high coverage of frequently operating taxis. Besides the typical yellow taxis there are also green taxis, which are also called "boro taxis". Those green taxis were introduced in 2013 for gaining more distribution in the boroughs outside Manhattan. This was initiated after inspecting the distribution of pic-up points of yellow taxi GPS trajectories: 95 % of pic-ups occurred within Manhattan and the rest in the outer boroughs[1].

Our data set is coming from the NYC Taxi & Limousine Commission (TLC)[2] and includes taxi trip records from all trips.

For our approach of detecting frequently visited locations within a short distance radius, we are only using the taxi drop-off points, where customers are leaving the green taxis.

As we suppose, we have more fluctuations from outer boroughs into Manhattan on weekends as on working days. Therefore, we select one Saturday in 2015: 13th of June. In total there are 24.820 green taxi trips with the same number of drop-off points. From the 20 available attributes, we only use geodetic coordinates of drop-off points. There is no given attribute indicating specific taxi identifications.

---

[1] Background on the Boro Taxi program. NYC Taxi & Limousine Commission. URL: http://www.nyc.gov/html/tlc/html/passenger/shl_passenger_background.shtml; Retrieved December 18, 2013.

[2] http://www.nyc.gov/html/tlc/html/about/trip_record_data.shtml

NYC road network information from the OpenStreetMap (OSM) project

OpenStreetMap (OSM) is an open Crowdsourcing project that was founded in 2004 by Steve Coast with the aim to create an open geodatabase. Since then, worldwide volunteered mappers produce Volunteered Geographic Information (VGI). For Stanica et al. (2013) the OSM has one of the most accurate freely available road networks. Its practical use for vehicle routing was tested by Graser et al. (2014) for the case of Vienna. The conversion into 1-D network space sometimes comes along with problems in connectivity and has to be modified for practical routing applications.

Defining complicated crossings and frequently visited locations in NYC

Our Method consists of creating polygons based on two different data sources. Besides complicated crossings from OSM road networks, we infer taxi drop-off point cluster polygons. After matching these two polygon types, we define frequently visited locations. This workflow is pictured in the diagram in *Figure 1*.

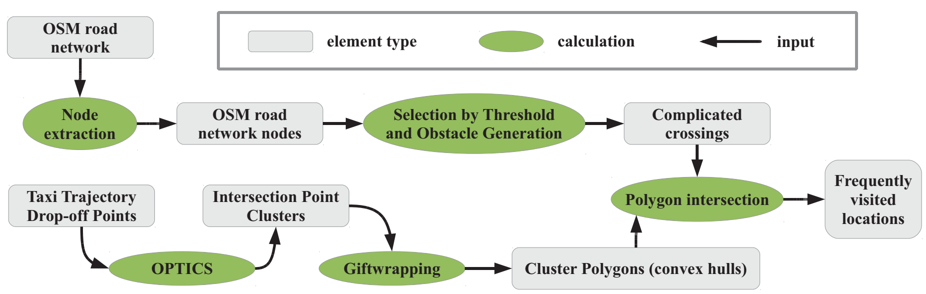


Figure 1. Workflow for the definition of "frequently visited locations".

We have rethought the idea of introducing a representative search distance for applying the OPTICS algorithm, which was introduced by Ankerst et al. (1999).

As provided in Krisp & Keler (2015) we can use an average distance of roundabouts (in this case 60 m) for selecting a threshold for the creation of obstacle polygons. These obstacle polygons are so called complicated crossings and are based on two-dimensional Kernel Density Estimation of street nodes (see *Figure 1*). In case of typical American cities we have to think about something else: Since Summer 2015 there is only one roundabout in New York City. This pictures the unpopularity of this transportation infrastructure element, which is very popular in Western Europe: France has with over 30.000 roundabouts the highest number in the world. After inspecting the transportation infrastructure in Manhattan, we keep the search radius on 60 meters.

In parallel we have to define taxi drop-off point clusters by using the OPTICS algorithm. In case of this algorithm, we have to define a search distance (Epsilon) and a minimum number of points (MinPts) for estimating the density. For the search distance Epsilon we take the maximum Street width in Time Square of 102 feet, which equals around 31 meters (31.0896 meters). Our minimum number of taxi drop-off points will be 2 (MinPts = 2). With those two parameters we define our density connection between the drop-off points. The resulting 1.867 clusters are then transformed by the gift wrapping algorithm (Jarvis 1973) into polygons.

In the last step of defining frequently visited locations we match the 613 complicated crossings with 1.867 taxi drop-off point polygons in NYC. *Figure 2* shows a cutout of the in total 1.466 defined frequently visited locations in NYC on Saturday, June the 13th 2015, which will be the base for our further analyses.

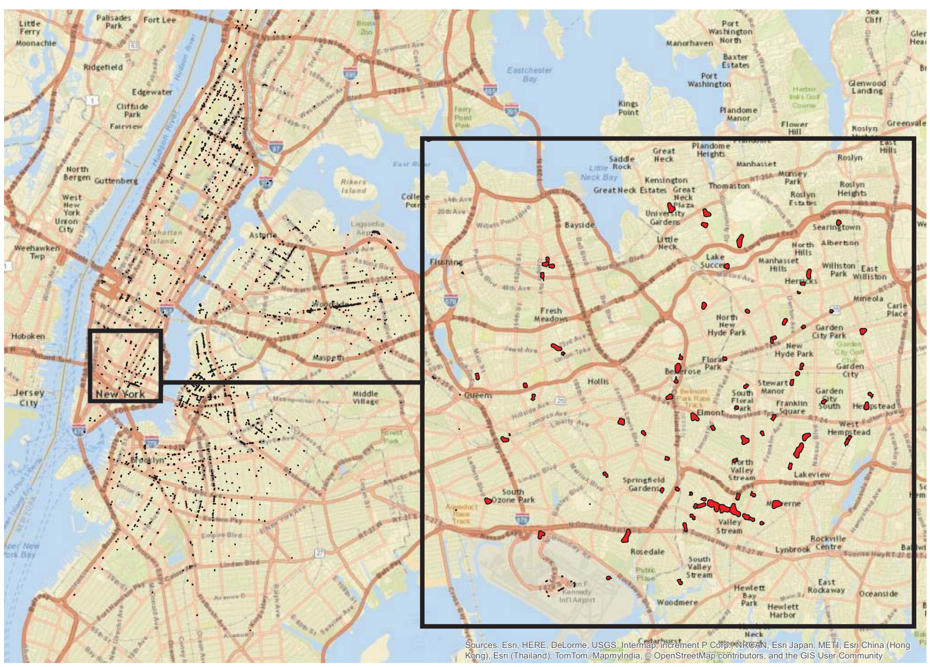


Figure 2. Defined frequently visited locations in NYC on Saturday, June the 13th 2015.

References

Ankerst M, Breunig MM, Kriegel H-P, Sander J (1999) OPTICS: Ordering Points To Identify the Clustering Structure. In: ACM SIGMOD international conference on Management of data. ACM Press, pp. 49-60

Castro PS, Zhang D, Chen C, Li S, Pan G (2013) From taxi GPS traces to social and community dynamics: A survey. ACM Computing Surveys (CSUR), 46(2): Article No. 17

Ester M, Kriegel H-P, Sander J, Xu X (1996) A density-based algorithm for sparse representations. In: Proceeding of the 2nd International Conference on Knowledge Discovery and Data Mining, pp. 226-231

Graser A, Straub M, Dragaschnig M (2014) Is OSM Good Enough for Vehicle Routing? A Study Comparing Street Networks in Vienna. In: Gartner G, Huang H (eds) Progress in Location-Based Services, Lecture Notes in Geoinformation and Cartography. Berlin: Springer, pp. 3-18

Jarvis RA (1973) On the identification of the convex hull of a finite set of points in the plane. Information Processing Letters 2: 18-21

Krisp JM, Keler A (2015) Car Navigation - Computing Routes That Avoid Complicated Crossings. International Journal of Geographical Information Science (IJGIS) 29(11): 1988-2000

Krisp JM, Polous K, Peters S, Fan H, Meng L (2012) Getting in and out of a taxi: spatio-temporal hotspot analysis for floating taxi data in Shanghai. In: 6th International Symposium “Networks for Mobility”, Conceptual paper, September 27/28, 2012.

Li B, Zhang D, Sun L, Chen C, Li S, Qi G, Yang Q (2011) Hunting or Waiting? Discovering Passenger-Finding Strategies from a Large-scale Real-world Taxi Dataset. In: 2011 IEEE International Conference on Pervasive Computing and Communications Workshops (PERCOM Workshops), MUCS 2011: 8th IEEE International Workshop on Managing Ubiquitous Communications and Services, Managing Contexts, pp. 63-68

Pan G, Qi G, Wu Z, Zhang D, Li S (2013) Land-Use Classification Using Taxi GPS Traces. IEEE Transactions on Intelligent Transportation Systems 14(1): 113-123

Rinzivillo S, Pedreschi D, Nanni M, Giannotti F, Andrienko N, Andrienko G (2008) Visually driven analysis of movement data by progressive clustering. Information Visualization 7(3-4): 225-239

Sander J, Ester M, Kriegel H-P, Xu X (1998) Density-Based Clustering in Spatial Databases: The Algorithm GDBSCAN and Its Applications. Data Mining and Knowledge Discovery 2(2): 169-194

Zhang D, He T (2012) pCruise: Reducing Cruising Miles for Taxicab Networks. In: Proceedings of the 2012 IEEE 33rd Real-Time Systems Symposium (RTSS 2012), pp. 85-94

Zhang D-Z, Peng Z-R, Sun DJ (2014) Comprehensive Taxi Assessment Index Using Floating Car Data. Journal of Harbin Institute of Technology 21(1): 7-16

Learning Pedestrian Profiles from Movement Trajectories

David Jonietz

Institute for Cartography and Geoinformation, ETH Zurich

Extended Abstract

Pedestrians are highly heterogeneous with regards to their physical capabilities and preferences, which in turn determine their individual infrastructural needs (Saelens et al. 2003, Millonig 2006). Other than in current pedestrian navigation systems, therefore, the possibility to compute personalized walking routes would be desirable, a precondition of which, however, is to derive detailed user profiles (Gartner et al. 2011, Jonietz 2016a).

In the context of personalized routing, historical GPS-trajectories of car drivers have been used to mine their individual preferences and restrictions (e.g. Letchner et al. 2006, Yang et al. 2015). This work, however, builds on a previous study which proposed to infer the infrastructural needs of individual pedestrians by extracting selected environmental properties of their previously visited areas, as identified from movement trajectories (Jonietz 2016a). Here, the focus is placed on gradually refining a user profile based on new input movement data, in particular the problem of handling new value inputs which, depending on their plausibility, might entail different procedures:

- an adaptation of the user profile (valid refinement or update of infrastructural need)
- an adaption of the context model (changed infrastructural need, however likely related to temporary contextual conditions, e.g. the weather or time of day)
- no action (implausible input value likely caused by measurement error)

Published in "Proceedings of the 13th International Conference on Location-Based Services", edited by Georg Gartner and Haosheng Huang, LBS 2016, 14-16 November 2016, Vienna, Austria.

Based on Jonietz (2016a), table 1 lists relevant pedestrian infrastructural needs which can be computed for each walking trip based on its trajectory and, if rated plausible, should be stored in a user profile for future personalized route calculation.

Feature	**Description**
maxBenchDist	max. walking distance between potential resting places
minBuildingDist	min. space needed for walking between buildings or other obstacles
maxVisibleAesthBuildings	visual exposure to aesthetical buildings (max. number of simultaneously visible aesthetical buildings)
maxLightDist	max. acceptable distance to the nearest streetlight
minCyclelaneDist	min. safety distance buffer kept to cycle lanes
minStreetDist	min. safety distance buffer kept to streets
maxHeight	max. step height (relative height difference)
maxSlope	max. acceptable slope
maxVisibleStreet	visual exposure to street traffic (normalized max. amount of visible street)
minSurface	min. acceptable surface quality type of footpaths
maxVisibleTrees	visual exposure to urban greenery (max. number of simultaneously visible trees)

Table 1. Features to be Extracted from Movement Trajectories

For refining a user profile, checking the plausibility of new value inputs is non-trivial. A new input value with regards to a hard restriction (e.g. the maximum tolerated slope), for instance, can either represent a valid new information about the user's capabilities, or simply be the result of uncertain positioning or errors in the underlying spatial data layers which, if erroneously being represented in the user profile, could result in the recommendation of routes which are in fact inaccessible. Furthermore, explicitly identifying the influence of temporary contextual factors, such as the time of day with regards to the feature *maxLightDist*, on behavioral adaptions would be desirable for a later context-aware routing.

For these purposes, we propose the general procedure as illustrated in figure 1. First, in a heuristics-based noise filtering step, the focus is put merely on the geometric characteristics of the raw input tracking data. In a velocity-based filtering, the travel speed between consecutive tracking points is computed, and, if it exceeds a predefined realistic threshold value for pedestrian movement, filtered accordingly (c.f. Zheng 2015). In a second filtering step, an overlay procedure is employed in a Geographic Information System (GIS) to identify and delete all tracking points which are located outside of the walkable area, and therefore clearly due to positional error.

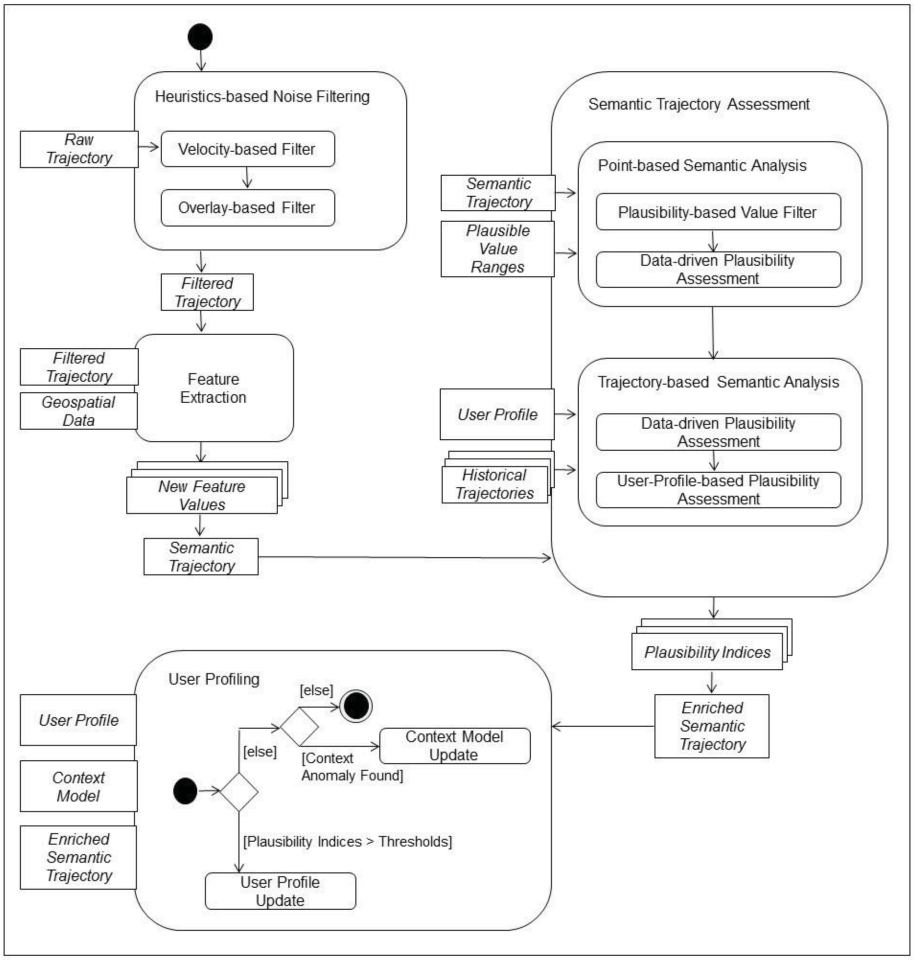


Figure 1. General Framework for Handling Input Data

Then, as described in Jonietz (2016a), the new feature values are calculated by overlaying with pre-computed raster layers for each environmental attribute as listed in table 1, extracting the underlying values and attributing the property values to the tracking points. These semantically enriched trajectories are then assessed for their plausibility. This procedure is based on the following assumptions:

- the new value must lie within a predefined range of plausible domain values

- the larger the deviation of a new value from the corresponding values of the temporal neighbors of its respective tracking point, the lower its plausibility

- the larger the deviation of a new value from all previously recorded values for this user (historical trajectories), the lower its plausibility

- the larger the deviation of a new value from the one currently stored in the user profile, the lower its plausibility

The first assumption guides the implementation of a plausibility-based value filter, which filters tracking points with feature values outside of predefined plausible ranges, e.g. slope values above 40%. In the following step, a sliding window approach is used to compare each feature value with the corresponding values of its temporal neighbors, meaning all preceding or subsequent tracking points within a certain time interval, and compute according outlier scores (c.f. Chandola et al. 2009). Points with scores exceeding a preset threshold are filtered from the dataset. This step is motivated by the general assumption that the location of temporally adjacent tracking points should be set in comparable environmental conditions, which, however, clearly depends on the temporal resolution of the position measurements.

After the level of the individual tracking points, the trajectory as a whole is examined. First, the index values as shown in table 1 are computed. Then, in a data-driven plausibility assessment, the derived values for each trajectory are compared to the movement history of the same user, i.e. the entire set of his or her previously recorded trajectories. Comparable to the previous step, an outlier or plausibility score is calculated for each trajectory based on the relative deviation of its index values with regards to the whole set. At this stage, however, no filtering takes place, but instead, the computed plausibility scores are attributed to the respective trajectories. A second score is calculated in the final step of user-profile-based plausibility scoring, where the deviation of the index values of each trajectory with regards to the values currently stored in the user profile is assessed.

The semantic trajectories, further enriched with the plausibility scores, finally provide the input for the user profiling process, where a threshold-based decision process evaluates whether to update the user profile based on a preset ruleset, check for possible explaining anomalies in the contextual data (e.g. weather data at time of walking) and, if necessary, update the context model, a step which is currently omitted, or disregard the new value as a probable measurement error. In an iterative process, thus, the user profile can be further refined and updated with regards to new input data.

At the present stage, the described framework has been implemented in Python, and tested with a set of movement trajectories derived from an agent-based pedestrian simulation which is further described in Jonietz (2016b), and features virtual pedestrians with differing infrastructural needs. In the context of this study, the simulation model has been extended to include simulated positional errors of the tracking mechanism. The generated trajectories and user profiles are stored in a PostGIS database. In this preliminary testing scenario, the proposed method shows promising potential for filtering inaccurately positioned tracking points as well as derive the individual infrastructural needs of pedestrian agents. For future work, it is planned to implement the context model updating process, test the model with real pedestrian data, as well as embed it within a personalized pedestrian routing system. In this context, the quality of the derived user profile could be assessed by comparing the recommended routes with the actual choice a user made, and use this evaluation for further refining the sketched procedure.

References

Chandola V, Banerjee A, Kumar V (2009) Anomaly detection: A survey. ACM Computing Surveys 41(3): 15

Gartner G, Huang H, Millonig A, Schmidt M, Ortag F (2011) Human-centered mobile pedestrian navigation systems. Mitteilungen der Österreichischen Geographischen Gesellschaft 153: 237-250

Jonietz D (2016a) Personalizing walkability: a concept for pedestrian needs profiling based on movement trajectories. In: Sarjakoski T, Santos MY, Sarjakoski LT (eds) Geospatial data in a changing world. Springer, Heidelberg, 279-297

Jonietz D (2016b) From space to place: A computational model of functional place. Doctoral thesis. University of Augsburg, Germany.

Letchner J, Krumm J, Horvitz E (2006) Trip router with individualized preferences (TRIP): incorporating personalization into route planning. In: Porter B (ed) Proceedings of the 18th conference on Innovative applications of artificial intelligence - Volume 2 (IAAI'06), AAAI Press, 1795-1800

Millonig A (2006) Routennetze für mobile Fußgänger-Navigationsanwendungen: ein neuer Ansatz für die Optimierung auf Basis von quantitativen Bewegungsdaten. In: CORP 2006, Vienna, Austria

Saelens BE, Sallis JF, Frank LD (2003) Environmental correlates of walking and cycling: Findings from the transportation, urban design, and planning literatures. Annals of Behavioural Medicine 25(2):80-91

Yang B, Guo C, Ma Y, Jensen CS (2015) Toward personalized, context-aware routing. The VLDB Journal 24(2): 297-318

Zheng Y (2015) Trajectory data mining: An overview. ACM Transactions on Intelligent Systems and Technology 6(3): 29

Narrative Extraction through the Detection and Characterisation of National and Local Events

Nicholas Bennett, David Millard, David Martin

University of Southampton

Extended Abstract

1. Introduction

Social media are popular forms of information dissemination with users potentially accessing an audience numbering in the millions. With the power and popularity of smartphones and other GPS-enabled smart devices, the creation and widespread publication of user-generated location-based content has rapidly grown in recent years. Twitter, a key platform in this trend, has been extensively researched by academics in the past (Crooks et al., 2013; Hamed, 2014); however, the frequency of location information is increasing and the ability to extract it from the text-based data to understand human activity, mobility and events is a key field for academics both from the data-driven and sociological disciplines. Furthermore, mapping companies interested in real-time change and event data would also benefit from a concise understanding of these aspects. The work defines "event" as a union of Pohl et al. (2012), Dou et al. (2012) and Smith et al. (2015)'s definitions: an activity taking place within a physical location that has a social representation. This definition covers such events as music festivals, pop-up markets and other transient geospatial activities.

Existing data-driven event detection and classification methods focus heavily on large-scale events, aiming to extract location information from human reactions to earthquakes, floods and other natural disasters (Sakaki et al., 2010). Recent work has refined these two methods of analysing street-level data (Middleton et al., 2014; Smith et al., 2015); however, the field is still

Published in "Proceedings of the 13th International Conference on Location-Based Services", edited by Georg Gartner and Haosheng Huang, LBS 2016, 14-16 November 2016, Vienna, Austria.

very new and in much need of further development. With the increase in number of services that monetise location-based understanding, there is a vested interest in researching the area.

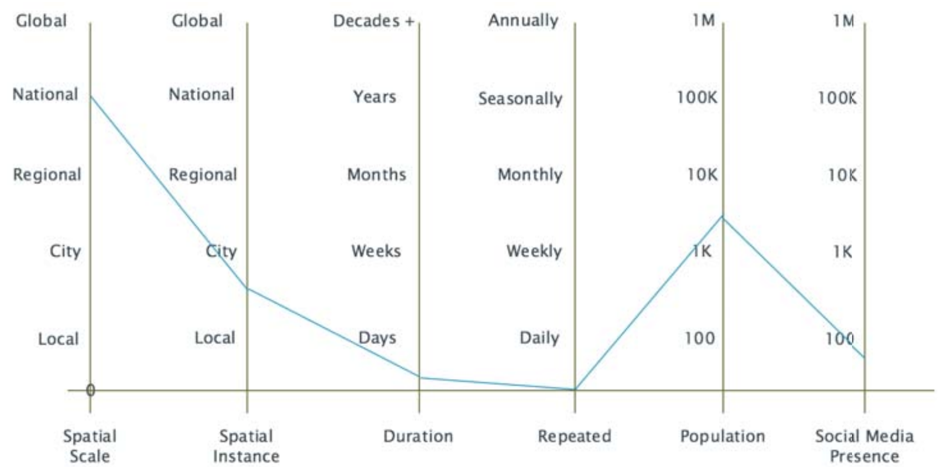


Figure 1: The parallel coordinate graph enables classification of social events. A small music festival example has been plotted.

2. Methodology

Collecting and analysing social media data includes significant linguistic problems, namely discovery of relevant terms and extraction of event descriptions. To mitigate against this, the project captures geolocated tweets from Southampton by applying coordinates to the Twitter API request parameters to obtain over 330,000 tweets from the 9th-20th June 2016. Whilst this method gathers significantly more data than a keyword search, it avoids keyword bias and allows for spontaneous hashtags and peripheral connections to be captured; however, it does include location bias (such as densely populated cities naturally producing more data) but as it is a relatively small boundary box search the results are not limited to Twitter's 1% feed.

A parallel coordinate model is proposed as appropriate for modelling social events (seen in figure 1). The model allows for the representation of several aspects of social events. This permits distinct multivariate profiles for different types of events to aid in their classification, as well as narrowing the scope of applicable events.

To test the model, UK-based event-related BBC News articles are taken as ground truth and applied to the axes. The Twitter data is first analysed for its popular topics and then searched for discussions about the related BBC News events.

3. Preliminary Results

The preliminary results show a discrepancy between nationally important news and topics of interest to the local population. There are often news articles of assumed importance that have no Twitter reflection at all. However, there are certain topics such as the shooting of MP Jo Cox that prominently feature in both the BBC News articles and the Twitter data. Therefore, whilst some news articles are assumed to have national social significance, local interests often differ.

4. Future Work

Only detecting the presence of a social event, however, does not create a holistic understanding. Dynamic sentiment analysis aids in creating a rich, semantic impression of a location. This work aims to extract sentiment for a particular area not only to understand what users are doing but how they are doing it, with whom and how they are feeling at the time. The overlay of narratives onto a physical location adds a new dimension to existing practises. More work is needed to verify these event detection methods such as automatically integrating other social media and web resources to form a consensus, and to incorporate rigorous natural language processing to differentiate between event and non-event related data. Once accurate information is extracted, the Twitter data can be used to plot the event profile without the use of a ground truth article.

The output of this project will be a change and event detection algorithm that pulls social media and web data to create a verified database of semantically rich location information. This methodology will aid in improving existing practises and offer accurate, reliable, real-time change and event information to interested parties.

References

Crooks A, Croitoru A, Stefanidis A, Radzikowski J (2013) #Earthquake: Twitter as a Distributed Sensor System. Transactions in GIS, 17(1), 124–147.

Dou W, Wang X, Ribarsky W, Zhou M (2012) Event Detection in Social Media Data. IBM Almaden Research Center, (pp. 2–5).

Hamed A (2014). An Exploratory Analysis of Twitter Keyword-Hashtag Networks and Knowledge Discovery Applications. Doctoral dissertation, University of Vermont.

Middleton S E, Middleton L, Modafferi S (2014) Real-time crisis mapping of natural disasters using social media. IEEE Intelligent Systems, 29(2), 9–17.

Pohl D, Bouchachia A, Hellwagner H (2012) Automatic sub-event detection in emergency management using social media. Proceedings of the 21st international conference companion on World Wide Web - WWW '12 Companion, (pp. 683).

Sakaki T, Okazaki M, Matsuo Y (2010) Earthquake shakes Twitter users: real-time event detection by social sensors. WWW '10: Proceedings of the 19th international conference on World wide web, (pp. 851).

Smith L, Liang Q, James P, Lin W (2015) Assessing the utility of social media as a data source for flood risk management using a real-time modelling framework. Journal of Flood Risk Management.

Method for Construction of Spatial Sentiment Lexicon using Place Reviews: Case Study on Theme Parks

Youngmin Lee*, Mikyeong Moon**, Inyoung Chae*, Kiyun Yu*, Jiyoung Kim*

* Seoul National University; daldanka@snu.ac.kr; ciy5164@snu.ac.kr; kiyun@snu.ac.kr; soodaq@snu.ac.kr
** National Information Society Agency, mkmoon@nia.or.kr

Extended Abstract

With the development of GPS (global positioning system) technology and smart devices, the use of location-based services is constantly increasing. As the use of this technology increases, reviewing and grading places through the use of location-based services has also become a common practice among users. Previous reviews of a place can significantly affect their potential visitors. A user-created review is the result of a visitor's actual positive or negative sentiment expression, and the sentiment could be expressed as a positive, negative, or neutral opinion.

In order to perform sentiment analysis, each word should be separated by its POS (part-of-speech) through natural language processing. To do this, a database of features for place and spatial sentiment words should be constructed. In the past, sentiment analysis has been used mainly for product reviews (Chang 2009, Hu & Liu 2004, Myung et al 2008, Scaffidi et al). No spatial sentiment lexicon for sentiment analysis of places has been constructed yet. Specifically, Hangeul lacks in terms of research on sentiment word analysis, compared to English. Hangeul, unlike English, has complicated characteristics and is composed of complex adjectives and suffixes (Jang et al. 2015).

Therefore, in this study, we propose a method to construct a spatial sentiment lexicon using place reviews written in Hangeul. In this study, we focused primarily on a “theme parks’ out of the many possible place categories. Although the general polarity (positive, negative, or neutral) of senti-

LBS 2016
13th Conference on Location-Based Services
Vienna, 14–16 November 2016

Published in “Proceedings of the 13th International Conference on Location-Based Services”, edited by Georg Gartner and Haosheng Huang, LBS 2016, 14-16 November 2016, Vienna, Austria.

ment for a place is important, analyzing the polarity for a specific place property, according to certain place categories is also valuable. We construct a spatial sentiment lexicon in accordance with each category of a place because the properties of a place and the language around the place changes according to the characteristics of the place. Accordingly, in this study, we preferentially constructed a spatial sentiment lexicon for a theme park. Other types of spatial sentiment lexicon could be constructed using the same methodology.

Generally, sentiment words written in Hangeul are represented by adjectives such as 'good', 'nice', and 'beautiful'. However, in this research, we included verbs such as 'crowded', 'take a rest', and 'take a walk' in order to consider other types of words describing the places. In addition, nouns representing a sentiment for a place such as 'recommendation', 'satisfaction', and 'disappointment' were also included as candidates for spatial sentiment words.

The following three aspects were considered in the construction of a spatial sentiment lexicon. First, the polarity of the sentiment word is analyzed. To do this, we calculated sentiment polarity and probability using the results of our survey. Second, it should be taken into account that some sentiment words are associated with properties of a place. For example, 'many' or 'little' could be positive or negative sentiments depending on the place. For example, 'green' could have a positive implication when paired with 'many', but 'people' could have negative connotation with the same word. In this case, the survey was carried out using a combination of spatial features and predicate configuration. Lastly, the spatial features and predicate characteristics of a place should be classified. We defined the combination of the spatial feature and the predicate as the 'spatial feature sentence'. By considering these characteristics, we designed the spatial sentiment lexicon to manage the meaning of sentiment words separately, according to the place categories.

The work flow used in this study is shown in *Figure 1*. The list of POIs (points-of-interest) was collected through Naver map search. Then, the place reviews for the POIs were collected through Google maps API. The analysis of place reviews were collected from the Google map API as follows. First, morpheme analysis through natural language processing for the reviews was implemented. Second, the morpheme was converted to a POS-tagging word; at this time, noun, adjective, and verbs were extracted as the candidates for spatial sentiment words. Third, the polarity and probability of the sentiment words were calculated by the survey conducted using the candidate of spatial sentiment words. Finally, the combination spatial feature sentence was created and the probability of sentiment is calculated using the result of the survey.

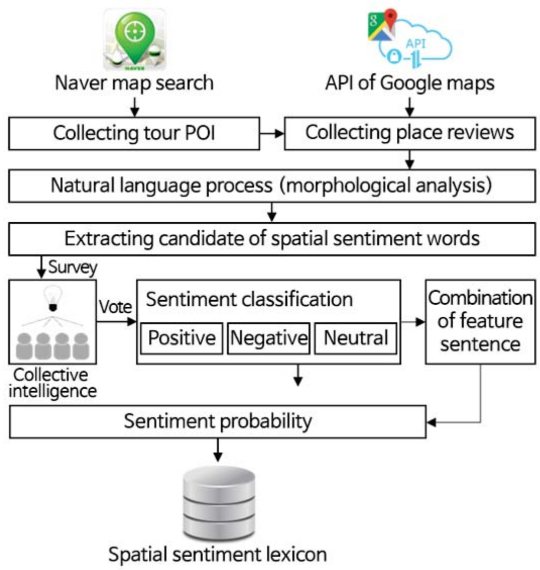


Figure 1. Research workflow.

For the experiment, we collected 118 search results of places within 'Seoul theme park' from the Naver map. We then collected 80 location IDs and matched them with 118 location names using the Google map API (application programming interface). Then, we collected 80 place reviews corresponding to the ID using details from the Google places API. As a result, we collected 204 reviews for 63 locations. We did not collect the remaining 17 reviews because they did not have reviews or there was no return value through the API.

We conducted a survey using the words extracted through morpheme analysis for location reviews collected through Google maps. The survey consisted of 150 questions. Possible responses were positive, negative, neutral, or inappropriate for words describing a place. We received more than 50 responses for the 150 questions. As a result, we calculated whether each word had a positive (+1), negative (-1), or neutral (0) polarity. The probability for sentiment of 16 nouns, 73 adjectives, 25 verbs, and 24 spatial feature sentences was found. The 12 words that were determined as inappropriate descriptors for representing a location were excluded from the spatial sentiment lexicon. Moreover, the spatial sentences were composed using the calculated results from the survey (*Table 1*).

Spatial sentiment words	POS	Sentiment polarity	Probability
'Recommendation'	Noun	Positive (+1)	1.000
'Inappropriate'	Noun	Negative (-1)	1.000
'Quiet'	Adjective	Positive (+1)	0.558
'Walk'	Verb	Neutral (0)	0.660
'People', 'Numerous'	Noun, Adjective	Neutral (0)	0.764
'Exercise', 'good'	Verb, Adjective	Positive (+1)	1.000
…	…	…	…

Table 1. Part of the spatial sentiment lexicon.

The spatial sentiment lexicon could be utilized as a reference when performing sentiment analysis on the contents of various social media platforms, and could offer useful information to those who want to visit a place. In future work, we will study a method used to extend the lexicon by adding synonyms for pre-constructed sentiment words, as well as a methodology to analyze syntax more precisely through a combination configuration of spatial feature sentences.

Acknowledgement

This research, "Geospatial Big Data Management, Analysis and Service Platform Technology Development," was supported by the MOLIT(The Ministry of Land, Infrastructure and Transport), Korea, under the national spatial information research program supervised by the KAIA(Korea Agency for Infrastructure Technology Advancement) (16NSIP-B081011-03).

References

Chang J (2009) A sentiment Analysis Algorithm for Automatic Product Reviews Classification in On-Line Shopping Mall. 14(4):19-33

Hu M, & Liu B (2004) Mining and Summarizing Customer Reviews. In proceedings of the tenth ACM SIGKDD international conference on Knowledge discovery and data mining. 168-177

Myung J, Lee D, & Lee S (2008) A Korean Product Review Analysis System Using a Semi-Automatically Constructed Semantic Dictionary. Journal of KIISE:Software and Applications. 35(6): 392-403

Jang K, Park S, & Kim W (2015) Automatic Construction of a Negative/positive Corpus and Emotional Classification using the Internet Emotional Sign. Journal of KIISE. 42(4):512-521

Scaffidi C, Bierhoff K, Chang E, Felker M, Ng H, & Jin C (2007) Red Opal: Product-Feature Scoring from Reviews. In proceedings of the 8th ACM conference on Electronic commerce. 182-191

Analysis of Preference of Tourist Destination using Twitter: Case Study on Theme Park in Seoul, South Korea

Inyoung Chae*, Jiyoung Kim*, Youngmin Lee*, Kiyun Yu*

* Seoul National University; ciy5164@snu.ac.kr; soodaq@snu.ac.kr ; dal-danka@snu.ac.kr; kiyun@snu.ac.kr

Extended Abstract

Recently, the number of travel-related texts posted by SNS users has increased and studies have been conducted to analyze them for the purpose of recommending meaningful tourist destinations for tourists.

However, existing studies do not consider cases where the contents include complaints about a destination because they consider only the frequency of destination mentions. Therefore, the results of the studies may not always recommend destinations that tourists actually prefer. Therefore, in this study, we quantified the preference for tourist destinations by considering positive and negative opinions about the destination mentioned in the SNS.

The subjects of this study were 118 theme parks that are tourist destinations in Seoul, the capital of South Korea. The subjects were selected from the re sults obtained after searching for the terms 'theme park in Seoul' using the POI search function in Naver map, a representative map of South Korea. A mong the 138 search results obtained, we removed several POIs that were n ot theme parks. Afterward, 118 theme park POIs were used for the study. S NS data used in this study comprised of Twitter posts collected by using the open API based on REST. We collected data from 22 July 2015 to 26 Februa ry 2016. After de-duplication, 273,515 posts were used in this study. Therefo re, in this study, we calculated the frequency of theme park mentions in the text of the aforementioned Twitter data and the preference for the theme pa rks in Seoul using sentimental analysis.

In order to quantify the preference for the theme parks, we first created a co rpus from collected Twitter data and removed stop words. Second, we extra cted Twitter texts containing theme park POIs among 273,515 Twitter data. A total of 1,674 Twitter texts were extracted, and the number of theme park

Published in "Proceedings of the 13th International Conference on Location-Based Services", edited by Georg Gartner and Haosheng Huang, LBS 2016, 14-16 November 2016, Vienna, Austria.

POIs mentioned more than once in the text was 38. Third, morphological a nalysis for natural language processing was conducted.

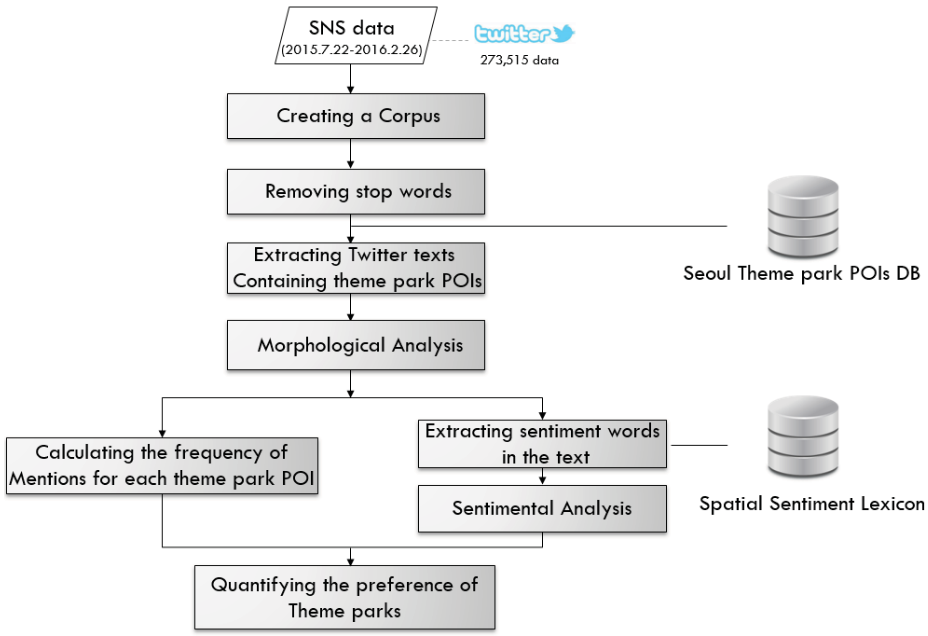


Figure 1. Research workflow

Next, we calculated the frequency of mentions for each theme park POI. We also analyzed the sentiment expressed in the extracted text to identify posit ive and negative opinions about the theme park POIs. Here, in order to anal yze the sentiment about the theme park, sentiment word describing places s uch as 'quiet or crowded' should be extracted. Thus, by utilizing existing spa tial sentiment lexicon such as in *Table 1*, we classified the sentiment present ed in the Twitter text as positive, neutral, or negative.

Spatial sentiment words	POS	Sentiment polarity	Probability
Recommendation	Noun	Positive (+1)	1.000
Best	Noun	Positive (+1)	1.000
Pleasant	Adjective	Positive (+1)	1.000
Noisy	Adjective	Negative (-1)	0.976

Table 1. Example of Spatial Sentiment Lexicon

At this point, in order to consider the context in the text, we conducted senti mental analysis by dividing the sentences expressing sentiments about the me parks into three types as shown in *Table 2*.

Type	Subject	Negatives	Predicate	Example
1	Theme park POIs	not	Sentiment word about places (adjective, verb, noun)	Lotteworld, (not), good
2	Spatial feature	not	Sentiment word about places (adjective, verb, noun)	Street, (not), pretty
3	Spatial feature	not	'many' or 'little'	flower, (not), many

Table 2. Types of sentences for sentimental analysis

The first type consists of sentences expressing sentiments about theme park POIs. The second type consists of sentences expressing sentiments about the spatial feature indicating the properties of the theme park such as 'street' and 'atmosphere'. The last type consists of sentences that can be either positive or negative when used with the terms 'many' or 'little' regarding the same spatial feature. In other words, 'uphill' can have a negative implication when used with 'many', while having a positive implication with 'little'. *Table 3* below shows an example of Twitter text of the second type.

Twitter text	Spatial feature	Sentiment word
I have a test tomorrow, but Lotteworld Christmas atmosphere is very good!	Atmosphere	good

Table 3. Example of Twitter text of the second type

Finally, we quantified the preference by using the frequency of mentions for each theme park POI and the results of sentimental analysis. The result is shown in *Table 4*.

Rank	Theme park POI	Preference	Rank	Theme park POI	Preference
1	Lotteworld	18000.25	6	Worldcup Park	209.55
2	Olympic Park	11506.96	7	Yeouido Hangang Park	148.00
3	Children's Grand Park	545.00	8	Namsan Park	66.00
4	Dosan Park	291.95	9	Children's Park	38.00
5	Dongdaemun History & Culture Park	248.00	10	Noeul Park	27.00

Table 4. Part of the preference results for theme parks in Seoul

'Lotteworld,' which had the highest preference, is a typical amusement park in Seoul. Therefore, it was mentioned many times in Twitter and had a high score in the results of sentimental analysis. In addition, 'Dosan Park,' which had the fourth highest preference, is notable because it had higher preference than 'Yeouido Hangang Park,' regarded as a representative park in Seoul. In other words, many positive opinions about 'Dosan Park' appeared in Twitter. These results may provide useful information for tourists who want to visit the park on the first trip to Seoul. Furthermore, we may help tourists to plan a travel route by analyzing the preference for various types of tourist destinations.

Acknowledgement

This research, "Geospatial Big Data Management, Analysis and Service Platform Technology Development," was supported by the MOLIT (The Ministry of Land, Infrastructure and Transport), Korea, under the national spatial information research program supervised by the KAIA (Korea Agency for Infrastructure Technology Advancement) (16NSIP-B081011-03).

References

Myung, J. S., Lee, D. J. & Lee, S. G. (2008) A Korean product review analysis system using a semi-automatically constructed semantic dictionary. Journal of KIISE: Software and Applications, 35(6): 392-403

An, J., Kim, H. W. (2015) Building a Korean Sentiment Lexicon Using Collective Intelligence. Journal of Intelligence and Information Systems, 21(2): 49-67

Ranking the City: The Role of Location-Based Social Networks in Collective Human Mobility Prediction

O. R. Abbasi, A. A. Alesheikh

K. N. Toosi University of Technology, Department of GIS Engineering, Faculty of Geodesy and Geomatics Engineering, Tehran, Iran.

Extended Abstract

Technological advances have led to increasing development of data sources. Since the introduction of social networks, numerous researches on the relationships between users and their behaviors have been conducted. Location-based social networks (LBSN) have provided the possibility of studying the relationships between users and places. Today, due to the wide availability of various spatial data sources, the long-standing field of collective human mobility prediction has been revived and some new models (e.g. population-weighted opportunities, radiation, and rank-based models) have been introduced. There are two major assumptions in modeling the human mobility patterns. Some models (e.g. gravity model) assume that trips are directly related to the distances between origins and destinations. In other words, the more the distance between an origin and a destination, the lower the probability of traveling from the origin to that destination (Zipf 1946). However, some models explain the human mobility using "*opportunities*" concept. These models assume that trips are not directly related to distance, but induced by opportunities provided at destination (Stoufer 1940). Recently, a parameterized model of predicting human mobility in cities, known as rank-based model, was introduced (Noulas et al. 2012). The model predicts the flow from an origin toward a destination using "*rank*" concept. In fact, each destination has a rank, with respect to the origin, that expresses the probability of going from a region to another. However, the question that "*how the rank should be computed?*" is not well answered yet. In this paper, we explore the potential of LBSN data alongside the rank-based model in predicting human mobility patterns in Manhattan, New York City.

LBS 2016
13th Conference on Location-Based Services
Vienna, 14–16 November 2016

Published in "Proceedings of the 13th International Conference on Location-Based Services", edited by Georg Gartner and Haosheng Huang, LBS 2016, 14-16 November 2016, Vienna, Austria.

According to the rank-based model, given a set of zones $u \in U$ in a city, the probability of moving from zone $u \in U$ to a zone $v \in U$ is defined as (Noulas et al. 2012)

$$P[u \to v] \propto \frac{1}{rank_u(v)^{\gamma}} \quad \text{(Eq. 1)}$$

where $rank_u(v)$ is the rank of zone v relative to zone u and γ is an adjustable parameter. Assuming that the total number of trips generated in each zone T_u is known, trip distribution matrix can be computed as (Yan et al. 2014)

$$T_{uv} = T_u \frac{rank_u(v)^{-\gamma}}{\sum_{k \neq u}^{N} rank_u(v)^{-\gamma}} \quad \text{(Eq. 2)}$$

where N is the total number of zones in the city.

Rank-based model, in contrast to the well-known gravity model, uses rank-distance rather than spatial distance. Because people and their behaviour, as the most important components in mobility, are neglected in this approach (i.e. using distance alone to rank the zones), the resulted mobility patterns always remain unchanged. In this paper, we consider three methods to compute the ranks in the city using rank-distance and LBSN data. These methods include: 1) computing the rank using rank-distance; 2) considering the rank as the number of venues located in a circle centered at the destination with a radius equal to the distance between the origin and destination ; 3) using a check-in weighted rank concept in the model. Since the rank-based model is parameterized, a repetitive procedure is needed to determine the adjustable parameter. In this paper, the method introduced by Hyman (1969) was employed to minimize the difference between the real average travel distance and modeled average travel distance. Moreover, since the rank-based model presented in (*Eq. 1*) does not guarantee the equality of real and predicted attracted trips, a balancing process called Furness is applied on the matrix. In this paper we considered Manhattan's census tracts as trip zones. The zones and distribution of venues are shown in *Figure 1*.

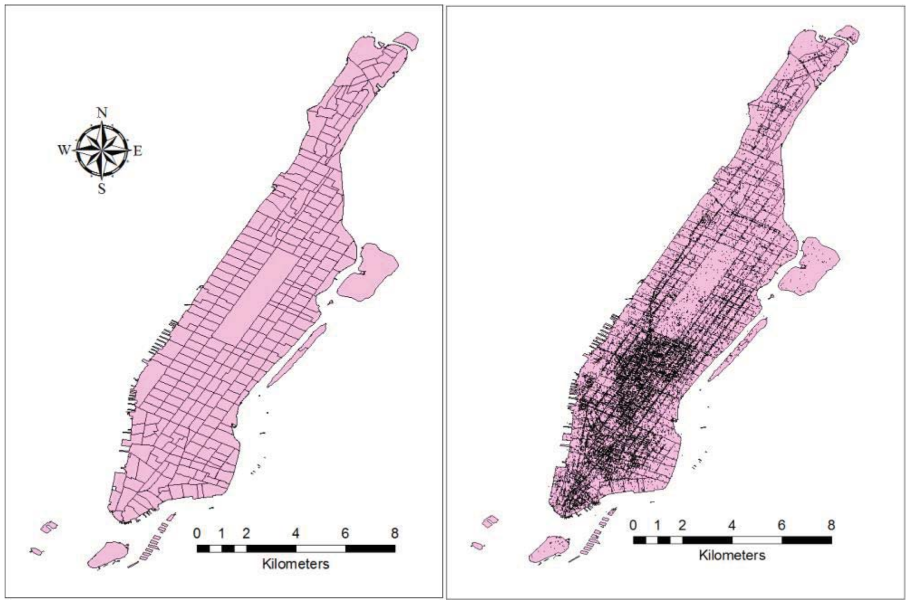


Figure 1. Distribution of venues (right) and census tracts (left) in Manhattan.

In order to evaluate the results obtained from the model and compare the rank concepts, GPS traces of taxi vehicles over Manhattan were used. Following the work of Kang et al. (2015), the Sorensen Similarity Index (SSI) was used as a measure of similarity between real and predicted trip distribution matrices. This index ranges from 0 to 1 where numbers closer to 1 indicate more similarity between two matrices. *Figure 2* presents a comparison among the performances of ranks in the model based on SSI.

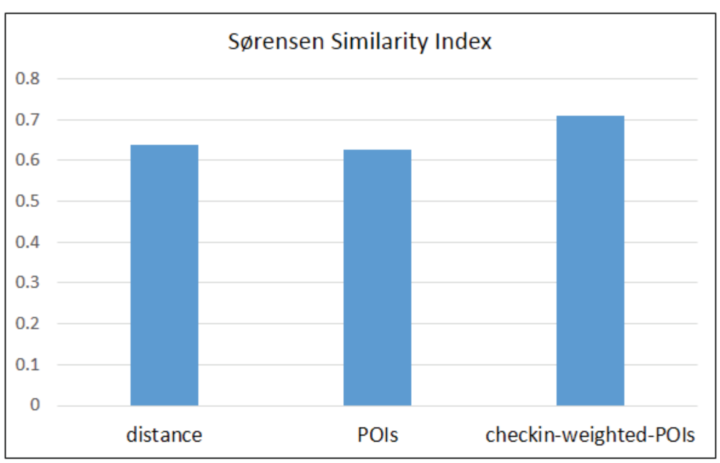


Figure 2. Evaluation of resulted trip distribution matrix based on Sorensen Similarity Index

Figure 2 indicates that using a check-in-weighted rank will result in slightly more similar predictions to reality. In order to have a statistical measure of how close the predicted data are to the real data, we determined R^2 value form regression analysis. The identity line is considered as the ideal case, where all the predicted trips are equal to real trips. *Figure 3* compares the results in terms of R^2.

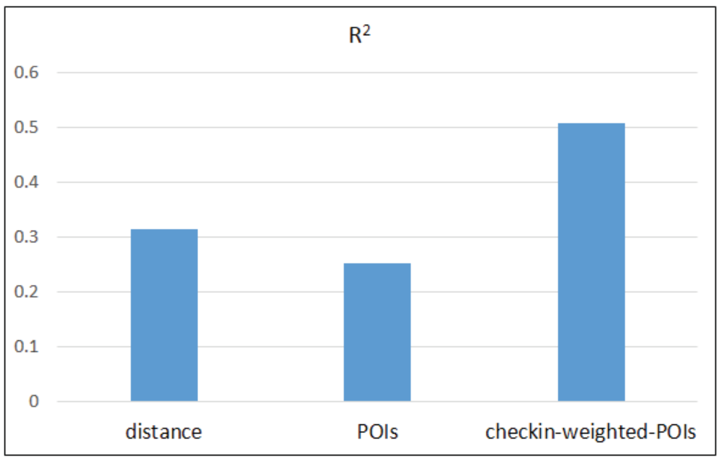


Figure 3. Evaluation of resulted trip distribution matrix based on R-squared

As *Figure 3* illustrates, the value of R^2 for rank-based model along with a check-in-weighted rank concept has been increased. So, check-ins play a significant role in improving the predictability of mobility patterns.

Considering the rank as variables such as distance and number of POIs is somewhat objective in a way that they are not representing real specific conditions of a city. In other words, the concepts of distance and number of POIs are the same for all cities in the world. But, using check-in weights, a real dimension will be added to the model. Surely, the role of a crowded park in human mobility is not the same as a hotel, for example. Thus, applying check-ins occurred at each POI will result in closer predictions to reality.

Moreover, the dynamicity of human mobility could be accounted for. As the check-ins data are dynamic, they can consider the variations in people's interests and behaviors. Using check-ins, any change in land use of POIs is also accountable.

References

Kang, C., Liu, Y., Guo, D., & Qin, K. (2015). A Generalized Radiation Model for Human Mobility: Spatial Scale, Searching Direction and Trip Constraint. *PloS one, 10*(11), e0143500.

Noulas, A., Scellato, S., Lambiotte, R., Pontil, M., & Mascolo, C. (2012). A tale of many cities: universal patterns in human urban mobility. *PloS one, 7*(5), e37027.

Stouffer, S. A. (1940). Intervening opportunities: a theory relating mobility and distance. *American sociological review, 5*(6), 845-867.

Yan, X.-Y., Zhao, C., Fan, Y., Di, Z., & Wang, W.-X. (2014). Universal predictability of mobility patterns in cities. *Journal of The Royal Society Interface, 11*(100), 20140834.

Zipf, G. K. (1946). The P 1 P 2/D hypothesis: on the intercity movement of persons. *American sociological review, 11*(6), 677-686.

An Interactive System for Intrinsic Validation of Citizen Science Data for Species Distribution Mapping and Modelling Applications

Hossein Vahidi*'**[1], Brian Klinkenberg**, Wanglin Yan*

* EcoGIS Lab., Keio University, Japan
** Lab for Advanced Spatial Analysis, University of British Columbia, Canada

Abstract. This paper presents a conceptual model for assurance of the quality of species occurrence observations in citizen science projects. To this end, we adopted the notion of trust as an indicator of VGI quality and defined the concept of trustworthiness of VGI as a function of four main contexts: consistency with habitat, consistency with neighbors, consistency with the temporal life cycle of the species, and the competence and credibility of volunteers. In this sense, the quality of an observation is quantified in terms of the level of the trustworthiness of the submission by using fuzzy set theory. Moreover, the different possible ex-post and ex-ante architecture of the proposed system is briefly discussed to empower the end user (data consumer), expert reviewers, and volunteers (data producers) to perform more robust and precise VGI quality assurance practices. Finally, the paper ends with concluding remarks and some tips for future research directions.

Keywords. Volunteered Geographic Information (VGI), Citizen Science Data Quality Assessment, Species Distribution Mapping and Modelling

1. Introduction

In the current research trend on volunteered geographic information (VGI), much concern has been directed to the issue of data quality and validation of the crowdsourced data, focused on the issues of accuracy, credibility, and the possibility of vandalism in the crowdsourced data. The issue of VGI data quality assessment and evaluation has become very sensitive and vital, as we usually do not have access (or we have limited access) to the real-world data to collect the ground truth when the geographical and temporal dimensions of the data are relatively large.

In the context of ecological studies, the habitat of a species (plant or animal) is mapped and modelled by using the collected data on the species' presence (i.e., occurrence data), which include a sample of locations with known presence of the target species (Merow et al. 2013).

Conventionally, presence records are collected by experts and authoritative sectors to ensure the quality of the data; however, recently, because of the popularity of citizen science programs in ecological studies, non-experts are also enabled to contribute to the process of data collection through participation in VGI and citizen science projects for biodiversity/conservation observations (e.g., E-Flora, iNaturalist, and eBird). Legions of citizen scientists record their

[1] Corresponding author (E-mail: vahidi@sfc.keio.ac.jp)

Published in "Proceedings of the 13th International Conference on Location-Based Services", edited by Georg Gartner and Haosheng Huang, LBS 2016, 14-16 November 2016, Vienna, Austria.

observations of all types of species by identifying and recording the location of the observed species as well as other relevant attributes and meta data about the target species (e.g., taxon, time of observation).

Various factors, such as uncertainties in the measurement of the spatial component of observations by amateur naturalists, the complexity of taxonomy and species identification by non-experts, different understandings of the concept of quality from experts' and non-experts' points of view and diverse motivations, and the knowledge level and background of the participants in citizen science projects, may trigger questions about the quality of VGI data in biodiversity observation projects (Ali and Schmid 2014). To control the quality of the crowdsourced data in the context of citizen science projects, several approaches have been implemented and tested in previous practices.

Cross-referencing the VGI on species presence with the existing authoritative data, checking the consensus and agreement of reports at each location, and expert or community-based (by the participation of other volunteers) data quality control of the user submissions are the most popular approaches adopted for data quality assurance in citizen science biodiversity observation projects (Goodchild and Li 2012).

Nevertheless, the lack of authoritative data in the biodiversity domain and the existing uncertainties within the available datasets usually may avoid the use of the cross-referencing method in most VGI activities. However, when the spatio-temporal extent and the diversity of species are relatively large and there is a large data space in comparison with the number of active volunteers, not all localities in the study area may be observed frequently by the different participants, so the consensus-based approach to data quality assessment may not be applicable. Furthermore, the validation of all VGI submissions based on expert or community-based data quality control method could be very time and energy consuming (and costly in the case of using recruited experts) and mostly impractical, as the relative number of skilled human resources is usually limited, not all members of the community have the motivation or skill to participate in such a process, and sometimes there is not enough information for validation of the submission as well as the opportunity for in-situ data collection when it is applicable (particularly in wild and remote areas).

In this paper, we propose the general schema of an interactive system for intrinsic validation of VGI species occurrence datasets to reduce the dependence of data quality assessment processes on authoritative data as well as the participation of experts and the community in the process of VGI data quality control.

2. Related Work

One of the most common approaches for the assessment of the VGI quality is to compare VGI with ground truth reference datasets (i.e., authoritative dataset) (Barron et al. 2014). However, high-quality authoritative datasets for conducting extrinsic quality assessment are often not accessible/usable because of the lack of such data, costs, and licensing restrictions (Mooney et al. 2010) or the nature of the problem. Therefore, in cases where the direct cross-referencing approach is not applicable, researchers have explored more intrinsic approaches to evaluate the quality of VGI by using other proxies and indicators for quality measures (Senaratne et al. 2016).

Goodchild and Li (2012) discussed a geographic approach as an intrinsic VGI quality assurance method that relies on identifying rules that connect different information based on their location to evaluate whether an attribute of a VGI submission is reported correctly at a certain location.

The notion of trust has been used in a number of previous studies (Bishr and Janowicz 2010, Bishr and Mantelas 2008) as a proxy for data quality assessment of VGI contributions by making a link between the notion of spatial data quality and the established notion of interpersonal trust. It is expected that the trusted contributors provide more trustworthy VGI than less trusted ones (Yan et al. 2016). Thus, the trustworthiness of VGI can be substituted with traditional quality indicators of spatial data (e.g., completeness, logical consistency, and positional accuracy) (Yan et al. 2016), particularly when authoritative data are not available and the extrinsic quality assessment approach is not applicable.

Yan et al. (2016) presented a system to ensure the quality of VGI acquired for the means of species surveillance. In this system, they adopted trust as a proxy of VGI quality by defining trust as a function of the provenance of user expertise and the fitness of a submission according to geographic context. The quality of VGI is quantified in terms of the level of the trustworthiness of a submission by using fuzzy set theory.

Bordogna et al. (2016) broke down the existing adopted approaches for improving the quality of VGI by considering the time of their application as related to the time of VGI item creation into two main categories: ex-ante and ex-post. The former category refers to all quality assurance approaches that perform the quality improvement task before the creation (i.e., final submission) of VGI to prevent the creation of low-quality VGI. The latter category includes approaches in which the data quality improvement task is undertaken after the collection of VGI and a cleaning and enhancement activity is executed after the VGI is created (i.e., submitted) (Bordogna et al. 2014).

In the next section, we propose a conceptual framework for the intrinsic quality assessment of VGI in citizen science biodiversity projects using the trust notion as a proxy for data quality in the framework of both ex-ante and ex-post VGI quality management mainstreams.

3. Methodology and Conceptual Framework

A conceptual model is developed for the intrinsic quality evaluation of participants' observations in citizen science biodiversity projects.

In the simplest and non-interactive architecture of such a system, the observation records for a particular species are submitted to the system by non-expert volunteers who are participating in the citizen science project.

To ensure the quality of all the submitted data in database of such a project for the end user of the data (i.e., data consumers), we adopted the notion of trust as an indicator of VGI quality. In this context, we defined the concept of the trustworthiness of VGI as a function of four main contexts: consistency with habitat, consistency with neighbors, consistency with the temporal life cycle of the species, and the competence and credibility of volunteers (*Figure 1)*.

In the next sections, the four different components of VGI trustworthiness and the proposed rule-based fuzzy system to estimate the trustworthiness value will be briefly presented and the different possible architecture of the system will be discussed.

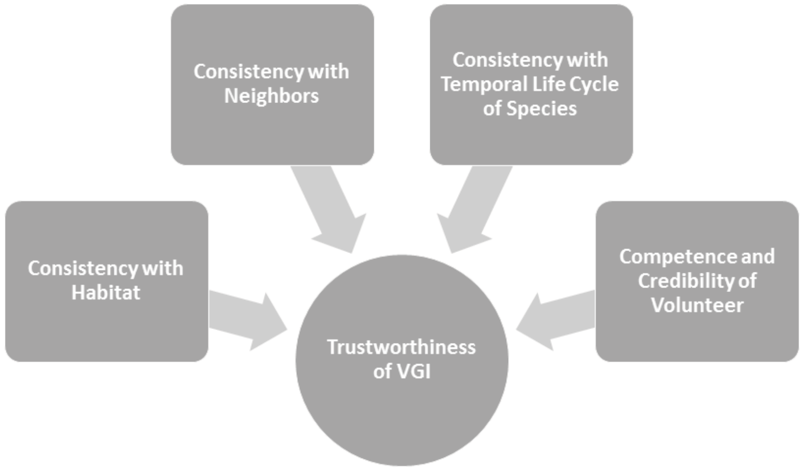


Figure 1. Components for the assessment of trustworthiness of the VGI in the proposed approach

3.1. Components and General Schema of the Proposed System for the Quality Assurance of Crowdsourced Species Occurrence Observations

To assess the validity of an observation (i.e., a purported report on the observation of a particular species at a certain location) in the database via the “consistency with habitat” metric, the submission is compared with a generated reference layer that indicates the suitability of the landscape at each location to be inhabited by a particular species or demonstrates the probability of the occurrence of a particular species at a particular locality. The generated reference layer is estimated by using an ecological niche modelling approach on the basis of estimating the similarity of the environmental conditions at unknown localities in the landscape to the environmental conditions (e.g., temperature, precipitation, and topography) at the locations of known occurrence of a species (Hijmans and Elith 2016). The few required occurrence records for training the ecological niche model can be adapted from authoritative sources (e.g., herbarium datasets) or high-quality crowdsourced datasets from previous projects. By cross-checking a purported species taxon that was reported by a contributor with the estimated possibility (or probability) of the occurrence of the species in that location on the generated reference layer, one can evaluate whether the reported taxonomy of the submission is plausible.

Nevertheless, as the results of ecological niche modelling approaches are error-prone, the proposed conceptual model is empowered by other intrinsic contexts for the evaluation of VGI submissions.

It is widely known that the occurrence of a particular species in the geo-graphical space is the function of the environmental conditions at that location in the landscape. Furthermore, according to the first law of geography (Tobler 1970), “everything is related to everything else, but near things are more related than distant things.” Hence, in the proposed conceptual model, the submissions that were tagged in the proximity of other submissions are considered more consistent with their neighbors and get higher scores.

Any species (plant and animal) has a particular temporal regime in its life cycle. For instance, it is widely known that flowers and seasons are closely related to each other and most flowers are season-specific, so they occur in specific time periods in the year. Or it is known that some animals go into hibernation during the cold winter months and wake up in the warm season. Thus, a purported observation has to be consistent with the temporal life cycle of the declared species.

The user's expertise and experience or the quality of previous contributions of a volunteer as well as the declared confidence in the quality of submissions by the volunteer could be indicators of the competence and credibility of the volunteer, and higher levels of these indicators increase one's expectation of higher levels of the trustworthiness of VGI.

Finally, to handle the uncertainties and ambiguities inherent in the four different trust indicators and to evaluate the quality of VGI in terms of the trust concept, we adopted a rule-based fuzzy system in the proposed conceptual model.

Figure 2 demonstrates the general schema of an automatic system for ensuring the quality of the observations of a particular species in a citizen science project. In this architecture, all the stored observations of the participants in the database of the system are evaluated in terms of the trustworthiness of records in an ex-post approach. Thus, if the trustworthiness of a record meets the minimum requirements of the end user (i.e., data consumer) that is characterized in terms of an acceptance threshold, it is reported to him/her as qualified data.

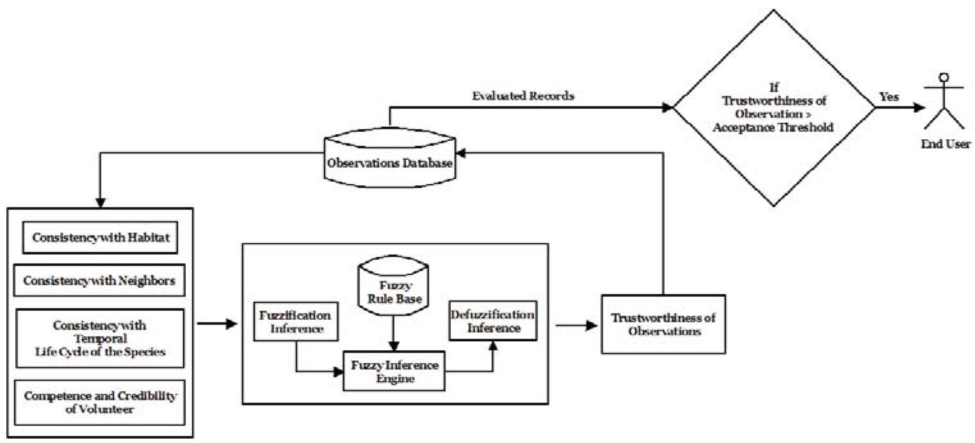


Figure 2. The proposed ex-post approach for the quality assurance of species occurrence observations in citizen science projects for the end user

3.2. An Ex-post Approach for Supporting Expert Reviewers in the Process of Quality Assurance

The proposed method can be utilized as a decision support system for empowering the expert reviewers who are in charge of the quality assurance task in a citizen science project. In the proposed ex-post approach, the trustworthiness of a single submission is evaluated, and if it does not meet the defined requirements of the experts, it is flagged for further manual review by the experts in the system (also, in a similar methodology, the estimated trustworthiness level of a submission can be used by the experts as an indicator of the quality of the VGI) (*Figure 3*). The suggested decision support system may help us to establish a semi-automatic VGI quality assurance system and reduce the workload of the expert reviewers and enhance the precision of the VGI quality assessment approach.

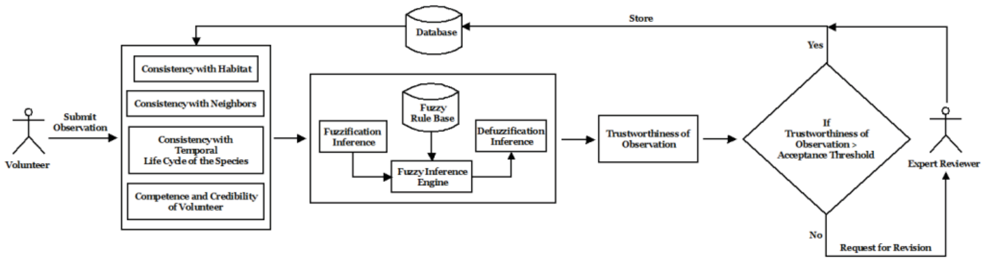


Figure 3. The proposed ex-post approach for supporting the expert reviewers for the quality assurance of species occurrence observations in citizen science projects

3.3. An Ex-ante Approach for Supporting Volunteers in the Process of Quality Assurance

Figure 4 shows the schema of an ex-ante representation of the proposed model for the quality assurance of species occurrence observations in citizen science projects. In this architecture, upon the submission of an observation by a volunteer, the system evaluates the trustworthiness of the submission during the entity creation process and before storing it in the database of the system and alerts the volunteer (i.e., data producer) to revise the submission if it does not meet the defined acceptance threshold for an observation. The volunteer receives feedback from the system interactively that enables him/her to evaluate the validity of his/her submission and modify it if it is applicable. Moreover, such a system encourages the user to learn more about the living environment and increase his/her expertise by its indirect training process.

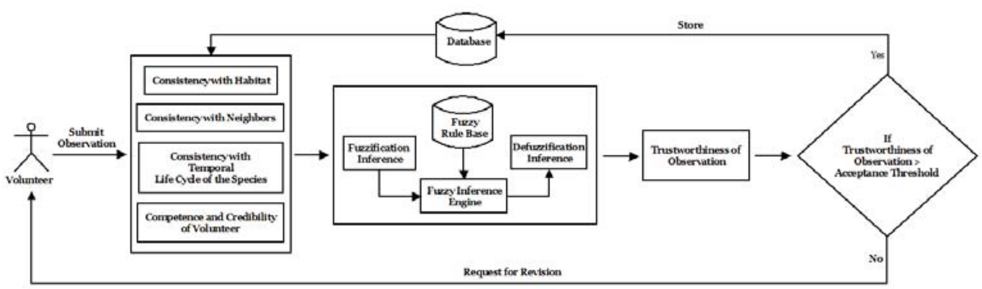


Figure 4. The proposed ex-ante approach for supporting the volunteer in producing qualified species occurrence observations in citizen science projects

4. Conclusion and Future Work

In this paper, we presented a conceptual model for the quality assurance of species occurrence observations in citizen science projects. To this end, we adopted the notion of trust as an indicator of VGI quality and defined the concept of the trustworthiness of VGI as a function of four main contexts: consistency with habitat, consistency with neighbors, consistency with the temporal life cycle of the species, and the competence and credibility of volunteers. In this sense, the quality of an observation is quantified in terms of the level of the trustworthiness of the submission by using fuzzy set theory.

Moreover, the different possible ex-post and ex-ante architectures of the proposed system were discussed to empower the end user (data consumer), expert reviewers, and volunteers (data producers) to perform more robust and precise VGI quality assurance practices.

The indicators of trustworthiness of VGI are not limited to the four aforementioned factors, so further investigation is required to define all the effective components of VGI trust in citizen science biodiversity observation projects.

Furthermore, in the proposed ex-post and ex-ante architectures for supporting the expert reviewers and volunteers in the process of VGI quality assurance, the completeness of the observation space is increased by increasing the number of submitted observations in the system over time. Thus, the consistency with neighbors rate for a submission might be changed by tagging more observations in the proximity of it. In addition, the first submitted observations may get a low value for the context of consistency with neighbors, as no observation was recorded in the proximity of them. Therefore, in future work, different options (such as enrichment of the data space by using existing authoritative sources or high-quality crowdsourced datasets from previous projects as well as defining the fuzzy rules in a dynamic approach) must be studied to address this issue.

In future steps, the two aforementioned ex-post and ex-ante architectures can be integrated with a recommender system to advise the expert reviewers and contributors to select the suitable taxon and scientific name for the observation at a certain locality.

References

Ali, A. L. and Schmid, F., 2014. Data Quality Assurance for Volunteered Geographic Information. *In:* Duckham, M.*, et al.* eds. *Geographic Information Science: 8th International Conference, GIScience 2014, Vienna, Austria, September 24-26, 2014. Proceedings*. Cham: Springer International Publishing, 126-141.

Barron, C., Neis, P. and Zipf, A. 2014. A Comprehensive Framework for Intrinsic OpenStreetMap Quality Analysis. *Transactions in GIS,* 18(6), 877-895.

Bishr, M. and Janowicz, K., Can we trust information?-the case of volunteered geographic information. ed. *Towards Digital Earth Search Discover and Share Geospatial Data Workshop at Future Internet Symposium, volume*, 2010.

Bishr, M. and Mantelas, L. 2008. A trust and reputation model for filtering and classifying knowledge about urban growth. *GeoJournal,* 72(3), 229-237.

Bordogna, G.*, et al.* 2014. A linguistic decision making approach to assess the quality of volunteer geographic information for citizen science. *Information Sciences,* 258, 312-327.

Bordogna, G.*, et al.* 2016. On predicting and improving the quality of Volunteer Geographic Information projects. *International Journal of Digital Earth,* 9(2), 134-155.

Goodchild, M. F. and Li, L. 2012. Assuring the quality of volunteered geographic information. *Spatial Statistics,* 1, 110-120.

Hijmans, R. J. and Elith, J., 2016. *Species distribution modeling with R* [online]. Available from: http://www.idg.pl/mirrors/CRAN/web/packages/dismo/vignettes/sdm.pdf [Accessed 07.09.2016.

Merow, C., Smith, M. J. and Silander, J. A. 2013. A practical guide to MaxEnt for modeling species' distributions: what it does, and why inputs and settings matter. *Ecography,* 36(10), 1058-1069.

Mooney, P., Corcoran, P. and Winstanley, A. C., 2010. Towards quality metrics for OpenStreetMap. *Proceedings of the 18th SIGSPATIAL International Conference on Advances in Geographic Information Systems*. San Jose, California: ACM, 514-517.

Senaratne, H.*, et al.* 2016. A review of volunteered geographic information quality assessment methods. *International Journal of Geographical Information Science*, 1-29.

Tobler, W. R. 1970. A Computer Movie Simulating Urban Growth in the Detroit Region. *Economic Geography,* 46(sup1), 234-240.

Yan, Y., Feng, C.-C. and Wang, Y.-C. 2016. Utilizing fuzzy set theory to assure the quality of volunteered geographic information. *GeoJournal*, 1-16.

Joining Spatial Visualization Tools with Social Media Data Using Free and Open Source Software

M. Zurbarán**, D. Oxoli*, C. E. Kilsedar*, P. Wightman**, M. A. Brovelli*

* Department of Civil and Environmental Engineering, Politecnico di Milano, Como Campus, Via Valleggio 11, 22100 Como
** Department of Systems Engineering, Universidad del Norte, Km 5 Via Pto. Colombia, Barranquilla, Colombia

Extended Abstract

The development of mobile technologies and its fast adoption by users promote virtual social activities and a growing dependence on location-based services for everyday tasks, i.e. accessing local news, finding a near shop, consulting transportation, etc. This phenomenon provides valuable digital footprint in a geographical context that was not possible in years before. In this work, the authors propose the use of crowdsourced georeferenced data from different social platforms along with a Web-based Geographic Information System (GIS) that visually communicates what is reported by social media users.

In the presented demo, data has been collected from Twitter and Foursquare since the beginning of 2016 focusing specifically on the Lombardy Region. Both, data collection and visualization are performed using only open data and Free and Open Source Software (FOSS), with the intention to keep it openly available for interested parties.

By combining different resources available, it is now possible to identify concentrations of Points of Interest (POIs) in real time and understand how these change over time using date ranges for filtering. This provides valuable insights related to important phenomena in the region (i.e. comparison of the behavior on

Published in "Proceedings of the 13th International Conference on Location-Based Services", edited by Georg Gartner and Haosheng Huang, LBS 2016, 14-16 November 2016, Vienna, Austria.

transportation terminals, social media usage during natural disasters or sport events, etc.).

For this spatio-temporal Web-based GIS client-server architecture is used, depicted in detail in *Figure 1*. On the server-side, the Web application that collects and serves the data is developed using the Django Web framework built with Python, which handles the daily collection of georeferenced data on a PostgreSQL database with the PostGIS plugin enabled. For Twitter the *Twitter Streaming Application Programming Interface* (API) is used that permanently stores the new tweets with a continuous streaming connection, whereas for Foursquare the *Venues API* is used that queries the Lombardy Region three times a day and stores the total check-ins each time for all the reported POIs. This data is subjected to restrictions that social media vendors may apply, but nevertheless represents a valuable source of users' location information.

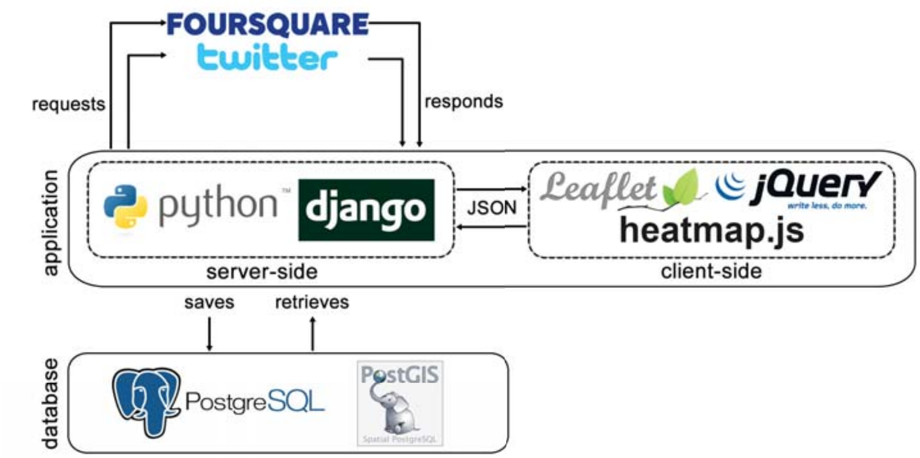


Figure 1. Architecture of the Web-based GIS

A Python script is developed on the server-side in order to aggregate the POIs stored in the PostgreSQL database using a predefined square grid. For this demo, a 200 m grid is selected, which allowed to optimize both the performance of the system and the visualization of the map. For the data aggregation process JavaScript Object Notation (JSON) is used with the list of the coordinates of the cell centers as keys and the associated count of POIs within the cell area as values. This JSON is passed as input to the client-side for the heatmap generation. The user is able to make requests filtering by date range and a keyword. While the grid is always static, the POIs are selected dynamically using the filters to display only the locations registered during the selected period and that include the keyword (if specified). The heatmap.js library and Leaflet are used to create a dynamic heatmap that is responsive to the zoom level over the map. Higher density locations are emphasized using a gradient color scheme depending on the amount of points included on screen, by using local maximum computation. Moreover transparency is added to the Twitter and Foursquare layers using heatmap.js, so that the overlaid layers can be visually interpreted. The users can also enable or disable data sources to be displayed on the heatmap using a legend. A sample use, where the start and end date is set to 1 August 2016 and 6 October 2016, Twitter tag is set to “hike” and Foursquare keyword is set to “Mountain” is given in *Figure 2*. On the map both the Twitter and Foursquare data is shown, where density variations, intersection and difference areas between two sources are visible. The demo application is available at http://geomobile.como.polimi.it/heatmap.

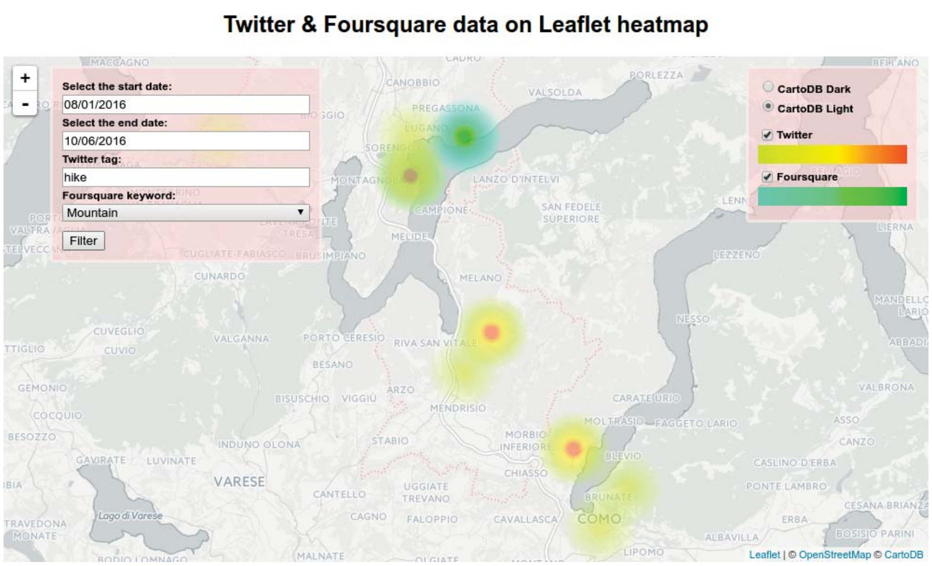


Figure 2. A sample use of the Web-based GIS

In conclusion, bringing all the data sources together is a useful novelty for anyone who is interested in the area for several purposes. Furthermore, presenting a large amount of data through a heatmap is an intuitive method where being able to filter it according to time and a keyword is an additional dimension to usefulness. This helps also to understand for what purposes different social media platforms are used by easing data analysis as well as inferring correlation between user activity and their geographical context. Moreover, the possibility of customizing queries to the database (e.g. by specifying tags) enables to display thematic heatmaps according to the user's needs.

References

Django: the web framework for perfectionists with deadlines. https://www.djangoproject.com. Accessed 23 September 2016

Heatmap.js: dynamic heatmaps for the Web. https://www.patrick-wied.at/static/heatmapjs. Accessed 23 September 2016

Leaflet,js: an open-source JavaScript library for mobile-friendly interactive maps. http://leafletjs.com. Accessed 23 September 2016

Evaluating cities' vitality and identifying ghost cities in China with emerging geographical data

Ying Long

School of Architecture, Tsinghua University, China

Extended Abstract

Urbanization in China has attracted much attention from around the world and is regarded as one of the most important events in human civilization. With the rapid urbanization of China, plenty of new urban lands have been developed with the great expectation to deal with all kinds of issues in old urban areas such as high population density, great demand on limited land resources, decaying environment, and etc. In recent years, real estate developments are the main form of urban spatial development in China and they generally cover over thirty percentage of total urban development in terms of area. The occurrence of these ghost cities has been widely criticized for debilitating the suitability of urban land as habitats, lowering the functioning effectiveness of urban system, hurdling the immigration trend of urban land, leading to disordered increase of urban land, messing up the whole plan of urbanization, and etc. Although there is unneglectable media coverage on ghost cites, which are supposed to be associated with wasting land resources and deteriorating healthy city development (Batty, 2016), the understanding on ghost cities in China is rather limited by lacking of clear and effectively evaluation criterion. This has been emphasized during the Central City Work Conference of China which is held at the end of 2015.

Considering the fact of ghost cities, we borrow the theory of urban vitality to identify and evaluate ghost cities in this paper. We argue that ghost cities are associated with very low urban vitality. Kevin Lynch believes that the primary criterion in the quality assessment of urban space form is the vitality, which is defined as a settlement that supports the vital functions and the biological requirements and capabilities of human beings, and how to protect the continuation of the species (Kevin, 1984). It is usual to say that, under these circumstances, people have 'quality of life'. Urban vitality is then an essential element to achieve urban quality of life. Ian Bentley described the vitality as affecting a given place, the extent of receiving diverse

LBS 2016
13th Conference on Location-Based Services
Vienna, 14–16 November 2016

Published in "Proceedings of the 13th International Conference on Location-Based Services", edited by Georg Gartner and Haosheng Huang, LBS 2016, 14-16 November 2016, Vienna, Austria.

characteristics of different functions(Bentley,1985). Jane Jacobs argued that human activity and life place intertwined constitute the diversity of city life, the vitality is the performance of the diversity in the city life (Jacobs, 1961).

In this paper, we profile ghost cities in China from the view of residential development vitality, which is the core issue contributing to ghost cities at the micro level. A residential project's vitality is associated with three components, ranging from morphological, functional to social aspects. In total, 535,523 residential land transactions from 2002-2013 with a total area of 7,770.2 km2 are collected from an official website in China. We use the national-wide road junctions, points of interest, and location based on service records of 2014/2015 for measuring the morphological, functional and social vitality of each residential project. We propose a vitality index considering three major components and suggest the vitality of a residential project is equal to the combined result of the three dimensions. This enable us the opportunity to calculate all residential projects' vitality values. We further distinguish all residential projects with the existing urban areas in the year 2000 (within or beyond) and these projects are then classified into two types, either they are in old urban areas (developed before or in 2000) or new ones (developed after 2000). We then aggregate the project level evaluation results into the city level. The ghost index G is proposed for identifying ghost cities, and it considers the vitality gap between the average residential project vitality of old urban areas and the vitality of the new urban areas (Figure 1). The larger the gap is and the lower the average residential projects' vitality in new areas in a city, the more the city tends to be a ghost city (a larger G for the city). The ghost cities are then identified by sorting all cities' ghost values, removing cities with small-scale residential developments in new urban areas and selecting the cities with the largest G values. Considering the straightforward nature of our proposed framework for identifying ghost cities, we do not include a serious validation step in this study. Rather, we benchmark our findings with existing studies and verify our results using other datasets.

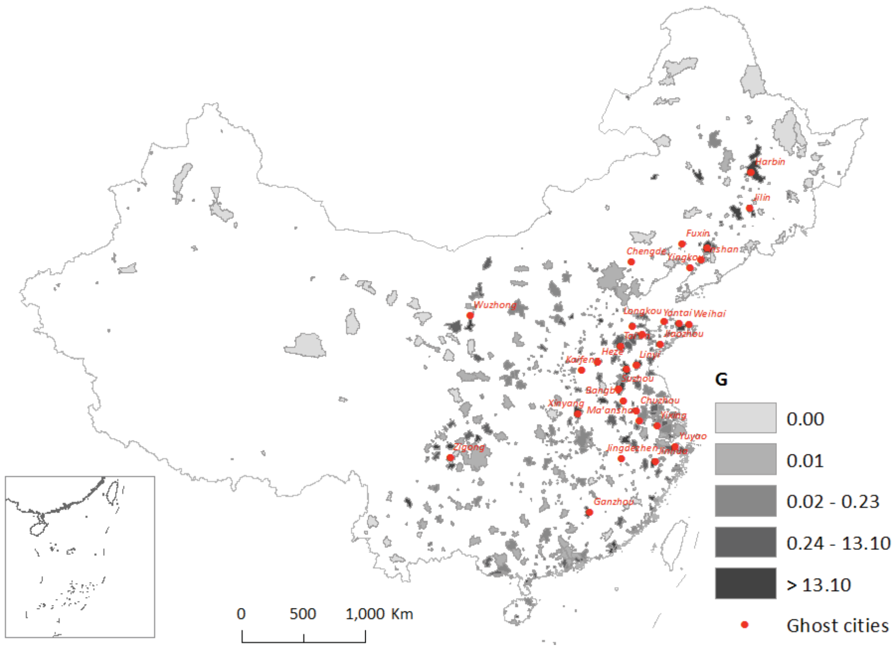


Figure 1 The ghost index (G) for all Chinese cities

References

Batty M (2016) Empty buildings, shrinking cities and ghost towns. Environment and Planning B: Planning and Design 43:3-6

Bentley I (1985) Responsive Environments. Architectural Press, New York

Jacobs J (1961) The Death and Life of Great American Cities. Random house, New York

Kevin L (1984) Good City Form. The MIT Press, Cambridge

Reducing Location Overhead in Educational Geogames

Christoph Schlieder, Peter Wullinger

Research Group on Computing in the Cultural Sciences
University of Bamberg, Germany
{christoph.schlieder | peter.wullinger}@uni.bamberg.de

Locomotion in location-based games

In location-based games, the player's physical position determines which game actions are available. As a consequence, locomotion between places of game play may consume a sizeable fraction of playing time. We present first results from an empirical study of player locomotion in an educational geogame.

The players of location-based games move in urban or natural environments using mobile devices to access spatial data and to solve place-related tasks. These games are also known as *geogames* (Schlieder et al. 2006). Most player actions in geogames may only take place at certain places in the geographic environment. This is a defining feature and provides the rationale for using them in educational contexts (Klopfer, 2008, de Freitas et al., 2012).

A geogame creates incentives to visit places which students probably would not visit otherwise. Furthermore, it motivates them to engage in place-related learning activities such as documenting a geofeature or analyzing spatial relationships (Schaal et al. 2012). As a consequence, the players move between places during the learning experience, often spending considerable time on locomotion. While this type of physical activity is generally welcome – and an integral part of the classical field trip – it should not dominate the learning process (Kremer et al. 2013).

We were confronted with the issue of locomotion overhead while designing a location-based game for the purpose of biodiversity education, the *FVsimulation* geogame. Its game mechanics combines a simulation of biodiversity with location-based tasks (Fig. 1). First data from GPS tracks and activity logs revealed that players moved very differently on the game fields,

LBS 2016
13th Conference on Location-Based Services
Vienna, 14–16 November 2016

Published in "Proceedings of the 13th International Conference on Location-Based Services", edited by Georg Gartner and Haosheng Huang, LBS 2016, 14-16 November 2016, Vienna, Austria.

some taking optimal paths, others seemingly wasting time by reiterating path segments.

FVsimulation belongs to the class of relocatable geogames. The game engine implements a framework which permits to restrict game actions to specific places of game play. In a first step, the organizer of the game, typically a teacher, has to define these places. He or she has considerable degrees of freedom in doing so. The game tasks where the player interacts with the simulation can easily be bound to different places (Fig. 1 left). Other tasks, however, are tied to specific places in the geographic environment. An example is the task of determining distances between trees in a fruit plantation (Fig. 1 right).

Figure 1. Interface of the location-based simulation game

In choosing the places of game play, the teacher acts as a co-designer of the game. Fig. 2a shows a rather small game field with 6 places of game play. Obviously, locomotion time depends on the design of the spatial layout of the places: a larger spatial coverage implies longer paths, and longer locomotion times. Topology also matters. The preferred path structure of a game field may be a linear chain or a tree or some graph containing cycles.

Figure 2. (a) Game field with 6 places of game play **(b)** GPS tracks of players

The game mechanics of *FVsimulation* requires the players to complete each task exactly once. In other words, on a game field of n places of game play, each of the n places has to be visited. The game mechanics, however, does not ask for a particular visit order neither does it prevent the players from revisiting places or walking on path segments which they have used before. Locomotion overhead is determined by the order in which the player decides to visit the places associated with learning tasks.

An example illustrates the issue. The GPS track data (Fig. 2b) show that players access and leave the game field (Fig. 2a) via place 2. However, many players choose to perform their first task at a different place. One team of players, for instance, choose to work on the tasks in the order 3-7-5-0-1-2. It turns out that the chosen task sequence produces considerable locomotion overhead. The chosen action sequence expands into the rather long path 2-7-5-**3**-5-**7**-**5**-3-**0**-3-**1**-3-5-7-**2**. This raises two related questions, the first two of which we addressed in an empirical study: Do suboptimal paths occur frequently? What spatial planning strategy could explain suboptimal paths?

Empirical findings from the case studies

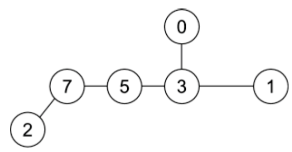
A total of 64 games were played by high students aged 10-16 on a playing field located near Filderstadt, Germany (Table 1, path network A). Additionally, a second data set of 39 games was collected at another geographic location, Eichstädt, Germany, with a comparable group of student players (Table 1, path network B). Note that the structure of the path networks differs. Network B is linear while Network A is structured as a tree, although with a single branching only. Both networks resulted from the choice of places made by teachers or education researchers with local knowledge.

An analysis of the georeferenced activity log reveals that suboptimal paths are quite frequent (Table 1). The length of an optimal path (it needs not be unique) depends on the entry and exit nodes of the network. Place network A is entered and left at node 2 while place network B can be entered or left at node 8 or 2. For path network A, optimal paths were chosen only in 5 of the 64 games. Most players chose an activity sequence which used 6 segments more on the path network than an optimal solution. The result is less pronounced for path network B, though clearly visible. Most games, 25 in total, are played on suboptimal paths, only 14 follow one of the two optimal paths.

Analysis and discussion

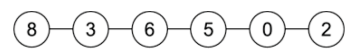
The finding that players frequently choose action sequences associated with suboptimal paths is surprising because the game mechanics puts no strategic advantage on any sequence of activities. On the other hand, players have an interest to minimize locomotion, if not for sheer laziness, then for maximizing the time available for solving the place-related tasks. What is it that makes players choose suboptimal action sequences?

path network A



excess path segments	example task sequence	frequency
0 = optimal	2-7-5-3-0-1	5
+2	5-7-3-0-1-2	2
+4	3-7-5-0-1-2	10
+6	1-3-7-5-2-0	43
+10 = worst	3-5-7-1-2-0	4

path network B



excess path segments	example task sequence	frequency
0 = optimal	8-3-6-5-0-2	14
+2	0-2-5-6-3-8	3
+4	6-3-8-5-0-2	9
+5	3-6-5-0-2-8	9
+6	6-5-3-8-0-2	2
+7	6-3-5-0-2-8	1
+10 = worst	5-0-3-6-2-8	1

Table 1. Frequency of suboptimal paths in two path networks

It is known that human problem solvers rely on a mixture of spatial strategies for path planning (MacGregor & al. 2006, Tenbrink & Wiener 2009). Some of the strategies are problem-specific, like the convex-hull strategy for travelling salesperson problems, others apply to a wider range of problems including path planning in networks similar to those of our two data sets. Among the universal strategies, the nearest-place-first strategy seems to be most widely adopted.

Consider a population of players most of which adopt the nearest-place-first strategy as their dominant approach to spatial search. For the path network A, which has the entry and exit at node 2, this strategy would produce the optimal activity sequence 2-7-5-3-0-1. As a consequence, we should observe a majority of optimal paths, which is not the case, as we have seen. Likewise, the strategy would produce an optimal action sequence on the linear path network B, for instance, with entry node 8 the sequence 8-3-6-5-0-2. Again, this not what the data shows.

Some additional strategy must be effective. A possible candidate is the strategy to avoid places at which other players are already engaged in game activities. While in principle many players can work at the same time on the same task, this seems to be the exception rather than the rule. For path network A, for instance, one finds at every node (with the exception of the entry node) most of the time only a single player. Players tend to avoid crowding at the places of game play.

Conclusions

In many if not most learning scenarios it is desirable that the players of an educational geogame start and finish playing at about the same time. Playing time spent on locomotion between places cannot be devoted to place-related learning activities. Our data shows that a major source of locomotion overhead is linked to suboptimal choices of place-related action sequences. Surprisingly, a majority of players were found to make these suboptimal spatial decisions. It seems that players tend to avoid crowded places where other players are already engaged in learning tasks. Future research will study the effect of network topology on locomotion overhead.

References

de Freitas, S.; Earp, J.; Ott, M.; Kiili, K. et al. (2012): Hot Issues in Game Enhanced Learning: the GEL Viewpoint. In: A. De Gloria et al. (eds.): VS-GAMES-12, Proc. Int. Conf. on Games and Virtual Worlds for Serious Applications. IEEE Press: 25–31.

Kremer, D., Schlieder, C., Feulner, B., Ohl, U. (2013). Spatial Choices in an Educational Game, In: Gatzidis et al (eds.) VS-GAMES-13, Proc. Int. Conf. on Games and Virtual Worlds of Serious Applications, IEEE Press.

Klopfer, E. (2008). Augmented Learning – Research and Design of Mobile Educational Games. MIT Press: Cambridge, MA.

MacGregor, J., Chronicle, E. , & Ormerod, T. (2006). A comparison of heuristic and human performance on open versions of the traveling salesperson problem. The Journal of Problem Solving, 1(1), 5.

Schaal, S., Grübmeyer, S. and Matt, M. (2012). Outdoors and Online-inquiry with mobile devices in pre-service science teacher education. World Journal on Educational Technology 4(2), 113-125.

Schlieder, C., Kiefer, P., & Matyas, S. (2006). Geogames: Designing location-based games from classic board games. Intelligent Systems, IEEE, 21(5), 40-46.

Tenbrink, T., & Wiener, J. (2009). The verbalization of multiple strategies in a variant of the traveling salesperson problem. Cognitive processing, 10(2), 143-161.

Location-based Image Viewing System Synchronized with Video Clips

Yuanyuan Wang*, Maho Nishizawa **, Yukiko Kawai ***, Kazutoshi Sumiya**

* Yamaguchi University, Japan
** Kwansei Gakuin University, Japan
*** Kyoto Sangyo University, Japan

1. Introduction

In recent years, various video clips, such as travel and educational videos, mainly provide a high-affinity geographic data, and the video clips in TV programs are often associated with closed captions. While watching TV programs, users are probably interested in some contents in the video clips and search related information through the Web. For example, users may search locations or check the current weather of tourist spots appeared on a travel channel using smartphones or tablets. However, current services cannot present location-based contents, such as location-based images, geographic maps, synchronized with video clips, and users difficult to grasp the surroundings of the geographic data, how the locations are related, and distances between them during the video clips. In particular, it is difficult to search appropriate location-based images from the huge number of users' posts on photo sharing sites, such as Instagram (2012) and Flickr (2005). For example, a user wants to grasp the surrounding scenery of Sanda that is a city located in Hyogo Prefecture, Japan by using a search query, Sanda. The search results also contain images about Sanda of Tokyo, because the search query is not appropriate. Therefore, it is necessary to analyze the semantics of the geographic data in a video clip, and supplement the video clip automatically with related information (e.g., location-based images, geographic maps).

In this work, the goal is to develop a novel automatic location-based image viewing system synchronized with video clips based on the concept of second screen service (Nandakumar & Murray 2014), (Geerts, Leenheer, Grooff, Negenman & Heijstraten 2014) by analyzing semantic structures of video clips (see Figure 1). To achieve our goal, we first extract location

LBS 2016
13th Conference on Location-Based Services
Vienna, 14–16 November 2016

Published in "Proceedings of the 13th International Conference on Location-Based Services", edited by Georg Gartner and Haosheng Huang, LBS 2016, 14-16 November 2016, Vienna, Austria.

Figure 1. An interface of the location-based image viewing system with video clips.

names which appear in closed captions of a video clip and detect their scenes of the video clip. Then, the system extracts a semantic structure that is a tree structure of extracted location names by utilizing Wikipedia categories, and detects relevant topics of location names in the semantic structure. Once a user watches a video clip, the system presents each location name appears in each scene with its relevant topic list, and images of Instagram related to each location name, are synchronized with the video clip. Also, the user can select any topic in the topic list; the system then presents images of Instagram related to the selected topic. Images can help the user easily grasp the surrounding scenery and appearances of locations in the video clip, and they can also rouse the user's interests. Location names and their relevant topics can also help the user easily obtain details and relevant knowledge of locations in the video clip.

As a result, our proposed novel system enables users to view images and location names with their relevant topics satisfy and joyfully during a video clip without additional search.

2. System Overview

The process flow of our automatic location-based image viewing system synchronized with video clips is described as follows:

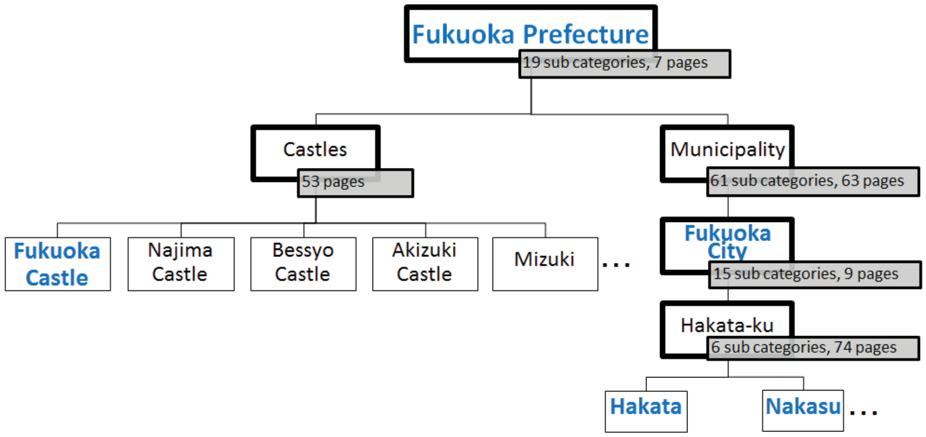


Figure 2. An example of a tree structure.

(1) Detecting location names and scenes of a video clip.

The system extracts location names using a morphological analyzer and their appearance time in closed captions from a MPEG-2 Transport Stream file of a video clip. In this work, we define one scene describes one location name. The system then divides the scenes of each location name if the next location name appears in the closed captions along the timeline of the video clip. In addition, if the same location names continuously appear in short time, they are determined in one scene. Furthermore, one scene is too short if the next location name appears within *T* seconds, this next location name will be eliminated. The time of each scene *T* is set to 3 seconds.

(2) Extracting semantic structure of a video clip.

The system extracts a tree structure of location names from Wikipedia categories using Wikipedia API (2006). Then, the system detects relevant topics if they have parallel relationships with location names from the semantic structure. A tree structure of a travel program called "New discovery! Tabipula" is shown in Figure 2, blue characters denote location names detected from closed captions of this video clip. "Hakata" and "Nakasu" have the parallel relationship, and "Fukuoka City" contains "Hakata." Therefore, geographical relationships between every two location names can be determined by using the extracted tree structure. However, a tree structure has a lot of nodes, and one location name may in many different tree structures. To solve them, we determine important categories if they contain a large number of reference pages. Then, we filter nodes of a tree structure if the reference pages of each node more than 5 pages. In addition, we select a tree structure of one location name by comparing the number of reference pages of its superordinate categories in different tree structures.

(3) Presenting images synchronized with video clips.

The system presents location names and their relevant topics in a list. Also, the system searches images from Instagram by matching hashtags and location names (relevant topics). Here, the system presents top-8 images by counting the number of "Like" from other users in Instagram.

3. User Study and Discussion

The purpose of this user study is to evaluate the effectiveness of presenting relevant topics and images with video clips. We evaluate four patterns of the same scenes from video clips as follows:

- (a) Location names synchronized with scenes (detailed information: text)
- (b) Relevant topics synchronized with scenes (detailed information + relevant information: text)
- (c) Images of location names synchronized with scenes (detailed information: images)
- (d) Images of relevant topics synchronized with scenes (detailed information + relevant information: images)

The video clips used for evaluation is from two travel programs in Japan, respectively. One is called "New discovery! Tabipula" introducing Fukuoka Prefecture in Japan with a total viewing time about 5 minutes 30 seconds; the other one is called "Eetoko" introducing Shiga Prefecture in Japan with a total viewing time about 2 minutes 30 minutes.

The study is completed by six participants, who never been to Fukuoka Prefecture and Shiga Prefecture. They completed the following 4 items (**Content Understanding**: $Q1$, **Interest-Arousing**: $Q2$, **Supplement Effects**: $Q3$, $Q4$) in a questionnaire after they watched the four patterns (a)~(d) of the same scenes from video clips.

- $Q1$: Could understand the video clips.
- $Q2$: Felt spread your interests.
- $Q3$: Write down relevant topics and images that are not related to the video clips

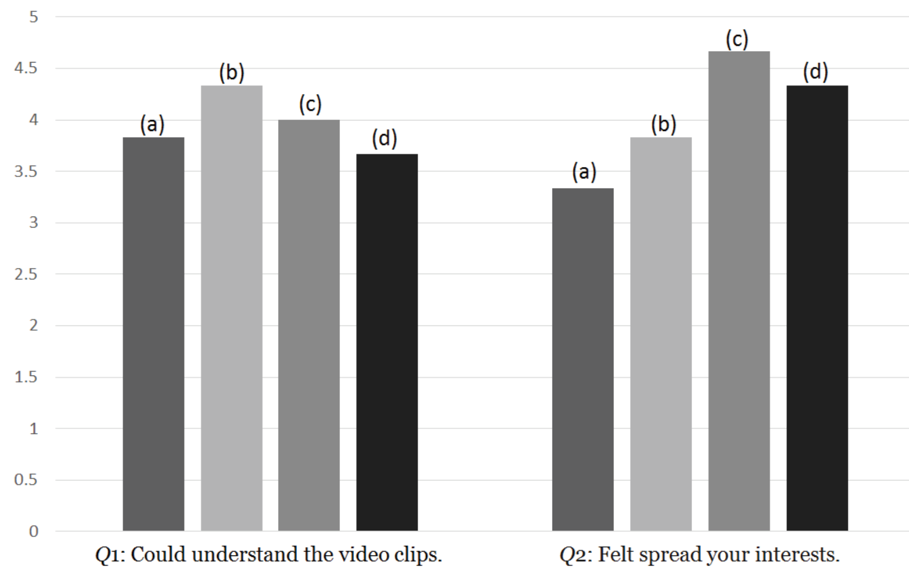


Figure 3. The results of *Q*1 and *Q*2 in the questionnaire.

- *Q*4: Write down relevant topics and images that you are interested in.

Figure 3 illustrates the average ratings of *Q*1 and *Q*2 in the questionnaire based on a five-level Likert scale. High user ratings indicate good results. The results and findings are shown as follows:

- *Q*1 for (b) gains a high rating, it can be said that it is most effective for understanding the video clip when presenting relevant information in text synchronized with scenes.
- *Q*2 for (c) and (d) gain a high rating, the ratings of images are higher than those of location names and their relevant topics in the text.
- In *Q*3 for the low relevant topics and images written by subjects, subjects felt several unknown topics are not related to the video clips. We need to present the relevances of locations in the video clips and their relevant topics. In addition, several general images about people or flowers are not related to locations in the video clips. It is necessary to extract images by considering features of locations.
- In *Q*4 for the interesting topics and images written by subjects, subjects are interested in when they watch the video clips. Then, the proposed

method is able to arouse the subjects' interests and can help the subjects enjoy the video clips.

4. Conclusion

In this paper, we developed a novel automatic location-based image viewing system synchronized with video clips based on semantic structures of the video clips. In order to extract semantic structure of a video clip, we utilize closed captions of the video clip. The system creates a tree structure of location names in the video clip by using Wikipedia categories and detects relevant topics of location names in the tree structure. Finally, we conducted a user study with the proposed system. The results of user study showed that the proposed system can help users enjoy video clips with relevant topics and images that suit users' interests.

In the future, we plan to improve the methods for presenting relevant topics and images by considering the meanings of hashtags in Instagram, and consider presenting relevant information of other types (e.g., voice, web pages, and microblogs). Another future direction is to extend the system by user interactions. For example, the system can be extended to allow viewers to decide whether and how to show the supplementary information.

Acknowledgment

This work was partially supported by JSPS KAKENHI Grant Numbers 26280042, 16H01722.

References

Geerts, D., Leenheer, R. D., Grooff, D., Negenman, J., & Heijstraten, S. (2014). In front of and behind the second screen: Viewer and producer perspectives on a companion app. In TVX 2014: Proceedings of the 2014 ACM international conference on Interactive experiences for TV and online video (pp. 95-102). ACM, New York, NY, USA.

Flickr (2005) Yahoo!. https://www.flickr.com/. Accessed 23 August 2016

Instagram (2010) Facebook. https://www.instagram.com/. Accessed 23 August 2016

Nandakumar, A., & Murray, J. (2014). Companion apps for long arc TV series: Supporting new viewers in complex storyworlds with tightly synchronized context-sensitive annotations. In TVX 2014: Proceedings of the 2014 ACM international conference on Interactive experiences for TV and online video (pp. 3-10). ACM, New York, NY, USA.

Wikipedia API (2006) SampleAPI. http://wikipedia.simpleapi.net/. Accessed 23 August 2016

Development of a Virtual Reality Application based on Libgdx Game Engine in Mobile Environment

Nasser Tahani*, Ali Asghar Alesheikh*, Mahdi Farnaghi*

* Faculty of Geomatics Engineering, K. N. Toosi University of Technology, Tehran, Iran

Extended Abstract

Presentation of real-world objects plays an important role in Geographic Information System (GIS) applications to provide different analysis capabilities and support users' perception about the environment. Mobile devices in particular, present the user's surrounding environment as 2D maps like Google Maps and OpenStreetMap (OSM) which provide capabilities like user navigation, exploring Point of Interests (POIs) and route finding. These types of maps are limited to a top-down view, and they do not truly support interaction with real-world objects by ignoring the vertical aspect of the environment. In contrast, 3D city models that contain common elements like buildings, vegetation areas, streets and surface terrain, improve users' visual perception of environment and provide more analytical capabilities based on the 3D nature of objects. In a 3D city model users can identify nearby objects according to their shapes and appearance attributes. Furthermore, these models can be utilized in variety of applications such as visibility analysis, utility management, 3D cadaster, indoor positioning and energy demand estimation (Biljecki et al. 2015). Recent improvements in the hardware and software specifications of smartphones, along with utilization of different embedded sensors and powerful CPUs and GPUs, encourage developers to apply them in novel mobile applications like Virtual Reality (VR) and Augment Reality (AR). VR is a technology that simulates objects of real world in a virtual environment and enables users to virtually interact with those objects.

In this research we have developed a mobile application to represent real-world objects in two approaches: bird's-eye view and first-person view. The bird's-eye view is similar to the view of applications like Google Earth and ArcScene, while in the first-person view, the VR approach is implemented by means of location awareness of the mobile device. The flowchart of *fig-*

Published in "Proceedings of the 13th International Conference on Location-Based Services", edited by Georg Gartner and Haosheng Huang, LBS 2016, 14-16 November 2016, Vienna, Austria.

ure 1, presents the steps of our research and the explanation of steps will be described in detail.

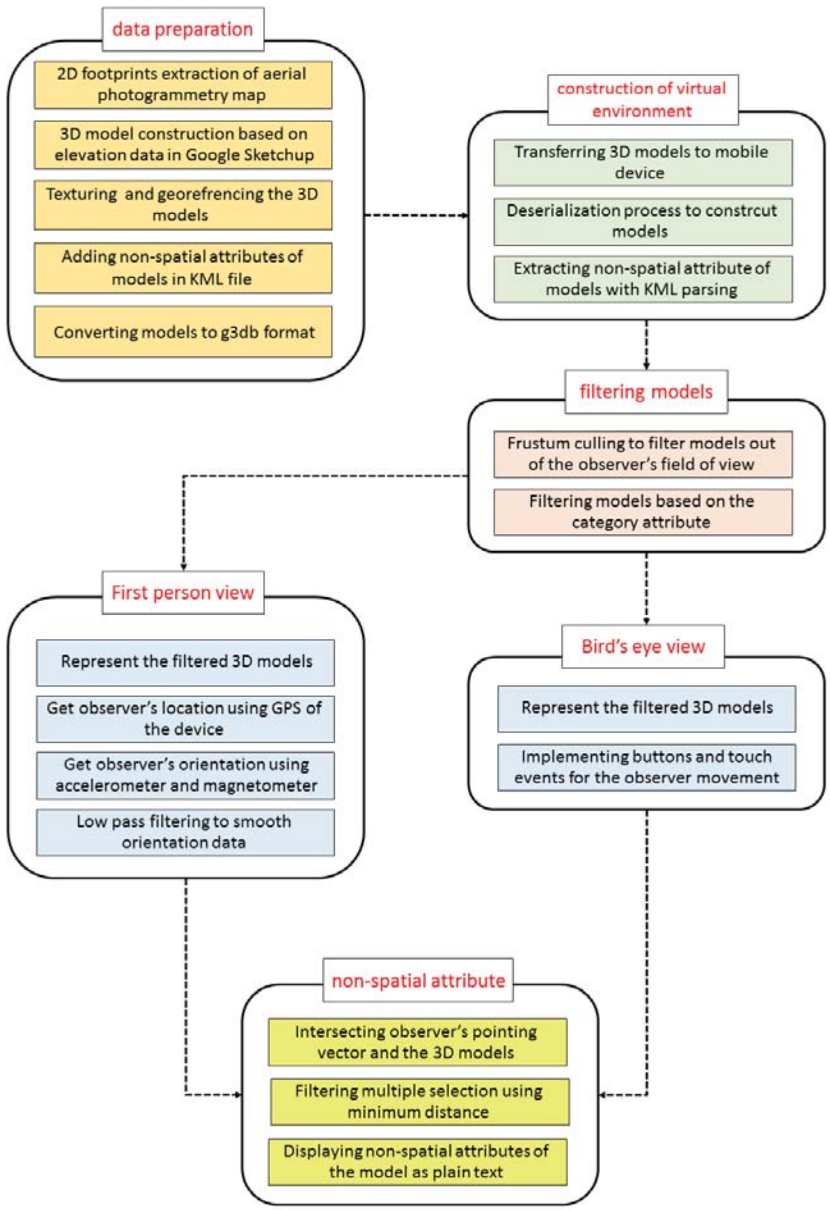


Figure 1. The flowchart of our research.

Presentaion of 3D city models on mobile devices can be devided in two categories based on rendering architecture: browser-based and client-server architecture. In the first group, 3D city models are visualized on the browser of mobile device as a web application (Prieto & Izkara 2012, Rodrigues et al. 2013). HTML5 and WebGL are widespread technologies of the first category. In the second group, data are stored in server-side and the client renders and visualizes the transferred 3D models on the mobile device (Nurminen 2008, Baldauf & Musialski 2010, Lethinen et al. 2012). The browser-based approach requires appropriate network connection; they may not have access to all smartphone sensors. On the other hand, in the client-server approach all hardware features of the mobile device can be accessed to make the application location-aware. But it needs more developing efforts due to different operating systems of mobile devices. In this research, the application have been developed accroding to the client-server approach to utilize location and orientation based sensors of the device.

OpenGL ES, a powerful API for rendering 2D and 3D features, provides the required functionalities to render graphic models in mobile devices. OpenGL ES utilizes the smartphones' GPUs to accelerate 3D graphic rendering. Additionally, various graphic libraries and game engines have been developed recently based on OpenGL ES. JmonkeyEngine3, Godot and Libgdx are instances of these libraries which provide features like shading, lighting, loading complex models, managing graphic resources and detecting collisions. In the developed application, we have used Libgdx game engine to make our virtual environment along with loading and rendering 3D models in the application.

3D city models are created with different methods like LIDAR (Light Detection And Ranging) and photogrammetric technologies. 2D city plans can be used to create 3D models in graphics softwares such as Google Sketchup and CityEngine as well. In our study, the city model contains objects in the campus of K. N. Toosi unversity of technology. The 2D city plans have been produced by aerial photogrammetry in 1:2000 scale and contains most city features like buildings, vegetation and streets. The 3D models were created in Google Sketchup software based on the 2D footprint and corresponding objects elevations. Then, the models were georeferenced and their coordinates and non-spatial attributes were exporeted as KML file. Regarding the limitation of obj format in rendering complex graphics, it is recommended to convert graphic objects to Libgdx standard format known as g3db (Bose 2014). Every objects of the 3D city model consists of three parts: the graphic part as .g3db file, the textures file and the KML file. We have utilized the deserialization process to construct graphic models in mobile device and locating them according to the coordinate attribute of KML file as shown in *figure* 2. Deserialization is the process of creating objects from sequence of bytes which resides on a storage space. The non-spatial attributes of models are extracted by parsing KML file and storing them in the set of key-value pairs.

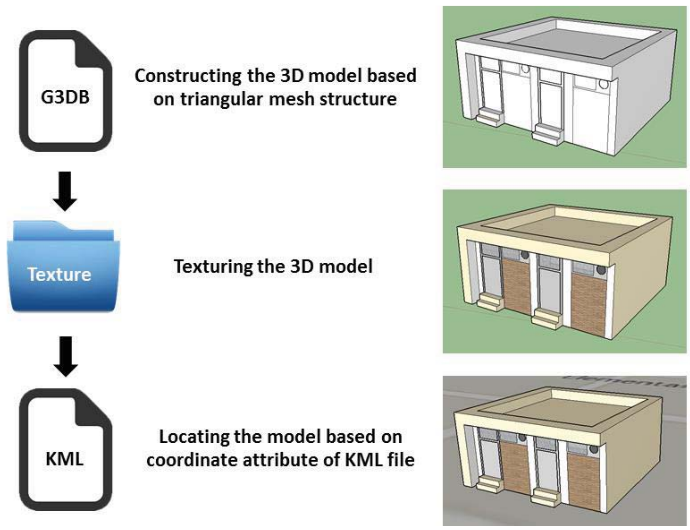


Figure 2. The deserialization of the 3D model.

Our developed application support two view approaches to represent 3D city model. In the bird's-eye view, the observer is elevated above the ground and can explore real world objects. In this view, exploring in the environment is provided by means of designed buttons and touch events on the screen as shown in *table 1*.

Event	Interaction
top-down button	observer moves up & down
left-right button	observer moves left & right
one finger touch	rotation of the observer
one finger long press	get non-spatial attribute of the object
two finger touch	zoom in & zoom out

Table 1. The task of touch events and buttons in the bird's-eye view.

Figure 3 demonstrates the campus in the bird's-eye view approach. At the top left of the screen, the attribute information of the main building is shown which includes information like its category, name, number of floors and area.

Figure 3. The bird's-eye view of the campus.

In the first-person view, we have utilized the location and orientation information extracted from sensors of mobile devices, like GPS, accelerometer and magnetometer. Unlike the bird's-eye view approach that controls the observer using buttons and touch events, in the first-person view, user's exploration in the virtual environment has been provided by aid of context awareness of the device. In the VR approach, the position of the observer is acquired by GPS and the pointing vector is determined by combining accelerometer and magnetometer data. Considering small sizes of accelerometer and magnetometer sensors, the retrieved data are noisy and need to be filtered. We have applied a low-pass filter as shown in *equation 1* to eliminate noise of the data.

$$y_i = y_{i-1} + \alpha * (x_i - y_{i-1}) \quad (1)$$

In this equation, the y_i is the output data, α is the threshold of the low-pass filter and the x_i is the input data retrieved from orientation sensors. *Figure 4* demonstrates the Faculty of Geomatics Engineering in the first-person view. The displacement of the models is caused by GPS positioning and the orientation errors as shown in the picture.

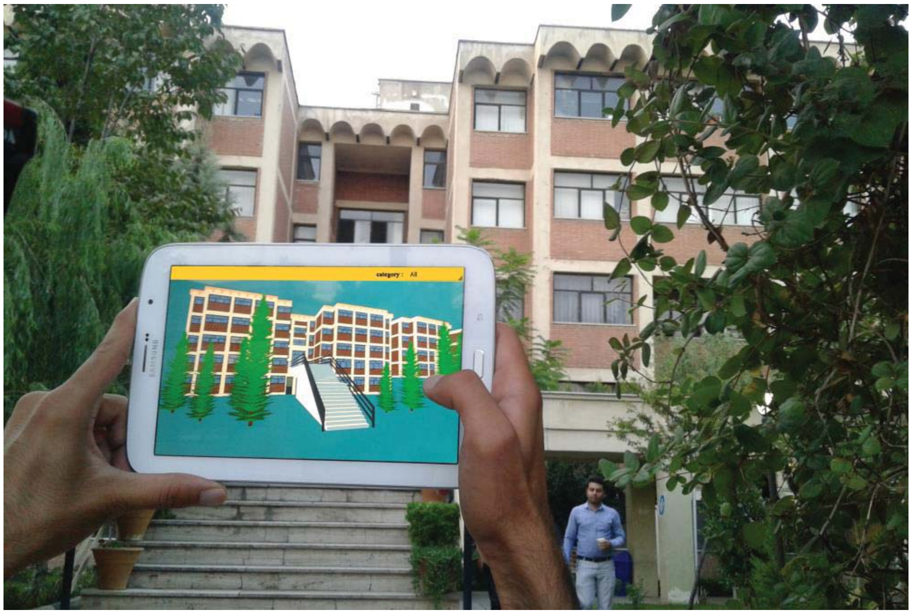


Figure 4. Presentation of the Faculty of Geomatics in the first-person view.

Typically, rendering process of complex graphics imposes work overload on mobile devices. Also due to the limited screen size of smartphones, it is not appropriate to load all graphic objects on the scene. We have utilized the concept of view frustum culling to overcome these problems. In this procedure, we have created the minimum bounding box (MBB) of objects and constructed the frustum of observer. The designed algorithm detects objects which are contained in the observer's frustum to render them at the graphic scene.

Considering the limited screen sizes of the mobile devices, the representation of all objects makes user confused among various 3D models. The developed application provides filtering data according to the category of the models to represent only selected layers of models. As mentioned, non-spatial attributes of models have been stored as set of key-value pairs. We have used collision detection concept to identify those objects that are selected by the user. In this approach, the object is selected if the observer's pointing vector intersects with the MMB of the object. In the case of multiple intersections, the minimum distance between observer and the models are taken into account to determine the desired object. Then, non-spatial attributes of selected objects are displayed as plain text on the screen.

The developed application helps users to explore urban environment in two views. In the bird's-eye view users can explore 3D city model using designed buttons and touch events. While in the first-person approach, the user can explore 3D objects as a VR application. To optimize the rendering process of the application, the view frustum culling has been applied to exclude those objects that are out of observer's field of view. Moreover, users can get attribute information of objects in both approaches by selecting the desired object. The filtering capability of the application supports the user to manage the representation state of different model types.

In spite of the improvement in smartphones hardware and software, simultaneous rendering of whole contents of a city model on the mobile device is an inefficient task. As a future work, in order to tackle this problem; we will implement indexing methods in client-side to interactively search and access spatial objects.

References

Baldauf, M., & Musialski, P. (2010). A device-aware spatial 3D visualization platform for mobile urban exploration. In The fourth international conference on mobile ubiquitous computing, systems, services and technologies (UBICOMM 2010), IARIA.

Biljecki, F., Stoter, J., Ledoux, H., Zlatanova, S., & Çöltekin, A. (2015). Applications of 3D city models: state of the art review. ISPRS International Journal of Geo-Information, 4(4), 2842-2889. in 1983)

Bose, J. (2014). LibGDX Game Development Essentials. Packt Publishing Ltd.

Lehtinen, V., Nurminen, A., & Oulasvirta, A. (2012, March). Integrating spatial sensing to an interactive mobile 3D map. In 3D User Interfaces (3DUI), 2012 IEEE Symposium on (pp. 11-14). IEEE.

Nurminen, A. (2008). Mobile 3D City Maps. IEEE Computer Graphics and Applications, 28(4), 20-31.

Prieto, I., & Izkara, J. L. (2012, August). Visualization of 3D city models on mobile devices. In Proceedings of the 17th International Conference on 3D Web Technology (pp. 101-104). ACM.

Rodrigues, J. I., Figueiredo, M. J., & Costa, C. P. (2013, July). Web3DGIS for City Models with CityGML and X3D. In IV (pp. 384-388).

Development and implementation of an iBeacon based Time Keeping System for Mountain Trails

Christian Hessing, Inst. for Cartography, Dresden University of Technology, and ch consulting,
Manfred Buchroithner, Inst. for Cartography, Dresden University of Technology

Abstract. Time Keeping is an essential functionality for many kinds of competition sports. Within the TU Dresden Project “Modelling of Physical Health Parameters Based on GIS and Sensor Technology“ (Hessing & Buchroithner 2011) a new and unique system for outdoor sports on defined trails was developed.

The most important feature required is a permanent infrastructure on the respective running trail which interacts with a smartphone App on the user’s device, a web-based database and an interface. Using iBeacon technology, an easy-to-maintain infrastructure for time keeping on mountain trails and running courses was built at the “AktivArena Oberammergau” in the German Alps. The system is available 24/7/365, and not only for race or dedicated events. Users can compete with other runners or hikers at any time and see their results immediately on the web platform. The course has the character of a reference trail with known best times of professional trail runners and thus one can compare her/his personal trail running time. The www-based social media platform “meinBerglauf.de” is an ideal approach to compare results. The fact that the trail is a reference course with a defined start and finish distinguishes it from services like Strava or Runtastic.

Key-technology within this project is the use of wireless iBeacons, a standard for Low Energy Bluetooth (BLE), which was established by Apple Inc. 2013.

As a byproduct, a lot of individual information about the users’ physical capabilities for sports and medical scientific research purposes is generated. The defined “meinBerglauf” courses can be used as an environment equal to a sports lab. Using the runners’ bio-parameters like heart rate and running speed, their weight in kg and body size in cm, the algorithms for the model the users’ physical health parameters can be calibrated for runners in mountainous terrain.

Published in “Proceedings of the 13th International Conference on Location-Based Services”, edited by Georg Gartner and Haosheng Huang, LBS 2016, 14-16 November 2016, Vienna, Austria.

Consequently, the presented project comprehends two aspects: 1. Bringing a new commercial product for time keeping for outdoor sports onto the market and 2. Scientific research concerning sports-medical issues in outdoor sports.

Keywords. iBeacon, Sports, Time Keeping, GPS, Navigation, Outdoor, Fitness, Company health program, smartphone App,

1. Introduction

Time keeping systems for sports competitions require a technology that provides a “link” to the individual athletes, so that every person can be identified at the start, along the track and at the finish line. An individual time stamp must be generated within an acceptable accuracy at a pre-defined location in the moment when the athlete passes. Time stamp and the athletes identification need to be stored in a database for further computing. On race tracks and for a dedicated event a high tech infrastructure for the time keeping can be set up. People can operate the computers and sensors along the track and huge batteries and generators can supply the energy which is necessary. The athletes need to be provided with a minimum of additional weight they have to carry. The here described system “meinBerglauf” offers a totally new concept for those demands.

2. “meinBerglauf”

2.1. Conventional Time Keeping

Most Time keeping systems for running or cycling competitions are usually based on RFID technology (*radio-frequency identification)*. The start number plates are equipped with an RFID transponder which identifies the individual start number of the participant. The RFID transponder is a very small, lightweight and passive chip that doesn’t require any power supply or battery. The necessary electric power to read the data programmed on the transponder chip comes from the RFID reader which is installed at least on the start and finish line of the race course and eventually on some places on the course. The coupling between transponder and reader occurs through alternating magnetic fields in short-range or high-frequency radio waves which are generated by the reader. That way the transponder is supplied with energy from the reader and the data from the chip are transmitted to the reader. The time keeping is based on the registration of the RFID transponders when they pass start and finish line: The information stored on the transponder identifies the individual runner and the time stamps of the registration supply the timing.

The advantage of this system is that the core technology is stationary in the reader and the infrastructure behind and the mobile component is very small, handy and does not need any maintenance or power supply.

Figure 1: RFID transponder (https://de.wikipedia.org/wiki/RFID)

Foto © MaxFunTiming

Figure 2: RFID reader (www.kleinezeitung.at, time keeping at “Kärnten läuft”)

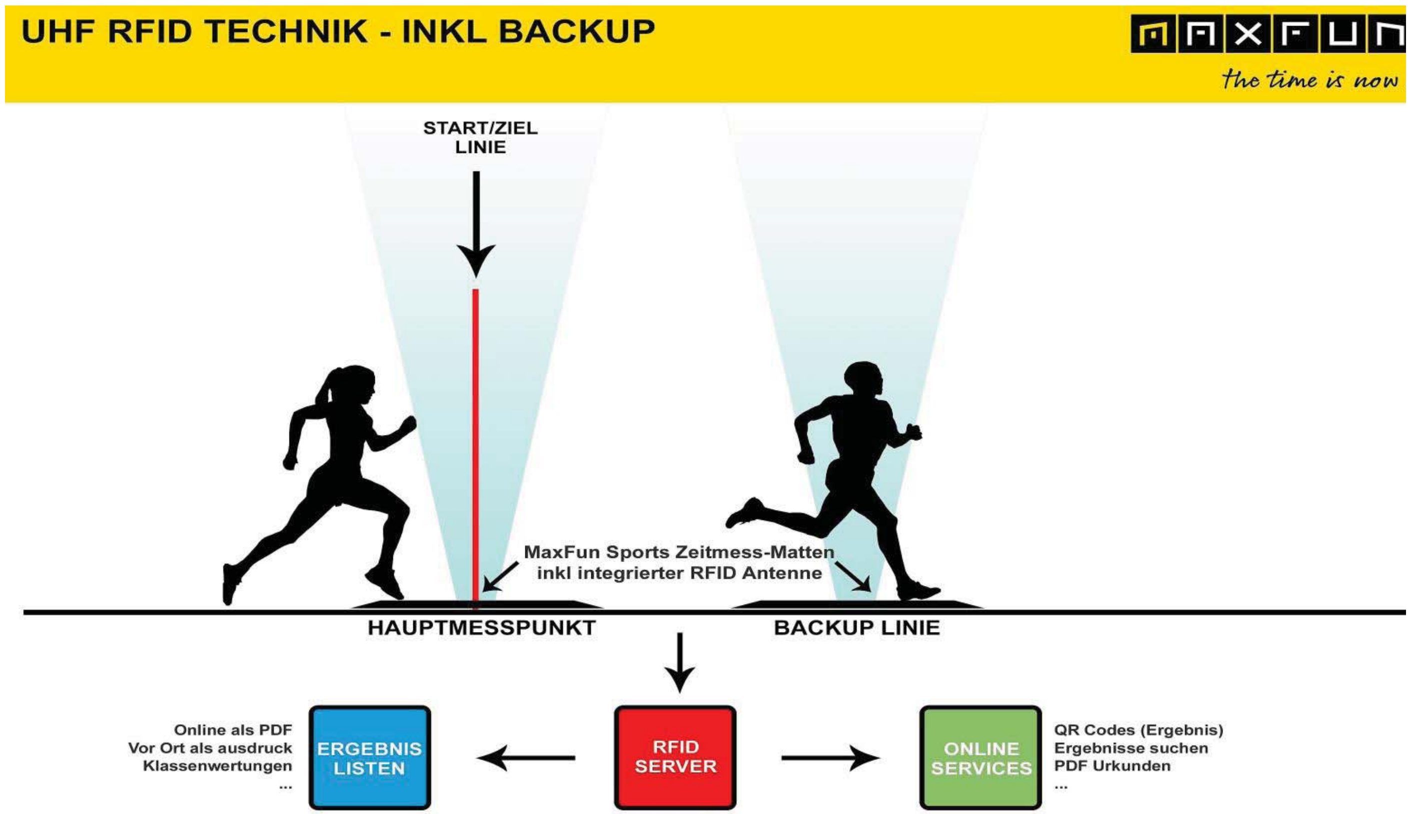


Figure 3: Conventional time keeping system (www.kleinezeitung.at, time keeping at “Kärnten läuft”) © MaxFunTiming

2.2 The Approach

The approach of this study is the development of a time keeping system that can be used in remote places with a minimum of maintenance needs and no transponder or any other hardware should be necessary on the user/runners' side except a smartphone. That leaded to the concept of turning around the conventional time keeping concept: The passive component, a transponder or something else, should be placed on the trail running course. The active component should be the runners' smartphone.

To set up a prototype of a demonstration system, a test course was established in the German Alps in Oberammergau at "Kolbensattel, Activ Arena". We installed two pillar like constructions at the start point of the test and reference course: One at the start place close to the parking lot of that tourist area and the other at the finish line on the mountain, close by a mountain hut.

Picture 1: Start and finish pillars on the test course in Oberammergau

After evaluating several systems, NFC tags (near field communication) were excluded because they are not supported by Apples iOS and RFID transponders because they need dedicated readers which are not standard in modern smartphones.

Finally, the iBeacon technology was the most appropriate solution for this approach.

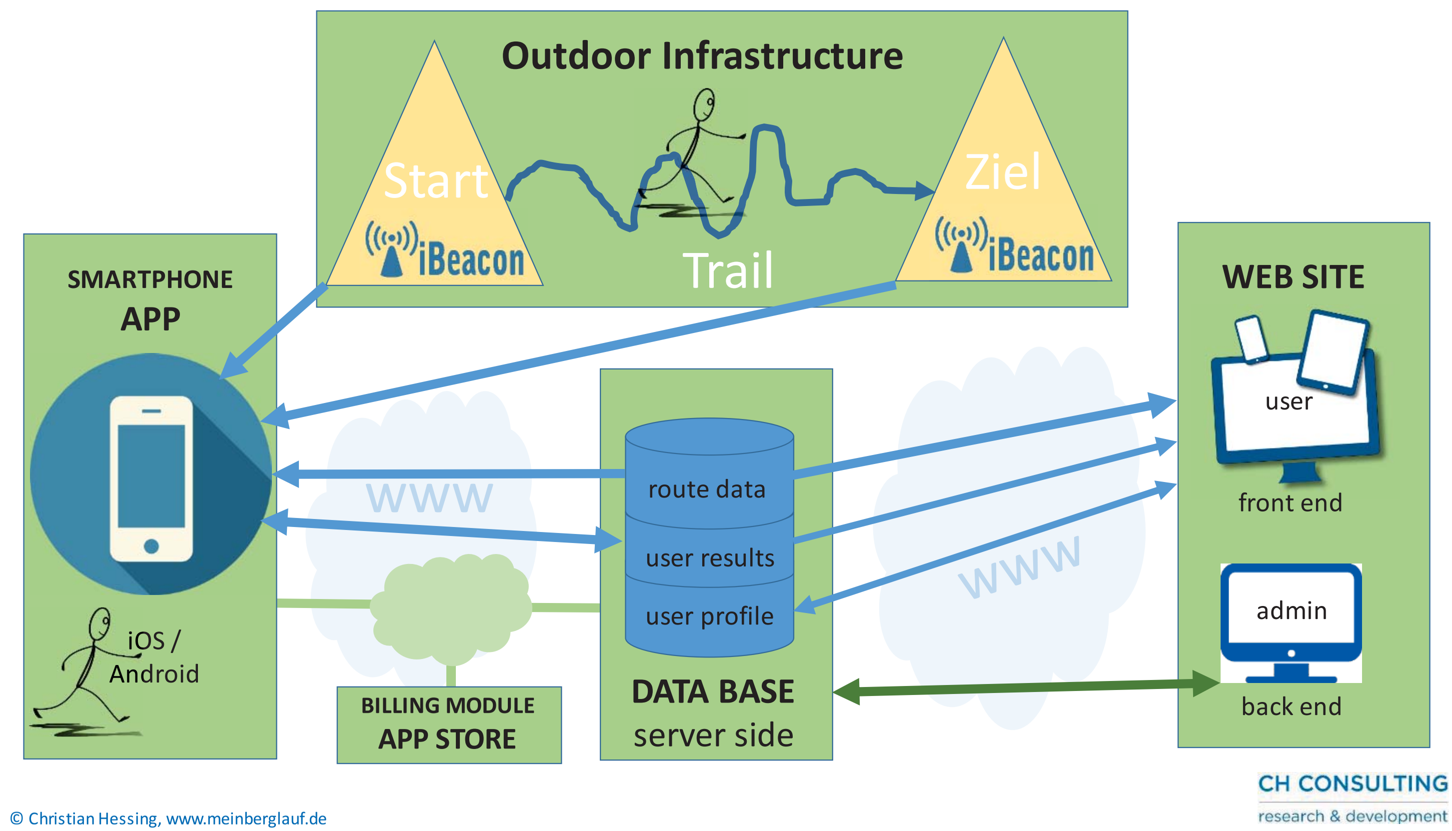


Figure 4: Infrastructure of "meinBerglauf"

The brand name “iBeacon” was established in 2013 by Apple Inc. and is a pretty new standard for indoor navigation. Based on Bluetooth Low Energy (BLE) the beacons can transmit digital information that was stored on the device. The broadcast interval can be defined up to 10 Hertz so that a sufficient accuracy for the time keeping for trail running needs can be reached

2.3 Use Cases and Target Groups

Leisure Trail Running and Amateur Sports

Trail running is very popular today. Only in Germany the number of active amateurs is estimated up to 50.000. In Bavaria, about 5.000 runners are frequently participating in mountain trail running competitions. For those enthusiasts the “meinBerglauf” infrastructure offers a platform to compete with others at any time. Due to the fix installed infrastructure a runner can set his best mark at any time. And this is how it works:

Before the first use of the system

- the user needs to register at www.meinberglauf.de
- install the APP on his Android or IOS smartphone

At the start beacon

- start App on the smartphone
- App indicates the start beacon (radius 5m)
- pack away the smartphone and get ready to go

- approach slowly towards the start beacon and enter the near range
- listen to acoustic start signal
- acoustic start signal indicates active time keeping.

Figure 5: Approach and near range of the start beacon`

At the end of the trail
- enter near field range of the target beacon

- wait for the acoustic signal
- the resulting running time is displayed in the smartphone app
- the results are uploaded to the www.meinberglauf.de

On the web interface the user's results are displayed and interpreted in various ways. Very important for many users is the ranking, which makes every run a competition within all members of the participating trail running community.

Professional Training

The fitness and endurance training of professional athletes can be monitored perfectly on the "meinBerglauf" reference trails. The amount of energy needed for a dedicated speed in any segment of the trail can be calculated based on geodata and measurements. So the athletes and their coaches can optimize the performance of training and competition.

Everybody's Health and Fitness

Recreational hikers, mature people and everybody who wants to keep an eye on his weight control and health can profit from the "meinBerglauf" infrastructure. For those people a health and recreation app for smartphones will be developed. Many people used to start their hike with a speed much too fast for their potential and slow down when they get too exhausted. So at the end of the day their activity was not as efficient or healthy as it could have been. With the "meinBerglauf" health app the user will be supported to moderate the moving pace on a healthy level.

3. Conclusions

Location Based Services as a generic term covers a wide range of topics. Sports, health and fitness applications are a new demand for LBS and offer a lot of potential for further investigations. The Bluetooth Low Energy (BLE) technology provides a basis for this new time-keeping concept. Now experiences regarding accuracy and user acceptance have to be made. "meinBerglauf" is a first step for many further services based on LBS and sensor technology.

Hessing, Buchroithner 2011: Modeling of Physical Health Parameters Based on GIS and Sensor Integration, Proceedings of the 8th International Symposium on Location-Based Services, Vienna 2011

Android application to guide users through Slovenian hiking trails

Peter Žličar, Klemen Kozmus Trajkovski, Dušan Petrovič

University of Ljubljana, Faculty of Civil and Geodetic Engineering, Slovenia

Extended Abstract

There are 1661 registered hiking trails in Slovenia which cover over 10000 km. The trails are maintained by Alpine clubs. 287 Alpine clubs are organized within the Alpine Association of Slovenia (AAS 2016).

AAS is in authority for keeping a record of existing hiking trails as well as categorizing the trails. AAS also publishes hiking maps and a monthly journal. In the year 2002 a decision to contain each trail into the database was made.

The database has been established in four phases. The first phase was establishment of the database and filling it with any available information on hiking trails. The second phase was about checking the location accuracy. The third phase included adding attribute data into the database. The fourth phase was the representation of the collected data for wide spectrum of users.

An idea of creating an application for using the database on actual trails has emerged. The android platform has been chosen as it had been the most used smartphone OS at the time. The app has been developed in Android Studio environment using Java and XML languages. The database is in SQLite format. The tracks in the database are in GPX format. Data types are waypoints, routes and tracks.

The goal of the app is to guide hikers in the Slovenian mountains. Initially, user selects a mountainous area. Then a trail can be proposed by certain criteria, such as complexity, length or duration of the hike. Any trail can be selected directly from the list.

When the hike is started and GPS is turned on, the trail is shown with the current position on it. Additional information on the screen include heading, distance to the finish or junction point, height and the accuracy of the GPS signal.

LBS 2016
13th Conference on Location-Based Services
Vienna, 14–16 November 2016

Published in "Proceedings of the 13th International Conference on Location-Based Services", edited by Georg Gartner and Haosheng Huang, LBS 2016, 14-16 November 2016, Vienna, Austria.

Different background maps can be selected: Google (terrain, roadmap, satellite), OpenStreetMap or AAS hiking map, as can be seen in *Figure 1*.

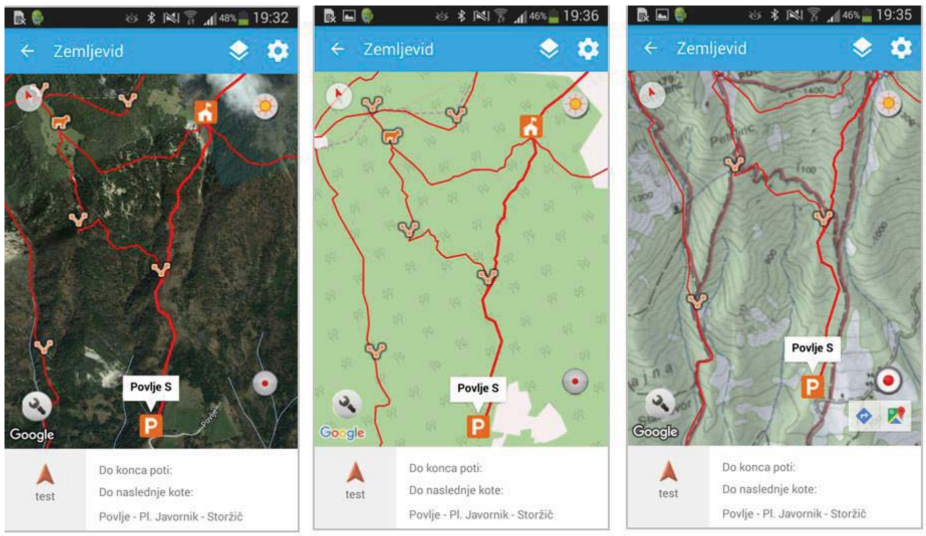


Figure 1. App main screen with background maps from Google (left), OpenStreetMap (center) and a hiking map (right) (Žličar 2016).

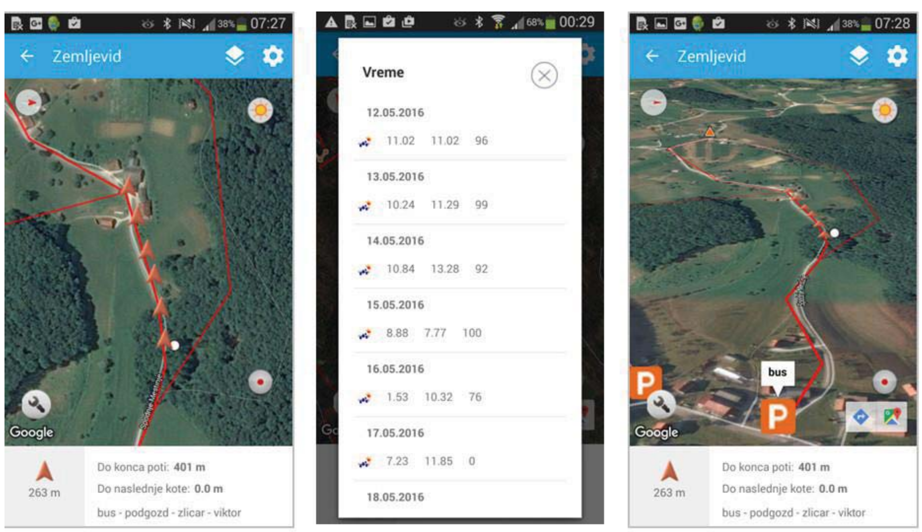


Figure 2. Navigation with an orthophoto background (left), weather data and forecast (center) and perspective view (right) (Žličar 2016).

Figure 2 left depicts actual navigation. The app contains additional features: error reporting, weather forecast (see *Figure 2 center*), logging of the track, compass and car navigation using Google services for guidance to the origin point. All saved tracks can be displayed over a background map. A fake 3D perspective view can also be shown, as seen in *Figure 2 right*.

References

AAS (2016) Alpine Association of Slovenia home page: http://en.pzs.si/. Accessed 15 October 2016

Žličar P (2016) Creating the application to guide users through Slovenian hiking trails: Graduation thesis. University of Ljubljana, Faculty of Civil and Geodetic Engineering

GeoReal: Location-based Services for Real Estate Agents in Florida

Martina Joisten*, Oliver Ullrich**, Katharina Hoven*

* Rheinische Fachhochschule Köln, Cologne, Germany
** Florida International University, Miami, Florida, USA

Extended Abstract

We present initial investigation and requirements analysis results on GeoReal, a location-based mobile app for real estate agents in Florida. The app will support real estate agents on-site, e.g. during showings, and while traveling. Through this project we explore new location-based services for realtors, and, eventually, for other traveling sales personnel. We will also explore how complex geo-tagged and location based data is optimally presented in a user-friendly mobile interface.

The GeoReal mobile app will be based on TerraFly, an online geospatial big-data analysis and visualization system developed by Florida International University‘s High Performance Database Research Center (http://hpdrc.fiu.edu/). The TerraFly system serves worldwide web map requests providing users with customized aerial photography, satellite imagery, and various overlays, such as street names, restaurants, services, and demographic data (Rishe et al. 2005, Zhang et al. 2015). Available spatial data sources in TerraFly include demographic census, real estate, disaster, hydrology, retail, crime, and disease related data.

Real estate agents are licensed experts who provide services associated with the purchase and sale of properties on a commission basis (Barwick & Pathak 2015). They usually have a greater knowledge concerning property transactions than their clients, either through access to a localized Multiple Listing Service (MLS) and, naturally, through their day to day business experiences (Johnson et al. 2015). They are typically involved in advertising property, suggesting listing prices, conducting open houses, and negotiating with buyers (Barwick & Pathak 2015). Current marketing strategies include MLS Virtual Tours, and MLS Photographs (Allen et al. 2015). Augmented Reality is also discussed as a service that can be of value to real estate agents when showing a property to a client (Paredes 2014). Additionally to MLS services, many real estate agents already use a range of mobile apps

LBS 2016
13th Conference on Location-Based Services
Vienna, 14–16 November 2016

Published in “Proceedings of the 13th International Conference on Location-Based Services”, edited by Georg Gartner and Haosheng Huang, LBS 2016, 14-16 November 2016, Vienna, Austria.

and web services, e.g. specific real-estate related websites and apps (e.g. Zillow, RPR mobile), routing and neighborhood exploration tools (Google Maps), recording and video streaming apps (e.g. BombBomb, Periscope, or Hyperlapse), floor plan assistants (Roomscan), and general document management tools (Sign Easy, DropBox).

In our research we apply a user-centered design approach with three iterative stages as described in Rogers et al. (2015). First, we conduct in-depth interviews with realtors in Florida to gather user requirements and user needs. Second, we create an interactive prototype running on mobile devices, and third, we test the prototype with realtors. The in-depth interviews were conducted to gain insight about the specific user needs of real estate agents. During the interviews we requested the agents to elaborate on a number of topics, including: desired mobile support for the planning and conducting of showings and follow-ups with clients; information needed to present to different groups of clients during showings; day-to-day work-related usage of mobile phones, apps, and websites; and current trends, desired improvements, and problems when out in the field.

Within the first interviews some initial user needs were identified:

- When a client wants to view a property, the real estate agent needs routing and parking information, and information on how to enter to the property. Often, doors can be opened with an e-key via the smartphone.
- If the property is part of a condominium building or estate, information about the whole site and common property is often missing during showings. The information needed includes e.g. the location of and access to swimming pools, gyms, basements, or garbage cans.
- During showings, there is often the need to reschedule subsequent meetings, (re-)plan tours, and to inform associated colleagues about any schedule changes.
- A relevant number of customers buy property without actually visiting the estate. Virtual showings with video streaming for clients that are not present during showings are thus another important need.
- Information about the neighborhood is mostly gathered by the clients themselves (either locally or via the internet). Due to the US Federal Fair Housing Laws real estate agents cannot discuss neighborhood demographics that could indicate discrimination.
- Information about the property itself, a condominium building's common property, and the neighborhood clearly has to be tailored for different demographic groups: age, number of children, pets, professional occupation, and other characteristics will result in different information needs.
- Keeping in touch with their network of colleagues, business partners and other acquaintances is very important for real estate agents, be-

cause anybody in the network might sooner or later buy or sell a house. The smartphone's versatile communication applications are already central tools for keeping in contact with acquaintances and scanning updates in their timelines.

- Statistics about the prices of sold and currently advertised houses in the area are important information that is currently not available in aggregated form. Matching property recently sold and on sale based on certain criteria could help real estate agents to more easily estimate an realistic price for the current object on sale, and help to match buyers and sellers based on financial information.

Our research is still in the first phase of requirements gathering and analysis. The analysis of the first interviews already shows user needs for innovative location based services. We will evaluate the current findings and identify more user needs by conducting more interviews. Based on the final results we will then design the location-based mobile interface, and evaluate it in a further step.

References

Allen M T, Cadena A, Rutherford J, Rutherford R C (2015) Effects of Real Estate Brokers' Marketing Strategies: Public Open Houses, Broker Open Houses, MLS Virtual Tours, and MLS Photographs. Journal of Real Estate Research, 37(3), 343-369.

Barwick P J, Pathak P A (2015) The costs of free entry: an empirical study of real estate agents in Greater Boston. The RAND Journal of Economics, 46(1), 103-145.

Johnson K H, Lin Z, Xie J (2015) Dual agent distortions in real estate transactions. Real Estate Economics, 43(2), 507-536.

Paredes A M (2014) An examination of Mobile Augmented Reality Apps for the Commercial Real Estate Industry in Mexico City. Master Thesis at London School of Business and Finance.

Rishe N, Gutierrez M, Selivonenko A, Graham S (2005) TerraFly: A tool for visualizing and dispensing geospatial data. Imaging Notes, 20(2), 22-23.

Rogers Y, Sharp H, Preece J (2015) Interaction design: Beyond human-computer interaction. 4th edition, Wiley John & Sons.

Zhang M, Wang H, Lu Y, Li T, Guang Y, Liu C, ..., Rishe N (2015) TerraFly GeoCloud: an online spatial data analysis and visualization system. ACM Transactions on Intelligent Systems and Technology (TIST), 6(3), 34.

A Proposal for Construction of a Floor Noise Map Using Web Scraping

Yang, Jong Hyeon*, Kim, Jung Ok**, Yu, Kiyun*

* Dept. of Civil & Environmental Engineering, Seoul National Univ.
** Institute of Construction and Environmental Engineering, Seoul National Univ.

Extended Abstract

In Korea, the proportion of multi-unit dwellings was 60% in 2014 and this proportion has been increasing annually. As a result, the number of civil complaints regarding floor noise have increased steadily. According to the Center for Floor Noise (CFN) operated by the Korea Environment Corporation, the number of civil complaints filled annually exceeds 15,000, with 15,455 in 2013, 16,370 in 2014, and 15,419 in 2015. The CFN provides services to tackle floor noise problems. However, as this center has only been operational on a national scale since June 3rd, 2014, it is hard to identify the national status of floor noise. This research aims to develop a floor noise map by city and province and analyze the spatial distribution of noise using data collected from March 2012 to June 2016 using web scraping.

The flow chart for the construction of a floor noise map is shown in *Fig. 1* and we used R 3.2.5 for our experiment. First, we searched for posts on Naver Cafe, the most popular portal site in Korea, with the key words "Floor Noise" to develop the floor noise map. The search period was limited to May, 2012 to June 2016 and the total number of search results was 116,465. We collected the title, contents of the post, and name of the cafe by using web scraping on the search results and excluded data with duplicate contents. Second, we conducted natural language processing on the 7996 data sets with no duplicate contents. We removed the URL, English, special characters, consonants and vowels in Korean. Then, we conducted morphological analysis with SimplePos22 in the KoNLP package. Third, we extracted the spatial position from the name of the cafe. We used the road name address basic map (20160809 version) downloaded from the National Spatial Information Clearinghouse as a reference. We investigated the name of the cafe to determine whether the administrative district, Gun or Gu, are included in the data. For duplicated Gun or Gu, we investigated whether the name of the province or city was included, and if it was not, we concluded that the data had no spatial location. We then extracted the data with the Gun or Gu included in the name of the cafe. The rest of the data were excluded from the research. Third, we examined the 2,565 posts with spatial location to check whether they were about floor noise. We divided the posts into 2 classes – a positive class and a negative class - using a Support Vector Machines(SVMs). We applied linear SVMs and used Term Frequency (TF) as term weights. We randomly extracted 826 samples and divided them into 550 training sets and 276 test sets. Finally, we constructed the floor noise map with 511 data sets classified as the positive class.

SVMs have been proven to outperform several other learning algorithms for text categorization. The procedure for text categorization with SVMs is explained in *Fig.2*. We constructed the data with results for NLP as in *Table 1*. With their ability to generalize well

Published in "Proceedings of the 13th International Conference on Location-Based Services", edited by Georg Gartner and Haosheng Huang, LBS 2016, 14-16 November 2016, Vienna, Austria.

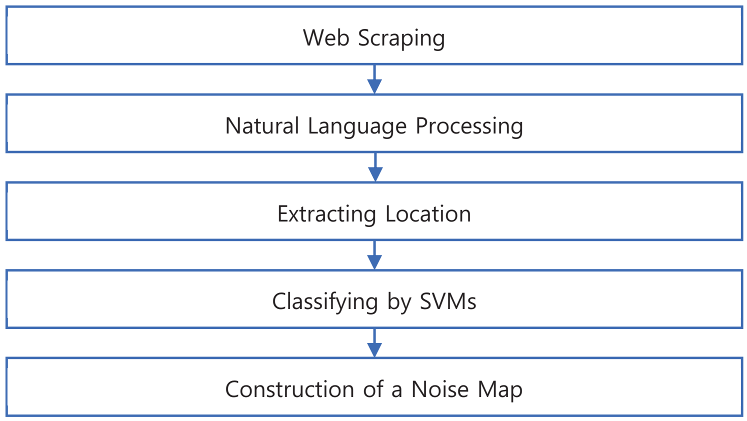


Figure 1. Flow chart

in high dimensional feature spaces, SVMs eliminate the need for feature selection (Joachims 1998). Therefore, we eliminated the feature with Document Frequency (DF) 1, to avoid being influenced by information for specific documents. We used the Linear SVMs because they provide good classification accuracy, are easy to learn and quick to classify new instances (Dumais et al. 1998). Moreover, we used TF for term weighting because it performs well (Lim 2000). We trained linear SVMs with a cost of 100 and γ 1.0. Finally, we tested SVMs with 276 test sets and evaluated performance with the $F_1 score$ in *Eq.(1)*.

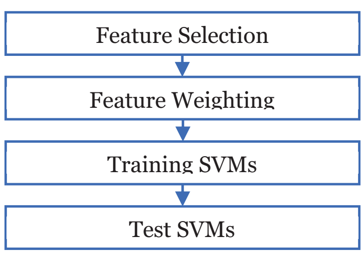


Figure 2. Procedure of SVMs

Table 1. Data type for SVMs

Type	Feature
Data1	NC (common noun)
Data 2	NC, PA (adjective)
Data 3	NC, PV (verb)
Data 4	NC, PV, PA
Data 5	Whole parts of speech in SimplePOS22

Table 2. A contingency table

	YES is correct	No is correct
Assigned YES	a	b
Assigned No	c	d

$$F_1 \ score = 2\frac{p*r}{p+r} \qquad (1)$$

$$\text{where } p = \frac{a}{a+b} \ and \ r = \frac{a}{a+c}.$$

The classification results are in *Table. 3*. Data 4 showed the best results and therefore we used the data set in our experiment. Before using data 4 in our experiment, we tested whether the value of cost and γ affects the results. We changed γ from 0.5 to 1.0 in increments of 0.1 and changed cost from 100 to 1,000 in increments of 100. The result was a value of γ 0.8 and cost 100. However, this value showed the same results as γ 1.0 and cost 100. By using data 4, we obtained 511 data points classified as positive. We analyzed the contents of the posts and constructed the noise map. By analyzing the contents of the posts, we could determine that not only does the victim post, so does the inflictor and the people who are suspected to be the inflictor. In addition, we analyzed the floor noise map in *Fig. 3* and determined that many people complain of floor noise in Sejong-si, Buchon-si, Ilsan-gu, Osan-si, Suji-gu, Paju-si, Gumi-si, and Gimhae-si.

Table 3. SVMs results

	Data 1	Data 2	Data 3	Data 4	Data 5
p	0.742	0.779	0.736	0.810	0.779
r	0.712	0.760	0.764	0.763	0.747
F_1 $score$	0.727	0.770	0.750	0.786	0.763

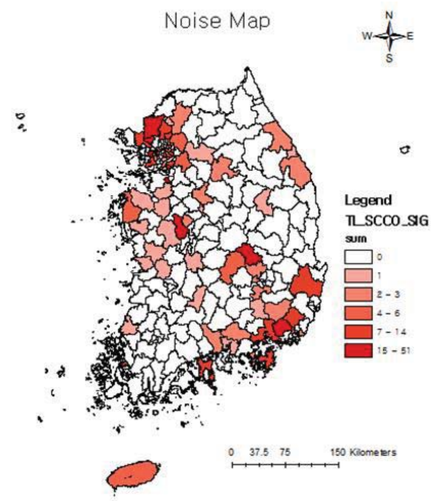


Figure 3. Noise Map

In this research, we developed a nationwide floor noise map using web scraping. We found that the combination of NC, PV, and PA showed the best results and the corresponding F_1 $score$ was 0.786, which is quite high. Moreover, we found that not only victims posted civil complaints. Inflictors and people who were suspected to be inflictors also posted in the cafe. Finally, we identified the district with many complaints of floor noise. There is a need for further research examining the relationship with socioeconomic values and the frequency of the post.

Acknowledgement

This research, "Geospatial Big Data Management, Analysis and Service Platform Technology Development," was supported by the MOLIT (The Ministry of Land, Infrastructure and Transport), Korea, under the national spatial information research program supervised by the KAIA (Korea Agency for Infrastructure Technology Advancement) (16NSIP-B081011-03).

References

Dumais S, Platt J, Heckerman D, Sahami M(1998) Inductive Learning Algorithms and Representations for Text Categorization. In Proceedings of CIKM-98, 7th ACM International Conference on Information and Knowledge Management (Bethesda, MD, 1998), p.148–155

Joachims T (1998) Text Categorization with Suport Vector Machines: Learning with Many Relevant Features. Proceedings of the 10th European Conference on Machine Learning, April 21-23 p.137-142

Lim H Y (2000) An Experimental Study on Text Categorization using an SVM Classifier, Master’s thesis, Yonsei University, Seoul, Korea, 81p

A Spatial Model against Air based Terrorist Attacks

Abouzar Ramezani*, MohammadReza Malek**

*, Malek Ashtar University of Technology, Tehran, Iran, abouzar.ramezani@gmail.com
** GIS Department, Faculty of Geodesy and Geomatic Engineering K.N.Toosi university of technology, Tehran, Iran, mrmalek@kntu.ac.ir

Abstract. As terrorist groups has undoubtedly acquired some missiles, preparing a spatial framework for analysis of such threats is of great importance for countries. Intelligent air based threats are considered as the main elements of the terrorist attacks that damage the critical infrastructures. Air defence systems playing a strategic and decisive role in defense networks require smart management and operational mechanisms to countermeasure the threats and risks, both quickly and decisively. The spread of terrorist groups, security around the world, have been threatened and should think over to reduce the vulnerability and increase the safety of critical infrastructure. Infrastructure safety management needs to consider all parameters that affect the vulnerability of infrastructure. To exploration the nature of each factor that effect vulnerability of infrastructure against airborne threat and the relation between factors will lead to the creation of a spatial framework. Our suggested spatial model facilitates the analysis, planning and decision-making in relation to reduce the vulnerability of infrastructure. To evaluate the efficiency of developed framework a method proposed to reduce vulnerability of infrastructures and to banish airborne threats equipped with GPS and INS.

Keywords. Spatial Model, Vulnerability, Airborne Threats, Infrastructure, Terrorism

1. Introduction

After the September11th terrorist attacks, worldwide focus on preventing and curbing terrorist activities is highly accelerated [1]. The total number of deaths caused by terrorism has been increased by 80 percent when compared to the figure in the prior year [2]. Terrorist groups have now achieved a variety of weapons, ammunition and equipment, and they have the capability to damage and destroy targets by their members without entering any official ground conflicts.

One of the most important factors that can curb terrorist threats is to identify their targeting areas. Lessons learned from the past support the idea that the terrorist objectives are to break the will of the people and weaken the state power, both militarily and economically, and their strategy is to destroy the centers of gravity, thereby focusing on bombing and destruction of the crucial infrastructures [2, 3].

Published in "Proceedings of the 13th International Conference on Location-Based Services", edited by Georg Gartner and Haosheng Huang, LBS 2016, 14-16 November 2016, Vienna, Austria.

Many studies in different countries have investigated the vulnerability of critical infrastructures against terrorist threats. The need for a framework that provides decision making in the field of security and risk is widely recognized. In this context, some studies have been carried out, one of which is a decision framework for safety and risk management [4]. Research conducted recently has been in the field of protective proceeding to reduce risk. A framework has been developed for managing a rapid response in the face of threats against oil and natural gas fields [5]. A risk-informed decision support for assessing the costs and benefits of counter-terrorism protective measures for infrastructures was developed in 2009 [6]. This decision support framework considers threat scenarios and probabilities, value of human life, physical damage, indirect damage, risk reduction and protective measure costs. Probabilistic terrorism risk assessments that quantify the costs and benefits are conducted for three items of infrastructure using representative cost and vulnerability data. Based on our knowledge, no work has addressed spatial framework for vulnerability assessment due to air based threats. One of the issues not resolved yet is introducing various strategies to reduce the vulnerability of infrastructures for which such a methodology could be proposed.

2. The principles of spatial framework

The aim of developing spatial framework is providing the ability of make different model to assessment vulnerability of infrastructure against airborne threats based on effective indicators, in order to understand, explain or predict the behavior of airborne threats and infrastructure. Our model is designed in such a way to reflect the fact that they embody certain aspects of the real world. After testing model a better understanding of vulnerability achieved.

In the developed spatial framework, there are four main objects that should be considered. These include passive defense object (D_p), active defense object (D_A), target object (T), and threat object (T_h). The relationship between objects are destruction (Des), deviation (Dev), protection (Pro), capturing information (Cap).

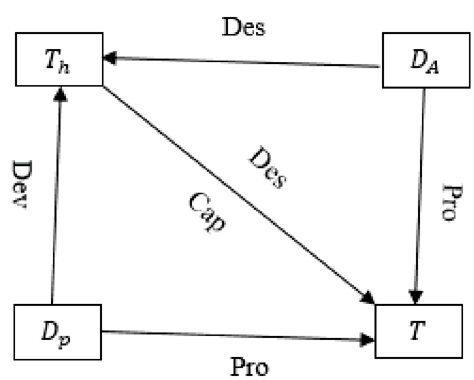


Figure 1. Relations between framework objects

A spatial framework for vulnerability analysis of infrastructure due to airborne threats as part of the general framework is developed. This framework has four main objects including airborne threat, infrastructure, radar system and misleading. Airborne threats as subset of the original threatened object are one of the main factors that damages infrastructure, which infrastructures are considered as a key element of life of a country. Radar detection systems as a protective operator have been deployed in many strategic areas of the country to identify airborne threats and avoid hitting to critical infrastructure. Jammers as passive operator protect and reduce the vulnerability of the infrastructure by disrupt the performance of threats.

Each of framework objects has properties that effect vulnerability analyzing of infrastructure. The Fig. 2 shows the properties of framework objects. Airborne threats for capturing information act like a dynamic spatiotemporal conical object. Properties include navigation error, start and end points of motion, movement restrictions and data about the volume, height and beam angle are specified. In this type of airborne threat behavior information capture by sensors and volume properties are determined by sensor resolution. Airborne threats for destructing infrastructures operate like a dynamic spatiotemporal point object, and its properties are specified. Radar system operation is like a dynamic in time spherical object and characteristics including position, horizontal and vertical coverage angle should be identified. Jammers operate like a conical static object and characteristics include beam angle and height are determined by this equipment.

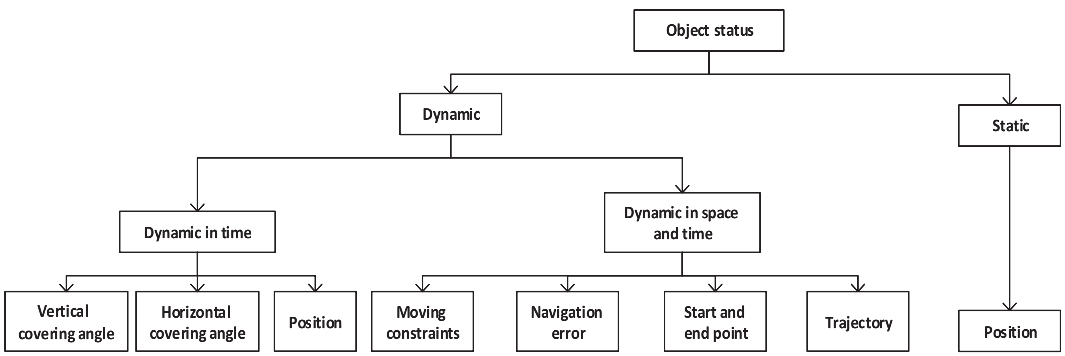


Figure 2. The properties of object status

Infrastructure behaves differently against threats. If terrorist want to capture information, infrastructure act such as a 3dimensional planar object. Whenever threats act as destructor, infrastructure act such as a 2 dimensional planar object. For a two-dimensional planar object, radius of vulnerability must be identified.

After determining the type of objects, affecting functions in vulnerabilities of infrastructure against airborne threats will be determined for each of the objects. For example, explosion functions of threat, vulnerability functions related to infrastructure and other functions of objects are specified. After determining the effective functions of each objects, framework provide the possibility to define different scenarios for vulnerability analysis.

3. Framework evaluation

For evaluating spatial framework, a model for analysis and reducing vulnerability of infrastructure is extracted and implemented. Fig. 3 shows implementation of the most probable path of airborne threats so that is would not be visible to radar object and the best location for deploying jammers. By identifying the vulnerability radius of infrastructure and the accuracy of the INS, locations of jammers could be estimated. By considering the explosion threat outside the vulnerability radius of the infrastructure, jammers should be positioned at a distance of 146.26 kilometers, or more with respect to infrastructure.

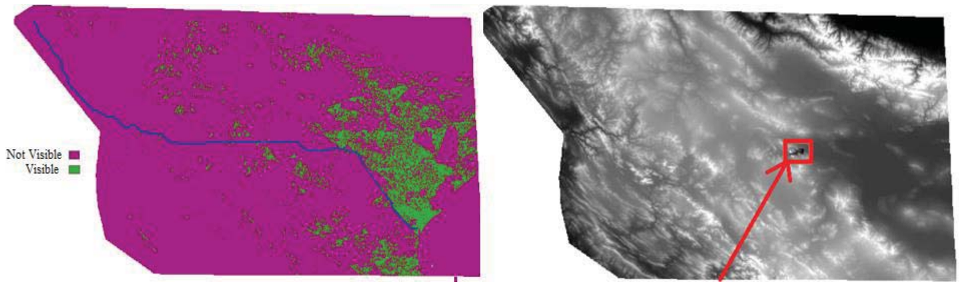


Figure 3. Implementing the most probable path of the threat by considering radar coverage

Fig. 4 shows the locations of the misleading in the three-dimensional view. As can be seen, the threat is moving in route and not visible to radar detection object.

At present, the focus is on the deployment of jammers near the infrastructure. Due to the high power of these jammers, they are identified by attackers and are, therefore, destroyed by the attackers. Another weakness of these systems is that the time of disturbance is short and against the high accuracy of inertial navigation system, thereby lowering the vulnerability degree of the infrastructure against new threats.

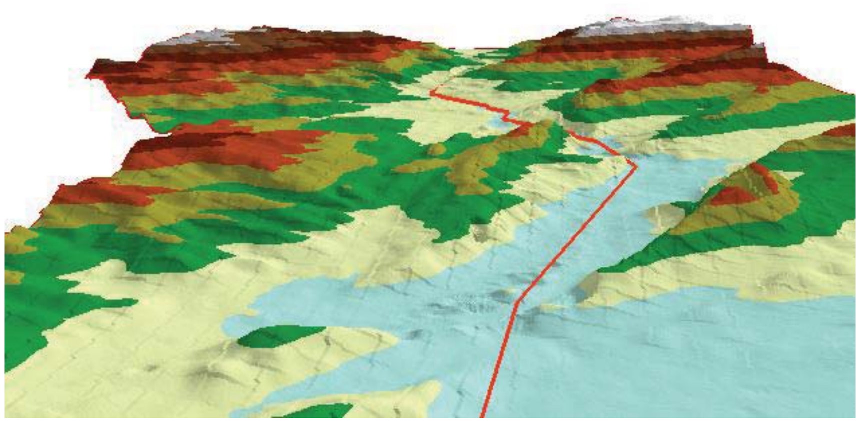


Figure 4. The three dimensional view of jammer position

By assuming that the jammers are not detected and the conventional model is employed, by establishing the high power jammer for 50 kilometers disturbances, the comparative results are shown in Table 1.

Table 1: Comparing the proposed model with the conventional model

The extent of damage	The distance between threat and target	Model
1%	1577	Proposed model
87%	183	Conventional model

4. Conclusions

A spatial framework for vulnerability Analysis against airborne threats is one of the basic needs of administrators, planners and stakeholders of infrastructures. Due to the increase in the number of terrorist groups and their access to military equipment, managers require a framework that can consider all the parameters that affect the vulnerability of infrastructures and employ measures to counter the threats. In this research, all factors influencing vulnerability of infrastructures were identified and a spatial framework was developed for the design and modeling of different scenarios. For evaluating spatial framework, a model for analysis and reducing vulnerability of infrastructure is extracted and implemented. In this model, the most probable paths of access to infrastructure were identified, and then the radius of the vulnerability of the infrastructure was calculated; in the final step, the optimum location of jammers was selected. Using the developed framework, different scenarios for analyzing vulnerability of infrastructure could be examined.

References

[1] M.G. Stewart, Risk-informed decision support for assessing the costs and benefits of counter-terrorism protective measures for infrastructure, International Journal of Critical Infrastructure Protection 3(1) (2010) 29-40.

[2] Global Terrorism Index, Measuring and Understanding impact of terrorism,institute for economics and peace, Sydney, 2015.

[3] M.G. Stewart, Cost effectiveness of risk mitigation strategies for protection of buildings against terrorist attack. Journal of Performance of Constructed Facilities, 22(2) (2008) 115-120.

[4] L. Twisdale, R. Sues, F. Lavelle, Reliability-based design methods for protective structures, Structural safety, 15(1) (1994) 17-33.

[5] M.G. Jaatun, E. Albrechtsen, M.B. Line, I.A.Tondel, O.H. Longva, A framework for incident response management in the petroleum industry. International Journal of Critical Infrastructure Protection, 2(1) (2009) 26-37.

[6] M.R. Driels, Weaponeering: Conventional weapon system effectiveness. American Institute of Aeronautics and Astronautics, Virginia, 2004.

A Multi-Agent Rescue Operation in a LBS Environment

Delavar, M.R. *, S. Azimi **, S.A. Hosseinpour **, A. Gholami **

* Center of Excellence in Geomatic Eng. in Disaster Management, School of Surveying and Geospatial Eng., College of Eng., University of Tehran, Tehran, Iran, Email: mdelavar@ut.ac.ir
** GIS Dept., School of Surveying and Geospatial Eng., College of Eng., University of Tehran, Tehran, Iran
Email: sanazazimi@ut.ac.ir, s.alihosein.p@ut.ac.ir
amin.gholami@ut.ac.ir

Abstract. Reduction of rescue operation time is of prime importance to minimize the risk associated with accident management in urban road traffic networks. With the ever increasing of urban traffic, rescue operation has to be improved. On the other hand, implementation of smart traffic and smart rescue operation within the framework of smart care is essential to establish a smart city. One of the most important steps for smart traffic and smart care concepts is to expedite the transfer of the injured caused by car accidents in urban traffic networks to the nearest and specialized medical centers. Traffic congestion in the urban traffic networks will decrease the efficiency of the rescue operation. This paper aims to propose a multi-agent based modeling to control traffic to expedite rescue operation. In order to achieve the aim, two solutions have been considered including the control of the traffic at road junctions for smooth movement of an ambulance as an agent and its interaction with other vehicles and traffic lights as other agents in the multi agent simulation. The second solution has been implemented as a location-based service (LBS) which leads to communicating some massages from the ambulance to the vehicles passing at the some lane to move to their nearest parking lots. This move aids the smooth passage of the ambulance in an obstacle free path. The two solutions have been simulated in Anylogic multi-agent software using three accident spots and a selected medical center in Tehran, capital of Iran. The scenario of this rescue operation is to simulate the transfer of the car accident injured from the three selected spots to Tehran Health Center based on the two solutions. In addition, the proposed methodology is tested

LBS 2016
13th Conference on Location-Based Services
Vienna, 14–16 November 2016

Published in “Proceedings of the 13th International Conference on Location-Based Services”, edited by Georg Gartner and Haosheng Huang, LBS 2016, 14-16 November 2016, Vienna, Austria.

using three case studies where the injured is transferred to the Tehran Health Center using the ambulance moving along with some other vehicles in the same route. The second case study consists of changing traffic lights to green based on the messages communicated to the traffic lights. The third case study considers the second one in addition to the messages which have been sent to the vehicles at the same route by the ambulance in order to guide the vehicles to their nearest parking lot. The results verified that up to 50% time reduction of the rescue operation could be achieved comparing the first and the third case studies.

Keywords. LBS, Rescue, Multi-Agent, Simulation, Smart city, Smart traffic, Smart care

1. Introduction

Emergency operation occurs anywhere at any location, at any time, and in various ways for those who are at risk. These situations require an urgent and informed response. Therefore it is very important to employ direct, fast and efficient actions to minimize the associated risks. With the increasing number of population in the metropolitan areas, the problem of traffic congestion has grown to an alarming situation. This problem has to be properly analyzed and the appropriate measures have to be taken. Even if each and every vehicle passing through the traffic has its own need, the prime importance is given to the ambulance and other emergency vehicles which should not wait in the traffic thereby decrease the probability of risk. Transfer of a patient to hospital in emergency seems very sensitive during peak urban traffic hours. Optimum utilization of the time after an accident in the golden hours of the accident management is a measure of effectiveness of an emergency response service provider system (Sangeetha et al. 2014).

Sonika et al. (2014) introduced a new vivid scheme called intelligent transportation system (ITS). The concept of this scheme was to green the traffic signal in the path of ambulance automatically with the help of radio frequency (RF) module. This will asist the ambulance to reach the accident on time and save human life. In this case, the the accident location will be introduced to the main server. The main server finds the nearest ambulance to the accident zone and sends the exact accident location to the emergency vehicle. The control unit monitors the ambulance and provides the shortest path to the ambulance at the same time to controll the traffic lights

according to the ambulance location and speed and thus arriving at the hospital safely. Bhandari Prachi et al. (2014) implemented the new system in which there is an automatic detection of accident through sensors provided in the vehicle. A main server unit has access to the database of all hospitals in the city. global positioning system (GPS) and global system for mobile communications (GSM) modules in the concerned vehicle will send the location of the accident location to the main server to call an ambulance from the nearest hospital to the accident spot. Along this there would be control of traffic light signals in the path of the ambulance using RF communication. A patient monitoring system in the ambulance will send the vital parameters of the patient to the concerned hospital. This system is fully automated, thus it finds the accident spot, controls the traffic lights, helping the ambulance to reach the hospital on time. López et al. (2008) developed a multi-agent system for coordinating ambulances for emergency medical services. The system architecture consist of some ambulance team agents and an ambulance coordinator agent. The ambulance coordinator agent collects requests for services from other external agents (including human operators). The medical service consists of reaching to the patient's location, giving the patient first aid, and transfering the patient to the appropriate medical center. Using a *winner determination algorithm*, the ambulance coordinator agent selects the ambulance to which it assigns the service. An ambulance team agent's goal is to estimate the time required to perform a service according to the ambulance current location using GPS infrastructure availability, and crew, and the traffic conditions. So, the time to get to the patient decreases.
In this article the interaction of smart traffic and rescue operations is considered as a multi-agent simulation (MAS). Intelligent transportation systems (ITS) are needed urgently to improve the road network capacity. MAS provides the actors with different abilities and goals, communicate with them in the common environment through the interaction between the accident messages delivery systems.

A smart city is an urban development vision to integrate multiple information and communication technology (ICT) and internet of things (IOT) solutions in a secure fashion to manage a city's assets which includes local departments information systems, schools, libraries, transportation systems, hospitals, power plants, water supply networks, waste management, law enforcement, and other communities services[1]. Smart cities can be identified along six main elements including: smart economy, smart mobility, smart governance, smart environment, smart living and smart people (Li at al. 2013). Smart city is a combination of sensor networks (Li et al. 2013).

[1] http://en.wikipedia.org/wiki/Smart_city

Of these, smart mobility refers to local and supra-local accessibility, availability of ICTs, modern, sustainable and safe transport systems (Vanolo 2013). Normal traffic light system operates on a timing mechanism that changes the lights after a given interval, however in the smart traffic system, drivers will not spend unnecessary time waiting for the traffic lights change.

Also, smart health is a complement to the concept of mobile health within the context of smart cities that provides a rich context-aware environment (Solanas et al. 2014). *Figure 1* shows different types of smart health in a smart city.

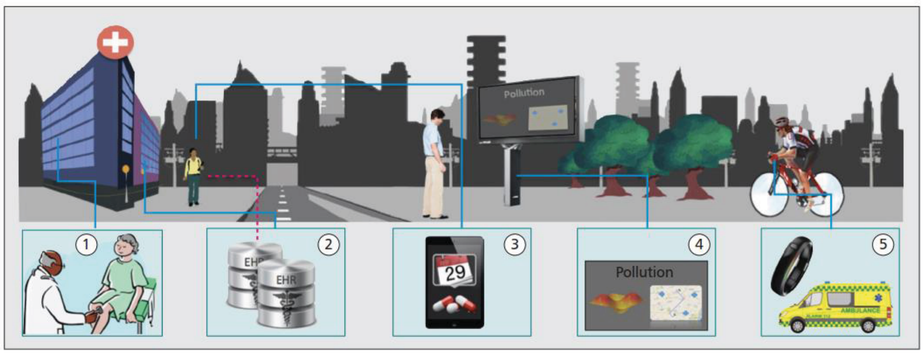


Figure 1. Examples of different kinds of health within the context of a smart city (Solanas et al. 2014)

Diffrent parts of Figure 1 are explained below:

(1) — Classical health. This is a typical health-related activity, that is, a doctor visiting a patient with traditional tools (which do not necessarily involve ICT).

(2) — E-Health. This involves the use of electronic health records (EHR) and databases that store medical information of patients.This is a subset of classical health that uses ICT.

(3) — M-Health. An example is a patient checking his/her prescriptions from his/her mobile phone to guarantee medication adherence. This is a subset of E-health since it uses mobile devices to access medical data.

(4) — S-Health. A patient gets information from an interactive information pole to check the pollution level as well as the level of pollen and dust for which he/she has allergies.Thanks to this information, the patient can avoid areas that could be dangerous for his/her health condition. The information pole informs him/her about the best route to go, and where the closest pharmacies are to buy antihistamine pills.

(5) — M-Health augmented with S-Health. A cyclist wearing a bracelet with accelerometers and vital constants monitoring capabilities has an

accident. The body sensor network detects the fall and sends an alert to the city infrastructure. When the alert is received by the system, the conditions of the traffic are analyzed, and an ambulance is dispatched through the best possible route. In addition, the traffic lights of the city are dynamically adjusted in order to reduce the time needed by the ambulance to reach the cyclist (Solanas et al.2014).

A multi-agent simulation for modeling of reduction of arrival time of ambulance in an accident is used in this article. According to the heterogeneity of the involved fields, there is no common agreement about a definition of the term agent (Sengupta and sieber 2007). An agent can be anything, such as a robot that perceives its environment through sensors and acts upon it through its effectors (Russell et al. 2003). This definition is shown in *Figure 2*.

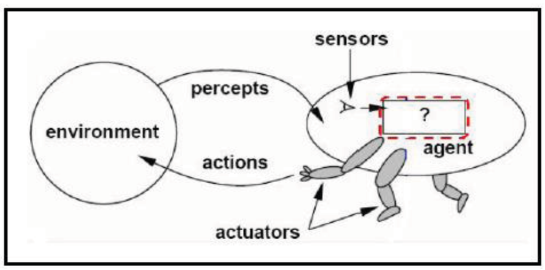


Figure 2. An agent in its environment (Russell et al. 2003)

Agents are autonomous entities or objects which act independently of one another, although they may act in concert, depending upon various conditions which are displayed by other agents or the system in which they exist (Batty and jiang 1999). Franklin and Graesser (1996) formalise the definition of an autonomous agent as "a system situated within and a part of an environment that senses that environment and acts on it, over time, in pursuit of its own agenda and so as to effect what it senses in the future". Agents are endowed with behaviours that are usually proscribed in a series of rules that are activated under different conditions. This is in the manner of stimulus and response (or push and pull, or some such reactive logic), and in this sense, agents always engender change (Batty et al. 2012).

Multi-agent systems (MAS) depict systems as a combination of multiple autonomous and independent agents and are therefore well suited to simulate collaboration of different actors (Sokhansefat et al. 2012). A multi-agent system consists of several agents working in cooperation within a single environment, towards a universal goal (Roozemond 2001).

Adapting the definition of Ferber (1999), the term multi-agent system refers to a system consisting of the following parts:

• The environment, E , consisting of the following elements:

- A set of objects O: Objects can be perceived, created, destroyed and modified by agents.
- A set of agents A: Agents are a subset of objects (A⊆O) capable of performing actions (the active entities of the system).
- A set of locations L determining the possible position of the objects (from the set O) in space.

• An assembly of relations, R ,which link objects and also agents to each other.

• A set of operations ,Op, enabling the possibility for agents to perceive, manipulate, create, destroy objects of O, in particular representing the agents' actions.

• A set of operators U with the task of representing the application of the operations from Op and the reactions of the world to modification. The operators from U are called the laws of the universe.

Rescue operation has been focused especially in urban environment due to the ever-increasing traffic in urban road networks. In terms of rescue operation, in addition to selecting the optimal route from different perspective, control and management of traffic for ambulance movement facilities, is an important factor. On the other hand, interaction and coordination among the ambulances and other vehicles on the road, is of prime importance for a proper rescue operation.

In order to have enough space for the passage of ambulance in a collision free path, some free paths should be allocated. In that case, the ambulance travel times is reduced. This arrangement can make a significant contribution to smart traffic which is an essential element for the creation of smart city.

Therefore, it is recommended to consider intelligent approaches such as Multi-Agent Rescue Operation.

In this article, we are faced with the question that, how do we accelerate rescue operation by ambulance, in a smart city and using its concerned elements and modeling of the multi-agent system by using a location based service? So, the hypothesis of this article is that selecting an optimal route, traffic control and interaction with vehicles and ambulance could accelerate rescue operation and the movement of ambulances. Also equipped ambulances by a GPS navigation system for smart city is supposed.

In this article, the allocation of the hospital to the accident site is not investigated. So, it is assumed that the selected hospital in this article is the best hospital allocated to the accident site. It is assumed that the ambulance is connected with other vehicles in terms of alarms and messages communica-

tion. This connection can be direct or via a communications center between the ambulance and other vehicles. So that other vehicles become aware of the existence of the ambulance on their ways or ambulance can notify them of its existence.
In this article, the transfer of the wounded to the hospital by ambulance is considered. According to the mentioned problems for this rescue operation, a method for reducing the arrival time of the ambulance from the accident site to the hospital is proposed. The proposed method models the message communication the ambulance to other vehicles and traffic lights for evacuating a lane in the urban traffic network for passing the ambulance in the multi-agent simulation software.

The rest of this paper is organized as follows: Section 2 explaines the details of the proposed multi-agent rescue operation, computation of optimal path for ambulance routing and the communications between the proposed agents in Anylogic software. Section 3 explaines input images, the proposed hospital, Anylogic multi-agent simulation software and 3 case studies for implementing of the proposed simulation. Finally section 4 presents results, conclusions and directions for future research.

2. Methodology

In this paper, a method for minimizing the ambulance travel time caused by traffic congestion and providing the smooth flow of emergency vehicles was proposed. According to this method, interaction of smart traffic and rescue operation is considered as a multi-agent simulation in Anylogic software. As shown in *Figure 3*, the proposed multi-agent rescue operation consists of a number of agents such as vehicles, ambulance and traffic lights which coordinate with each other and make sure that ambulance agent reaches the hospital at the shortest possible time.

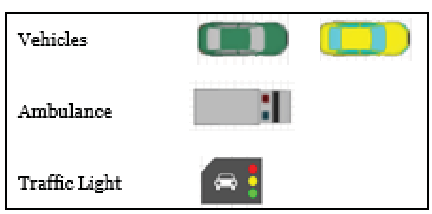


Figure 3. Illustration of the agents proposed in the multi-agent simulation in Anylogic software

Whenever an accident occurs, an ambulance of appropriate hospital is dispatched to the accident site. Selecting the optimal path through an urban traffic road network for transferring the wounded to the hospital by ambulance is an important issue in a rescue operation. The efficient management of ambulance routing from the incident site to the appropriate hospital is a vital aspect of the quality of health services offered to citizens. The routing algorithm is carried out in Anylogic software. This routing algorithm considers time, distance parameter parameters and the changes of traffic congestion for computing the optimal path. This routing algorithm is used for computing the optimal path for the ambulance routing.

The proposed multi-agent rescue operation simulation is divided in three units including the ambulance unit, the vehicle unit and the traffic unit which are explained below.

2.1. The ambulance unit

After finding the optimal path, this path is displayed by a GPS navigation system in ambulance as shown in *Figure 4*. The ambulance agent on the optimal path, sends some messages to existing vehicle agents on the same lane in addition to some messages to pedestrian traffic lights and traffic intersection lights to provide a free space for the vehicle agent crossing the lane to vacate the lane for the ambulance.

Figure 4. GPS navigation system in ambulance

2.2. The vehicle unit

Existing vehicles on the optimal path of the ambulance are received the messages from the ambulance agent and provided a free lane and assigned that lane to the ambulance. On the other hand, when the ambulance sends the messages to the existing vehicles on the streets and junctions, these vehicles updated their knowledge with the messages and withdrawn from the routes and evacuated the lane for the ambulance. The message from the ambulance to the drivers of vehicles will be announced through the GPS navigation system in vehicles as shown in *Figure 5*. In Anylogic software, some parking lots for navigating the vehicles to the side of the optimal path are considered.

Figure 5. GPS navigation system in the vehicles

2.3. The traffic unit

In this paper, intelligent traffic light system for controlling of traffic light signals in the route of the ambulance is considered. When the ambulance reaches within the specific range of the traffic intersection lights and pedestrian traffic lights, sends messages to them, then the traffic lights will change to red for other vehicles. On the other hand, the trafic light agents updated their knowledge with these messages. These traffic lights send a massage to other traffic lights in their neighborhood so they became red. Java codes is used for implementing of traffic unit in Anylogic software. The *Figure 6* shows the summary of the steps of project.

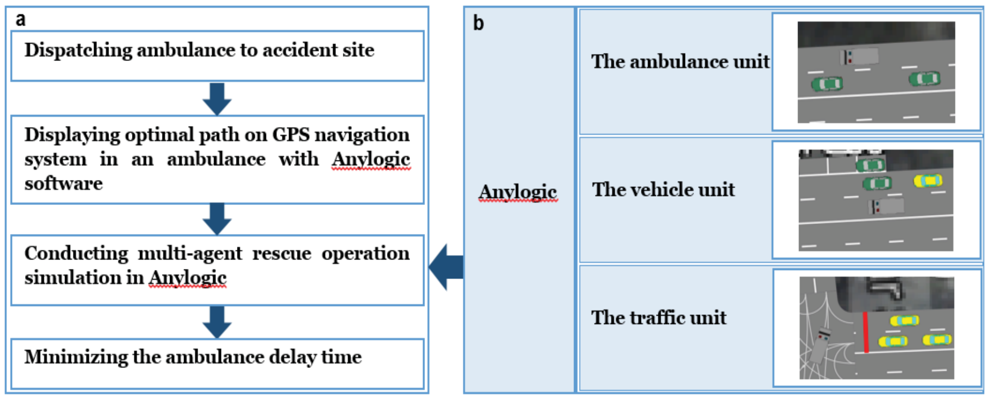


Figure 6. a) The summary of the steps of project. b) Three units of our multi-agent rescue operation simulation

3. Implementation

AnyLogic is the simulation tool that supports the most common simulation methodologies in place today including system dynamics, process-centric, and agent based modeling. Java and unified modeling language for Real Time(UML RT) are programming languages in this software. Anylogic software simulation has many benefits including reduction of the reduces cost and time of modelling, includes object libraries to provide the ability to quickly incorporate pre-built simulation elements and runs models anywhere. This multi-agent software supports both tile maps from free online providers and shapefile based map[2]. In this study, Anylogic software is considered for the multi-agent simulation. This software includes a traffic library for simulating traffic on highways and streets. This library supports detailed yet highly efficient physical level modeling of vehicle movement. Traffic library is suitable for modeling highway traffic, street traffic, on-site transportation at manufacturing sites, parking lots, or any other systems with vehicles, roads, and lanes.

The selected hospital for our simulation is Tehran Heart Center located in District No.6 of Tehran on North Kargar avenue (from 35°42'04.9"N 51°23'28.0"E to 35°44'47.9"N 51°23'20.7"E) at the west of Tehran capital of Iran. This hospital was inaugurated in 2001 having 460 inpatient's beds.

[2] http://www.anylogic.com/

This medical center is one of the best-equipped diagnostic and therapeutic cardiology centers in the region as shown in *Figure 7.*

Satellite images of Tehran Heart Center and surrounding areas provided by Google Earth. First, satellite images have been mosaiced and then these images used for the simulation in Anylogic software.

In this paper, three case studies have been considered for the proposed methodology. In these case studies, the location of the wounded has been changed. For each of the case studies, three types of multi-agent rescue operation simulations of the ambulance routing from the incident site to the Tehran Heart Center have been considered. In the first simulation, typical situation regardless of the messages from the ambulance to traffic lights and vehicles has been implemented. In the second simulation, only the messages from the ambulance to traffic lights has been implemented. The third simulation implemented the idea that messaging from the ambulance to traffic lights and other vehicles in the same lane have been considered.

Figure 7. Satellite image of Tehran Heart Center

In these case studies, traffic lights are considering 30 seconds red light and 15 seconds green light.

3.1. Case study No.1

In the first case study, it is assumed that an accident happened in intersection of Zommorrod Street and North Kargar Street as shown in *Figure 8* and the ambulance was dispatched to the accident site. As it was explained, three types of simulation of the ambulance routing from the incident site to the Tehran Heart Center have been implemented for this case study.

Figures 9, 10 and *11* have illustrated these simulations. Traffic library of Anylogic software has seven blocks for defining vehicle flow such as CarSource, CarMoveTo, CarDispose and TrafficLight. CarSource block Generates cars, puts them into the specified location inside a road network and soon. CarMoveTo block controls the car movement and CarDispose block removes the car from the model. TrafficLigth block simulates the traffic light and signalling device positioned at road intersections, pedestrian crossings, and other locations to control conflicting flows of traffic. For this case study, *Figure 12* shows ambulance agent behaviour and *Figure 13* shows vehicle agents behaviour through these blocks in road network in third simulation.

Figure 8. Implementation of the first case study (accident site shows with red circle)

Figure 9. The first multi-agent rescue operation simulation in the first case study (ambulance shows with red circle)

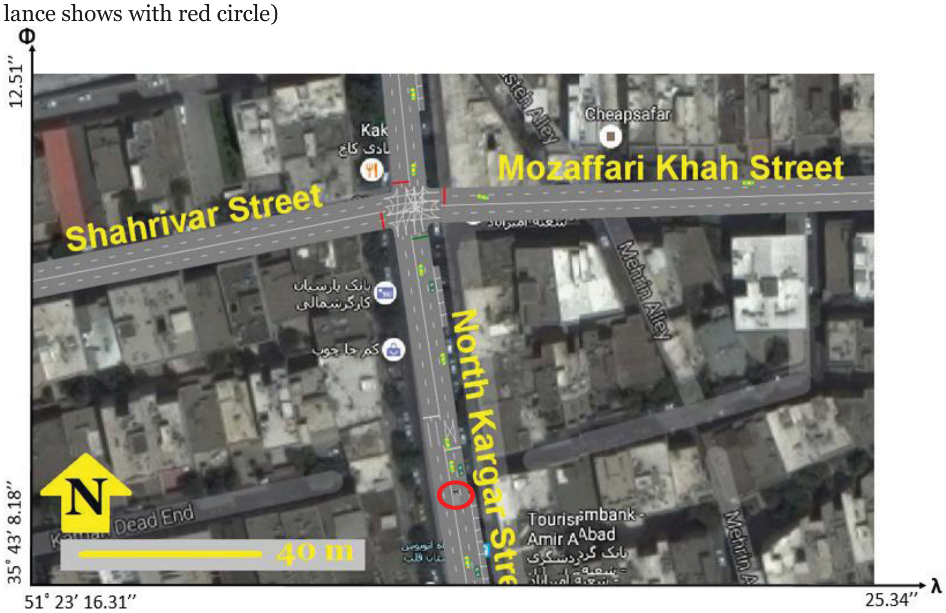


Figure 10. The second multi-agent rescue operation simulation in the first case study (ambulance has been shown with red circle)

Figure 11. The third multi-agent rescue operation simulation in the first case study (the ambulance has been shown with red circle)

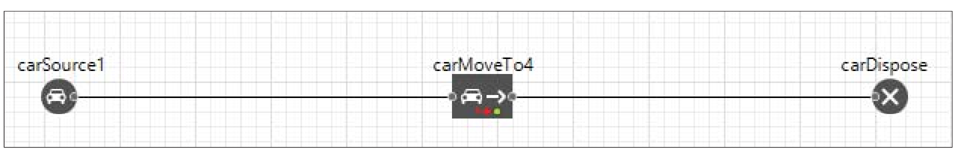


Figure 12. Blocks of traffic library for defining flow of ambulance in the road network for the third simulation of the first case study

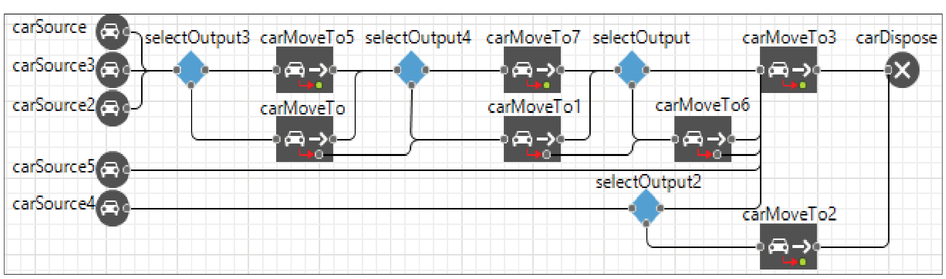


Figure 13. Blocks of traffic library for defining flow of vehicles in the road network for the third simulation of the first case study

3.2. Case study No.2

In the second case study, it is assumed that an accident happened in Mozaffari khah Street as shown in *Figure 14*. According to what was described, three multi-agent rescue operation simulations have been considered. For this case study, blocks of traffic library for determining the flow of the ambulance and the vehicles is considered.

Figure 14. Implementation of the second case study (accident site shows with red circle)

3.3. Case study No.3

An accident was happened in Salehi Street before Salehi and Majd streets intersection for the third case study as shown in *Figure 15*. According to the previous case studies, three multi-agent rescue operation simulations have been implemented and blocks of traffic library for determinig the flow of the ambulance and the vehicles is considered.

The arrival time of the ambulance from the accident site to Tehran Heart Center is measured in the three types of simulations in the form of the three case studies as shown in *Table 1*. According to the results of *Table 1*, the proposed idea of this paper led to significant reduction of the an ambulance delay time from the accident sites to Tehran Heart Center.

Figure 15. Implementation of the third case study (the accident site has been shown with red circle)

Case studies No.	Simulation 1	Simulation 2	Simulation 3
1	72.4	47.9	29.1
2	81.5	47.8	36.9
3	113.7	70.9	62.0

Table 1. Travel times of the ambulance to Tehran Heart Center in different scenarios (Seconds)

As the results suggest, accidents happen everywhere, if no solution is expected to reduce path traffic for ambulance, rescue operation may be done in a long time. In the next step, if the intersection traffic lights are always green for an ambulance, time relief 30%-40% can be reduced. In the final step, if in some way the communication between ambulances and other vehicles occur, For example, through special sensors as vehicles are aware of the arrival of the ambulance, the rescue time can be reduced by 18%-35%. Therefore, the combination of the second and third causes, time relief has been decreased by 48%- 61%. The rescue time depends on the traffic volume and the number of lanes. If the path length and traffic volume are high and the number of lanes is low, the coordination with the vehicles to change their lane significantly reduced.

4. Conclusion

Along with population growth, the number of vehicles on the road is increased. Therefore the problem of traffic management arises specially for emergency vehicles. In this paper, a novel idea is proposed for reducing the delay time caused by traffic congestion and providing the smooth flow of emergency vehicles by the multi-agent rescue operation simulation. The proposed idea was implemented in Anylogic software.In Anylogic software, the algorithm for computing optimal route for passing the ambulance considered time, distance parameters and the changes of traffic congestion. The multi-agent rescue operation simulation was divided in to the ambulance unit, the vehicle unit and the traffic unit. An ambulance sends messages to existing vehicles on the path, pedestrian traffic lights and traffic intersection lights to assign the free lane to the ambulance. Optimal route is displayed by the GPS navigation system in ambulance and the massages from ambulances to vehicles displayed by the GPS navigation system in the vehicles.

Tehran Heart Center was selected for the proposed simulation. Three case studies were considered for this multi-agent rescue operation that location of the wounded is different in these case studies. For each case study, three simulations were considered. In the first simulation, typical situation regardless of the proposed idea has been implemented and in the second simulation, only messages from the ambulance to traffic lights has been implemented. The proposed idea has been implemented in the third simulation.

According to the results of *Table 1*, the ambulance delay time in the second simulation to the first simulation has been reduced by 37.6% and during the third simulation compared to the first simulation,the delay time has been reduced by 53.3%. Also, the ambulance delay time in third simulation compared to the second one had 24.83% improvement. On the other hand, our idea was improved the ambulance delay time approximately 24.83% to previous ideas that only control traffic lights in the path of ambulance is cosidered. These results verify that our idea can accelerate rescue operation by the ambulance, in a smart city using smart care and smart traffic elements and modeling of the multi-agent system.

In our future work, we test the idea on another hospitals, road networks and accident sites to achieve more reliable results. If the allocation of the wounded to hospitals to be considered in the proposed simulation, the results of simulation become more closer to reality. For a more realistic simulation, dynamic modelling of streets and roads due to obstruction of roads and uncertainty in location of accidents and arrival time of ambulance can be considered. There may be some inconsistencie in messages between agents, so data fusion algorithms can be used to solve this inconsistencie.

References

Batty M, Jiang B (1999) Multi-agent simulation: new approaches to exploring space-time dynamics in GIS.

Batty M, Crooks Andrew T, See Linda M, Heppenstall Alison J (2012) Perspectives on agent-based models and geographical systems Agent-Based Models of Geographical Systems, Springer, pp.1-15.

Ferber J (1999) Multi-agent systems: an introduction to distributed artificial intelligence . Vol. 1: Addison-Wesley Reading.

Franklin S, Graesser A (1996) Is it an Agent, or just a Program?: A Taxonomy for Autonomous Agents. Paper presented at the International Workshop on Agent Theories, Architectures, and Languages, pp.21-35, Springer Berlin Heidelberg.

Li D, Shan J, Shao Z, Zhou X, Yao Y (2013) Geomatics for smart cities-concept, key techniques, and applications. Geo-spatial Information Science . vol. 16, no. 1, pp. 13–24.

López B, Innocenti B, Busquets D (2008) A multiagent system for coordinating ambulances for emergency medical services. Institute of Electrical and Electronics Engineers (IEEE) Intelligent Systems, pp.50-57.

Prachi B, Kasturi D, Priyanka C (2014) Intelligent Accident-Detection And Ambulance-Rescue System. International Journal of Scientific & Technology Research . vol. 3.

Roozemond Danko A (2001) Using intelligent agents for pro-active, real-time urban intersection control, European Journal of Operational Research, pp.293-301.

Russell Stuart J, Norvig P, Canny John F, Malik Jitendra M, Edwards Douglas D (2003) Artificial intelligence: a modern approach .Vol. 2 : Prentice hall Upper Saddle River.

Sangeetha K, Archana P, Ramya M, Ramya P (2014) Automatic Ambulance Rescue With Intelligent Traffic Light System. International organization of Scientific Research journal of engineering (IOSRJEN), pp.53-57.

Sengupta R, Sieber R (2007) Geospatial Agents, Agents Everywhere. Transactions in GIS, pp.483-506.

Sokhansefat G, Delavar M, Banedj-Schafii M (2012) Multi-Agent Simulation of Wayfinding for Rescue Operation during Building Fire. In Proceedings of World Academy of Science, Engineering and Technology, no. 72, p. 1204. World Academy of Science, Engineering and Technology (WASET).

Solanas A, Patsakis C, Conti M, Vlachos S,Ramos V, Falcone F, Postolache O, Pérez-Martínez A, Di Pietro R, Perrea N and Martínez-Ballestél A (2014) Smart Health: A Context-Aware Health Paradigm within Smart Cities . Institute of Electrical and Electronics Engineers (IEEE) Communications Magazine 52.8, pp.74-81.

Sonika S, Sathiyasekar Dr K, Jaishree S (2014) Intelligent accident identification system using GPS, GSM modem. International Journal of Advanced Research in Computer and Communication Engineering.

Vanolo, A. (2013) . Smartmentality : The Smart City as Disciplinary Strategy. Urban Studies Journal, pp. 1-16,.

Improving the Performance of Airport Service Cars Using Mobile GIS

AboozarRamezani*, MohammadReza Malek**

* Malek Ashtar University of Technology, abouzar.ramezani@gmail.com
**K.N.Toosi University of Technology,mrmalek@kntu.ac.ir

Abstract. Despite the traffic increases at the World airports, little works have been done to improve vehicles and airplanes services, increase efficiency and decrease service automobile voluminous of large number. With GIS abilities, airport managers would like using its potential for development and management of airports. So new issue in GIS is formed with Airport GIS (AGIS) title to study GIS applications in airport as wide and corporation all world airports and GIS specialists.

The main innovation of this research is to offer a spatiotemporal data analysis and introducing an efficient algorithm for service automobiles allocation optimization with reduction in departure time deferment constraint. Allocation has been done by considering the two parameters include push and tow time of aircraft and its distance to the service car. In this proposed solution servicing operation optimizes with considering two situations. Numerical results of using proposed method in Mehrabad international airport indicate in both situations, departure delay is lesser than usual method. Outcomes of minimizing service cars are: traffic reduction, increase management efficiency, decrease hazards due to large number of service cars and increase safety in airport field.

Keywords. Airport GIS, Pushback tractor, Airport, allocation

1. Introduction

Nowadays airport analyzers and engineers come toward GIS to support their efforts in planning, operation, maintenance, security with adding spatial information and modeling and use its potential in airport development and management [1]. So new issue in GIS is formed with AGIS title to study GIS applications in airport as wide and corporation all world airports and GIS specialists [2].

Increasing the number of airport flights causes the need for increasing in number of airport service cars. Increasing the number of service cars causes: increase in possibility of accidents, safety reduction, decrease operational efficiency and consequence decrease management efficiency [3].

One of the most important and expensive service cars in airport is pushback tractor that Mehrabad airport face to leakage of this car. For respond to

LBS 2016
13th Conference on Location-Based Services
Vienna, 14–16 November 2016

Published in "Proceedings of the 13th International Conference on Location-Based Services", edited by Georg Gartner and Haosheng Huang, LBS 2016, 14-16 November 2016, Vienna, Austria.

pushback tractor leakage and its outcome that increase number of airport service cars one effective solution is allocation optimization.

2. Modeling

Push and tow service is one of the several services that is serving to airplanes. In this service the push back tractor does carry the airplane from apron to taxiway. There are other services in airport. For example, there are passenger and cargo transport service, air condition service, lavatory service, water service and fuel service. These services could be done in two situations: 1) In this case service car must be return to its EPA. Fuel service operates like this situation.

2) In other situation service car after did service, can be go to ESA and park there. The air condition service could be move between all of airplanes and serving to their without returning to EPA. Pushback tractor spends time for travel form its station to aircraft station. Pushback tractor through push and tow operation transmit aircraft to taxiway. Push and tow procedure is dependent on distance from the plane to taxi and the traffic around. After transferring aircraft to taxi way, aircraft goes to runway and push back tractor returns to its EPA. We illustrate our proposed method in the figure 1 that includes total steps of solution.

$$min \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{o} \sum_{l=1}^{u} \left(\left(Ts_j^i + \frac{d_{kl}}{v_{kl}} + tp_j^i + A \right) - Td_k^i \right) x_{ij} z_{jl} y_{ik}$$

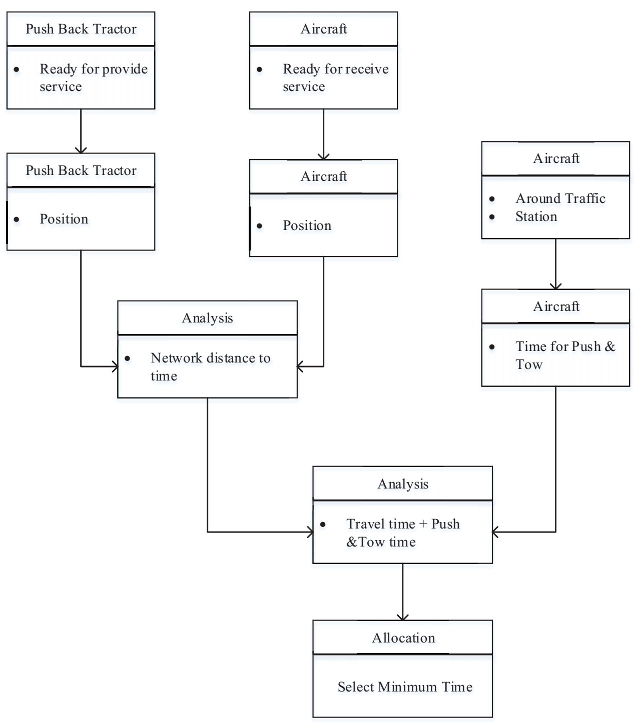


Figure 1. Steps of proposed model

3. Implementation

For implementing one of the traffic pick hours at Mehrabad airport has been considered. To evaluate the proposed method, we implement conventional methods at the airport for mentioned flights. Figure 2, 3, 4 shows the process of allocating pushback tractors to aircrafts.

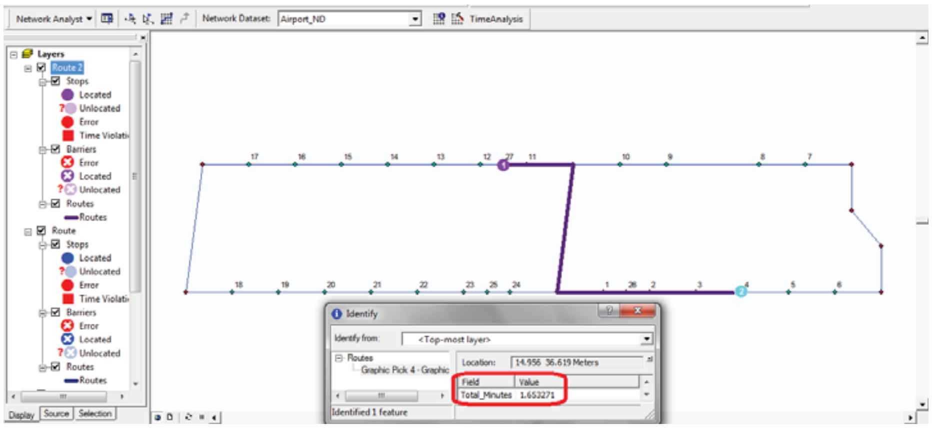


Figure 2. Calculation of network distance time for 4 and 27 stations

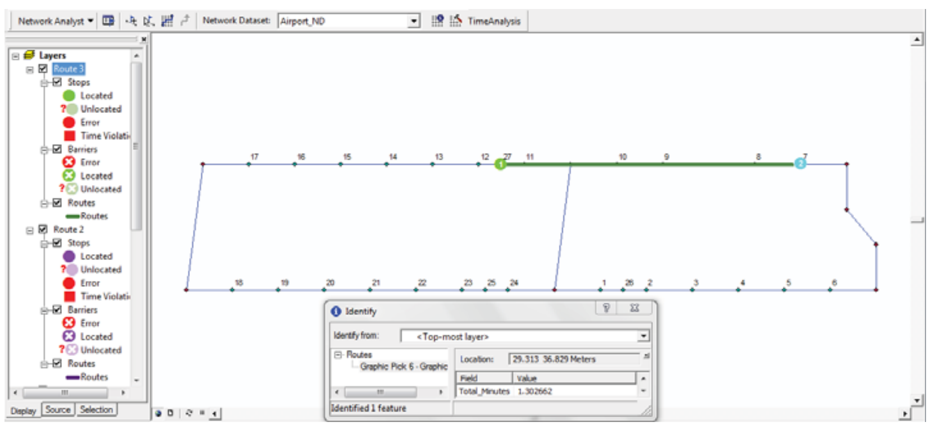


Figure 3. Calculation of network distance time for stations 7 and 27

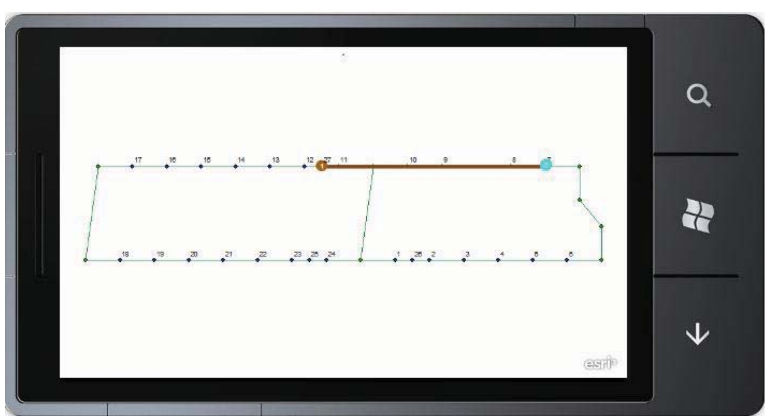


Figure 4. Informing pushback tractor to service the aircraft at station 7

Table 1 shows Comparison results of using usual method and proposed method if pushback tractor returns to EPA.

Table 1. Comparison results if pushback tractor returns to EPA

if pushback tractor returns to EPA	total delays
usual method	15.5min
proposed method	8.5min

Table 2 shows the total delays time using proposed and conventional method if pushback tractor returns to ESA.

Table 2. Comparison results if pushback tractor returns to ESA

if pushback tractor returns to ESA	total delays
usual method	7.5min
proposed method	3min

4. Conclusion

Increasing in airport traffic, force airport managements found solution that increases their management efficiency. In this article a new optimization method is suggested based on minimizing number of service cars with considering time conditions and constraints. Leakage of pushback tractor due to its high expenditure is reasonable cause for allocation optimization of this vehicle.

Optimization has been done for two situations. Using proposed method, the total delay times improved. To evaluate the proposed method, the usual method was applied. Comparison of results shows the proposed method will be has less delay in all conditions. Optimal allocation reduces traffic, increased safety, improve service operations and reduce costs.

References

[1] Gil Neumann, Mark Ricketson, Kevin Carlson, (2011). FAA’s Airport GIS Program. operations & technical affairs conference.

[2] Perry, (2009). Airports GIS and electronic ALP, Presented to RTCA SC-217/Eurocae WG-44 committee Oct 26.

[3] Rathinam, S., Montoya, J., & Jung, Y., (2008). "An Optimization Model for Reducing Aircraft Taxi Times at the Dallas Fort Worth International Airport," 26th International Congress of the Aeronautical Sciences (ICAS). Anchorage, Alaska, pp. 14-19.

[4] Williams, J. L., Hooey, B. L., and Foyle, D. C., (2006) “4-D Taxi Clearances: Pilots’ Usage of Time- and Speed-based Formats,”Proceedings of the AIAA Modeling and Simulation Technologies Conference, Keystone, CO, August.

[5] Smeltink, J., Soomer, M., de Waal, P., and Van Der Mei, R. (2005). "An Optimisation Model for Airport Taxi Scheduling," Thirtieth Conference on the Mathematics of Operations Research. Lunteren, The Netherlands.