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Head-mounted Augmented Reality Visualisation for Outdoor Pedestrian Navigation

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Abstract. Head-mounted augmented reality (AR) displays offer a great potential for pedestrian navigation that has not been fully explored so far. Here, we introduce the design of four visualisations for pedestrian navigation in outdoor settings. The first visualisation consists of cubes floating above ground and placed along the route ahead of the user. The second visualisation shows floating arrows that are positioned at turning points of the route. The third visualisation indicates the geometry with a flat line placed slightly above ground. The fourth visualisation is an animated bird avatar that is flying in front of the user. We describe the design of the four visualisations and document the implementation using the Unity game engine software and the Microsoft HoloLens hardware.

Keywords. Augmented reality, pedestrian navigation, Microsoft HoloLens

1. Introduction

Augmented reality (AR) has become a mainstream technology for pedestrian navigation with the recent introduction of Google Maps AR for smartphones (Google 2018). Our research investigates the next level of pedestrian outdoor navigation by designing visualisations for head-mounted AR displays such as the Microsoft HoloLens. These head-mounted AR devices augment the physical environment by displaying virtual objects on a screen in front of the user's eyes.

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So far, head-mounted AR displays have only been used for experimental outdoor navigation of pedestrians. Examples include the seminal "touring machine" by Feiner *et al.* (2012), the development of a campus navigation system for the Google Glass AR headset (Ang *et al.* 2018) or navigation with the Microsoft HoloLens in difficult terrain (Anandapadmanaban *et al.* 2018).

Most AR applications for pedestrian navigation are designed for mobile phones and other handheld devices. Visualisations for handheld AR devices proposed so far either consist of polyline geometry placed at ground level (for example, Huang *et al.* 2012) or virtual arrows (for example, Wenig *et al.* 2012, Rehman and Cao 2017, Google 2018). We are not aware of any work that uses more advanced geometry for outdoor pedestrian AR navigation.

2. AR Visualisations for Pedestrian Navigation

We investigated the design space of AR route visualisations by prototyping a variety of exploratory ideas. Prototypes included, for example, a virtual frog jumping along the route in front of the user, and an oversized human avatar positioned at turning points to indicate changes of direction with rhythmic arm movements.

Figure 1 shows the basic geometric elements of the four selected visualisations that we implemented in the Microsoft HoloLens: floating cubes, arrows placed at turning points, a tapered polyline placed along the route, and an animated bird avatar.

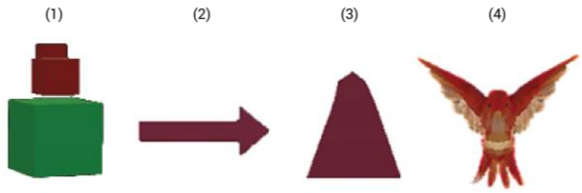

Figure 1. Geometric elements of the four route visualisations: (1) floating cubes, (2) arrows placed at turning points, (3) tapered polyline, and (4) animated bird avatar.

2.1. Floating cubes

Figure 2 shows the visualisation with floating cubes placed along the route. Three cubes float 1 metre above the ground, which reduces the likelihood for the cubes to intersect with the physical ground. To indicate the direction of movement, the floating cube closest to the viewer is coloured green and the following two cubes are red. If the distance between the user and the closest cube is less than 5 metres, the cube is hidden, a new cube is added beyond the last cube, and the colours of the three cubes are updated.

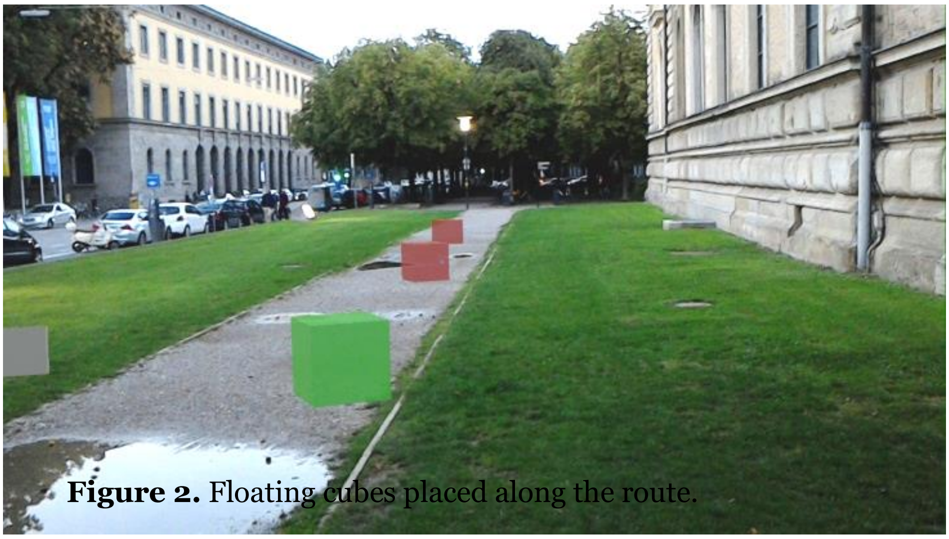

Figure 2. Floating cubes placed along the route.

2.2. Arrows placed at turning points

In this visualisation three-dimensional arrows are placed at turning points. The arrows float in the air and point in the direction of the route (Figure 3). Up to three arrows are shown, but the second and third arrows may be hidden when buildings block them. If an arrow is less than 5 metres from the user, the closest arrow disappears, and a new arrow is added at a distance.

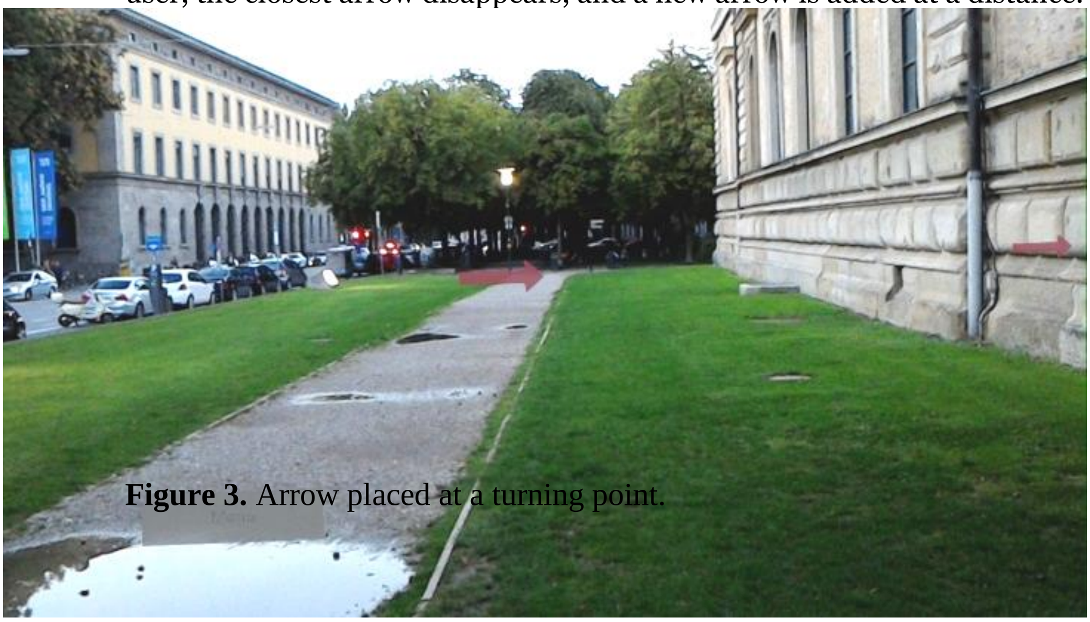

Figure 3. Arrow placed at a turning point.

2.3. Tapered polyline

In this visualisation a flat, two-dimensional polyline is placed slightly above the ground along the route (Figure 4). The line width is tapered, pointing in a forward direction. The line geometry is periodically adjusted to the user location. The line is drawn between the route point that is closest to the current user location and the subsequent three waypoints. The line geometry is updated every few seconds.

Figure 4. Tapered polyline placed slightly above ground.

2.4 Animated bird avatar

In this visualisation an animated bird avatar either flies along the route or hovers and flaps its wings in front of the user (Figure 5). A flying bird instead of an avatar moving at ground level was chosen to avoid intersections and occlusion issues of the avatar with the physical environment. The bird avatar has a moving state and an idle state. In the moving state, the bird flies in forward direction along the route. When the distance between the avatar and the user is greater than 5 metres, the bird switches to idle state, turns to the user, and hovers (with flapping wings) over its current location to wait for the user.

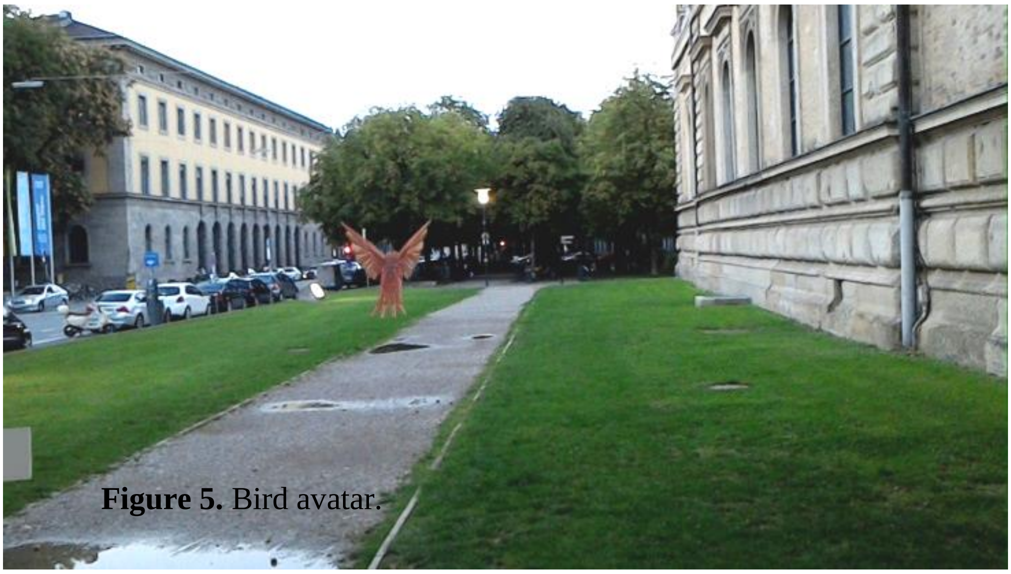

Figure 5. Bird avatar.

3. Implementation

A custom application running on the Microsoft HoloLens was built for creating the four visualisations. We used the Unity game engine, which provides the required methods for constructing a 3D scene (unity3d.com).

To supply GNSS position and compass orientation data to the HoloLens, an app running on an Android smartphone was developed. It captures the latitude–longitude position and compass orientation using standard smartphone sensors, and periodically broadcasts this information via Bluetooth.

A custom Bluetooth receiver module was built into the Unity game engine application. It uses the broadcast position and orientation information to align the user and the visualisations in a common coordinate reference system.

The Unity collider mechanism detects and reacts on nearness events, which are triggered when the user's position "collides" with invisible objects that are placed in the virtual scene. This was necessary for hiding and creating cubes and arrows and for switching the bird avatar between idle and moving states. Using invisible spherical colliders with a diameter of 5 metres meant the user triggered functionality when within 5 metres.

4. Conclusion

We will conduct a user study to evaluate the four presented visualisations using the Microsoft HoloLens AR headset. The task will consist in following a route indicated by the four visualisations in an outdoor setting. We plan to collect user feedback on preference, trustworthiness, confidence, as well as visibility of the four visualisations in a real-world setting.

We believe there is a great potential for designing engaging new AR experiences for pedestrian navigation, and hope that the proposed four visualisations will inspire others to further explore this design space.

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Gaze-Based Interaction with Maps and Panoramas

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Abstract. Novel interaction methods based on eye tracking can help users of location-based tourist guides to retrieve information about touristic features in the environment. However, these Gaze-Informed Location-Based Services (GAIN-LBS) do not assist their users with orientation. Here, we introduce Map-Enhanced GAIN-LBS which extend GAIN-LBS by an interactive map that provides extra information about the user's location and the inspected touristic features. The system is evaluated with a between-subjects study.

Keywords. Gaze-Informed Location-Based Service, tourist guide, orientation, interactive map, eye tracking, gaze-based interaction

1. Introduction

Tourists at vantage points often have problems with orientation and with identifying features in the panorama. Even though information can be retrieved from fixed installed panorama boards, classic audio guides, or mobile maps, it is often not easy to efficiently and effectively match the described objects with the view. While tourist guides have always attracted the attention of Location-Based Service (LBS) researchers, most systems have focused on audio- and map-based interaction (Raper et al., 2007), while other communication modes are still largely underexplored (Huang et al., 2018).
Here, we suggest to combine three communication modes for interacting with an LBS: gaze, audio, and maps (Gkonos et al., 2017). The use of gaze is motivated by eye tracking technology becoming increasingly pervasive (Bulling et al., 2011) and starting to enter the mass market (e.g., HoloLens 2 by Microsoft[1]). We thus enhance the recently proposed Gaze-Informed Location-Based Services (GAIN-LBS) (Anagnostopoulos et al., 2017) by an interactive map component, aiming at improving tourists' orientation.

[1] https://www.microsoft.com/de-ch/hololens/hardware (visited 10 July 2019)

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2. Map-Enhanced Gaze-Informed LBS

GAIN-LBS determine the orientation of the head with regards to the surrounding environment by analyzing the image obtained from the front view camera of a mobile eye tracker. Anagnostopoulos et al. (2017) described the system implementation and an evaluation for indoor and outdoor settings.
Here, we propose to enhance GAIN-LBS with an interactive map to help with orientation. The system detects the area of interest (AOI) the user is looking at, such as “Rigi mountain”. As illustrated in *Figure 1*, users can then listen to information about the AOI and obtain extra information via the interactive map. The spatial extent of the AOI is visualized on the interactive map and shown together with a list of attractions in this area. Users can select the listed attraction they want to know more about. Information is provided via audio, and the location of the attraction is additionally drawn on the map.

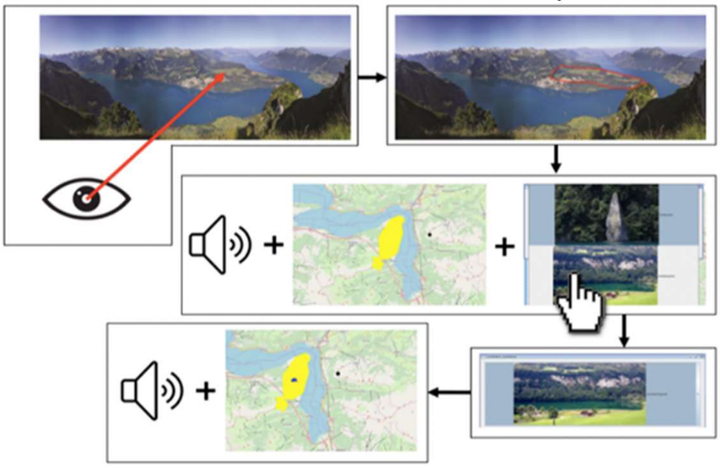

Figure 1. Flow of interaction for the Map-Enhanced Gaze-Informed LBS.

3. User Study and Results

The goal of the study is to test whether gaze-based interaction has the potential for improving tourists’ orientation, compared to a regular map without gaze interaction. A between-subjects study was carried out, comparing the baseline condition (condition A, i.e., a regular interactive map with pan and zoom) to a Map-Enhanced GAIN-LBS (condition B, *Section 2*). The rationale for including a map in both conditions – instead of using GAIN-LBS without map as a baseline – was to make the comparison regarding the spatial orientation tests fairer. This study focuses on the following research questions:

- RQ1) Do Map-Enhanced GAIN-LBS help to orient in the environment?
- RQ2) Do Map-Enhanced GAIN-LBS help to better situate and memorize what has been seen in the environment?
- RQ3) Do Map-Enhanced GAIN-LBS help to transfer the local position to a higher-level reference system?

3.1. Study Design

18 participants (7 females) participated in this user study (avg. age 22.9 yrs). Participants were equally and randomly assigned to the two conditions. The experiment was carried out in a room with a large panorama wall (5 x 2.3 meters, see *Figure 2*). Eye tracking data from an SMI 120 Hz eye tracker were used as input for the system.

Written informed consent was obtained. Questions about basic demography, familiarity with the area of the panorama view and the German version of the Santa Barbara Sense of Direction Scale (SBSODS) questionnaire (Universität Freiburg, 2011) were asked in the pre-questionnaire. Results of t-tests suggest that the two groups had similar orientation abilities ($t(16) = -0.137$, $p = .893 > .05$) and similar familiarity ($t(16) = 1.128$, $p = .276 > .05$).

During the experiment, participants could explore the view and use the (interactive) map freely for a maximum duration of 10 minutes. All participants in condition B were stopped by the experimenter after 10 minutes, while for condition A they spent an average of 8.67 minutes (SD= 1.15). Participants were then asked to fill in the post-questionnaire.

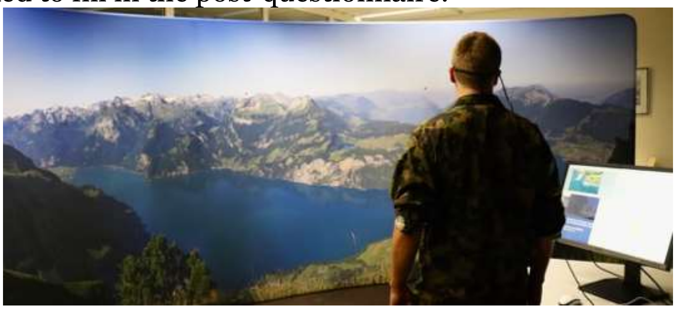

Figure 2. Experiment setup: a participant with eye tracker in front of the panorama wall.

3.2. Results

3.2.1. Usefulness of the Map

The post-questionnaire included three 7-Likert scale questions: "The map helped me to locate myself better in the environment", "The map helped to locate the areas", and "I am more familiar with the region after using the system". The t-test results show that condition B was rated similar to condition A in terms of helpfulness in locating oneself in the environment ($t(16)=0.677$, $p=.508 > .05$), locating the area ($t(16)=0.899$, $p=.382 > .05$) and increasing familiarity with the region ($t(16)=1.203$, $p=.247 > .05$).

3.2.2. Estimation of the Compass Direction

The view from the location of the panoramic photograph to Lucerne is directed to the northwest (NW) or to the west (W). Only 56% participants of condition A were able to indicate the direction to a specific AOI of the panorama correctly, while 89% participants of B selected the correct answer.

3.2.3. Memorizing Information on AOIs

The number of AOIs visited was on average 7 to 8 AOIs in condition B, all 14 AOIs in condition A. The open-ended questions “Which places did you look at?” and “What do you remember about these places?” were evaluated. The percentage of the AOIs remembered (out of the AOIs looked at) was calculated. Participants from condition B could remember almost 80% (SD= 34.16%), while those from A could only remember about 51% (SD= 21.87%). Meanwhile, on average, participants in condition B (M = 2.17) were able to list more pieces of information than those in A (M = 1.04, p = .001 <.05).

3.2.4. Drawing the Memorized Objects

Participants had to draw a sketch panorama and a sketch map based on their memory. The sketches were evaluated with the software GMDA (Gardony Map Drawing Analyzer; Gardony et al., 2016) for calculating the similarity between the sketches and the target panorama or map. Five key values were calculated: canonical organization, scaling bias, distance accuracy, rotational bias and angle accuracy. Participants from both conditions perform similarly in sketching the panorama. However, the results for the sketch maps reveal that participants in condition B were more accurate in terms of scaling and have lower direction of angular error (i.e., rotational bias) (see *Table 1*).

	Sketch Maps: M (SD)		Sketch Panoramas: M (SD)	
	Cond. A	Cond. B	Cond. A	Cond. B
SQRT of canonical organization (0 to 1)	0.44 (0.19)	0.31 (0.18)	0.47 (0.28)	0.43 (0.13)
Scaling bias	0.65 (0.04)	0.09 (0.05)	0.03 (0.03)	0.04 (0.04)
Distance accuracy (0 to 1)	0.81 (0.10)	0.8 (0.09)	0.89 (0.05)	0.86 (0.07)
Rotational bias in °	71.59 (49.93)	33.74 (30.36)	8.5 (10.27)	14.13 (7.76)
Angle accuracy (0 to 1)	0.64 (0.22)	0.77 (0.17)	0.86 (0.07)	0.84 (0.05)

Table 1. GMDA analysis results for sketch maps and sketch panoramas.

4. Discussion

RQ1 The results of the subjective measure (*Section 3.2.1*) indicate that there are no significant differences in term of helpfulness in locating oneself in the environment. However, our results from the objective measure (*Section 3.2.2*) suggest a different conclusion by indicating that the interactive map helps the participants to have a better sense of their environment. Therefore, even though the participants may not notice the help given by the interactive map, it seems that the interactive map has a positive influence on orientation.
RQ2 The self-reported helpfulness in locating the area (*Section 3.2.1*) is similar between 2 conditions. However, the evaluation of the open-ended question of listing out the visited AOIs (*Section 3.2.3*) and the sketched panorama

and map (*Section 3.2.4*) revealed that the subjects of condition B have a more accurate memorization. The better performance in condition B could be explained by two reasons: 1) participants in condition A have visited more AOIs and therefore had to memorize more places; and/or 2) condition B allows participants to obtain more related information of the place, which increases the amount of interaction and as a result helps them to better connect what they have heard and seen.

RQ3 Results in *Section 3.2.2* show that participants in condition B were more accurate in estimating the compass direction. Thus, the interactive map helps users to transfer the local position to a higher-level reference system. The difference can be explained by the fact that the amount of information exposed to the participants in condition B is more than that in A.

5. Conclusion and Outlook

We have introduced Map-Enhanced GAIN-LBS which combine three communication modes – gaze, audio, maps – to assist tourists in identifying features in the panorama and in orientation. The between-subject study demonstrated that for a tourist it is easier to orient when she has an interactive map to work with, and that she can remember more information about the views. The added value of a map without interaction to the normal GAIN-LBS was not tested. As a next step, we plan to integrate mechanisms of gaze-guidance and narrative generation (Kwok et al., 2019) with Map-Enhanced GAIN-LBS.

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Small Symbols With Big Effect? – A Cognitive-Affective Perspective on Map Symbolization on Small-Sized Displays

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Abstract. Maps have become ubiquitous, ever smaller, and simpler. With this, the way we engage with maps has also changed: from deliberate, cognitively effortful processing of complex maps to fast, associative, intuitive map reading of maps of daily, quick use. Smaller displays and the simplification of maps together with the ubiquitous but incidental engagement towards them re-calls for research on visual semiotics targeted to assess the impact of map design on small displays. This research, therefore, focuses on intuitive information processing of maps, in which judgments and decisions are made automatically, rapidly, and associatively. Findings from qualitative and quantitative user studies will be discussed, targeted at exploring the effects of map symbolization on small-sized displays on map users' responses of cognition and affect.

Keywords. Visual Communication, Semiotics, Psychology

1. Introduction

Throughout the past decades, empirical research in cartography has undergone two major shifts (Montello, 2002): In its beginnings, cartographic research focused on examining the effects of map elements isolatedly. While this approach accounted for results of high internal validity, it was criticized in the 1970s and 1980s for its lack of ecological validity, claiming that by isolating visual variables, the results cannot be transferred and generalized to maps due to their more complex, holistic nature (Petchenik, 1977; Montello, 2002). This critical perspective initiated a transition in research, from testing specific map elements towards analyzing the percep-

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tion of maps as a whole. Meanwhile, while current research has made a transition from low-level perceptual approaches to higher-level cognitive approaches, the technological development in the late 1990s accounted for a second transition in cartographic research and practice (Montello, 2002): The advent of new and well-accessible technologies, software, and devices, which brought new opportunities for geo-visualization (Słomska, 2018). The accessibility and availability of web and mobile services at any time, are major advantages of this development.

At the same time, the web as a new medium to display maps constrains the design to the – at times very small – physical display size. Hence, web maps nowadays require extra attention due to their particular characteristics and limitations. Well-designed web maps can be recognized as "relatively empty" (Kraak & Ormeling 2011, p.79).

While the maps used in our daily lives have become smaller and simpler, the way we engage with maps has changed as well. Regularly we encounter web maps in daily routines, such as when reading online news or when orienting or navigating in unfamiliar environments. The level of engagement in those maps, however, varies greatly. These maps will not always be cognitively processed deliberately or in detail, but at times be processed fast, automatically, effortlessly, associatively, and intuitively (Kahneman, 2002; Padilla *et al.*, 2018).

Humans constantly respond to their environments and the stimuli therein, responding differently with respect to the type and characteristics of the stimuli exposed to (Russell, 1980; Russell and Feldman Barrett, 1999). Applying this perspective to cartography indicates that the choices on how to depict and express data will affect how a map is perceived and interpreted (Monmonier, 1996). Thus, cartographic elements and their visual parameters (e.g. shape, color, hue, size, texture, and orientation) must be carefully selected to adequately represent and correspond with the particular aspect of information to be communicated (Bertin, 1974), since "changing the form of the signifier while keeping the same signified can generate different connotations" (Chandler 2007, p.143).

Cartographic semiotics provides a framework that guides the selection for the type of visual variables to use in maps, such as when to represent a particular content by shape, color, or size (Bertin, 1974). These rules, however, do not further differentiate within each type of visual variable, such as on the effects of different colors or shape symbols on the map reader's cognition, perception, or affect. In other words, while semiotics provides a shared set of signs and rules, it does not address how choices for or the composition of graphic variables may lead to different connotations, interpretations or judgments.

The current development of highly ubiquitous, simplistic maps, of rather incidental engagement calls for research on visual semiotics targeted to re-assess the impact of cartographic visual variables of these *relatively empty* maps on the map user.

2. Empirical Research

The present research focuses on the empirical study of shape-symbols and their effects on intuitive cognitive judgments and affective responses evoked by associative or low-level cognitive tasks.

In qualitative and quantitative studies, visual stimuli composed of symmetric, achromatic, geometric shapes are used to study participants' intuitive judgments and affective responses towards them. The selected visual stimuli refer to commonly used graphic variables in visual communication and in thematic cartography to indicate nominal data. In this research, geometric shape stimuli (e.g., circle, triangle, square) were studied first isolatedly, i.e., without a map context, followed by increasing the task complexity by setting the stimuli in applied scenarios and cartographic contexts.

2.1. Study 1: Cognitive Relatedness of Geometric Shapes

The first empirical study aimed at identifying the cognitive relatedness of geometric shapes and to disclose processes involved in people's intuitive cognitive judgments with respect to those shapes (for details see Klettner, 2019). The study's stimulus material comprised 12 two-dimensional, achromatic, geometric shape. All shapes were displayed in black on white paper cards. Participants were first instructed to sort the paper cards according to the shapes' similarities and later to explain their decisions. The study was conducted in individual settings and all participants, tested by the same instructor. In total, 38 individuals participated in the study (mean age M = 21.50, SD = 3.00). Each participant completed the following three tasks:

1. a free-sorting task (task 1) in which participants were instructed to sort the set of 12 geometric shapes according to their similarities,
2. a retrospective verbalization task (task 2) which aimed to identify strategies applied when grouping the geometric shapes, and
3. a labeling task (task 3) in which the participants were instructed to label each group by its most prominent characteristic(s)

Based on the results from free-sorting task 1, the frequencies of co-occurring pairs of shapes were mapped into a co-occurrence matrix. The matrix was further subjected to cluster analysis and multidimensional scaling to statistically reveal the (dis)similarities and proximities between the geometric shapes. Findings from cluster analysis revealed a three-cluster configuration, while multidimensional scaling further quantified the proximities between the geometric shapes in a two-dimensional space (see *Figure 1*).

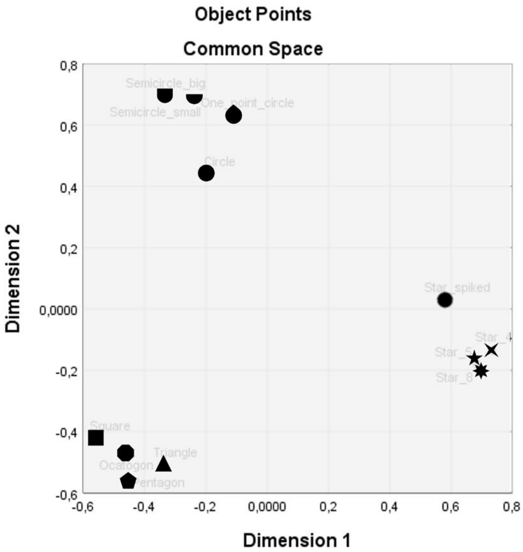

Figure 1. MDS results from free-sorting 12 geometric shape stimuli, indicating the shapes' cognitive relatedness (from Klettner, 2019).

The results from retrospective verbalization task 2 and labeling task 3 were subjected to qualitative and quantitative content analyses to identify processes involved in people's intuitive judgments with respect to the tested set of geometric shapes. Findings indicate four strategies underlying the participants' similarity judgments, that is, visual, affective, associative, and behavioral strategies.

2.2. Study 2: Affective Differentiation of Geometric Shapes

A second empirical study was conducted to further explore people's affective responses towards, again, two-dimensional, achromatic, geometric shape stimuli. The study comprised two tasks:

1. a shape evaluation task, in which geometric shapes were studied isolatedly, i.e., without cartographic context, followed by
2. a map evaluation task, in which the geometric shapes were displayed on maps

Designed as an online questionnaire, participants' were instructed to rate each shape and map stimulus by using a Semantic Differential technique (Osgood, Suci & Tannenbaum, 1967). Each shape and map stimulus was displayed successively. In total, 80 individuals participated in the study. 77 participants indicated their age (M = 22.06, SD = 3.80). A between-subject design was applied which allowed to minimize the number of stimuli ratings for each participant and to preclude participants from rating the same shapes twice in both shape and map evaluation tasks. The majority of participants used either smartphones (47.5%) or laptops (46.3%) for answering the survey. Tablet and Desktop PC were used by 5 individuals. No significant differences in participants' ratings by type of device was found according to Chi^2, at a significance level of $\alpha < .05$.

Preliminary findings strongly suggest that some geometric shapes lead to distinct affective responses and reveal unique affective shape profiles, while other shapes appear to be affectively more alike. Findings further indicate that some geometric shapes persist to evoke distinct affective responses when increasing visual complexity, such as when studying shape stimuli not only isolatedly but also in cartographic contexts. Yet, this effect was found to be of a lesser extent.

3. Conclusion and Outlook

Visual communication requires deliberate decisions to share and express information successfully. With a better understanding of map symbolization and their effects on map readers, more informed design choices can be made, allowing for effective and associative information visualization, in particular on small-sized displays. This research aims to contribute to this goal, by providing a differentiated perspective on the impact of symbolization on cognitive and affective responses.

The findings of this research strongly support the notion that even basic geometric shapes imbue particular qualities, leading to distinct associations, affective responses, and cognitive proximities. These effects were found in particular when studying shape stimuli deprived of complex visual context. Preliminary findings further suggest that some geometric shapes persist to evoke specific affective responses when increasing visual complexity, such as when studying shape stimuli in cartographic contexts. However, inasmuch as the present research contributes a cognitive-affective perspective on shape symbolization, the findings' transferability is yet limited. Future research in applied cartographic scenarios is therefore crucial to further advance our understanding of shape symbolization and its effects on the map user.

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Map-based Dashboards versus Storytelling Maps

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Abstract Map-based dashboards and storytelling maps have been increasingly used in data management, information communication, and decision-making support. In this study, we systematically investigate the state-of-the-art map-based dashboards and storytelling maps to identify and categorize their purposes, user interfaces, contents, and their evaluations. We design a framework for the comparative study to support outlining the characteristics of map-based dashboards and storytelling maps, and summarizing the strengths and weaknesses of these two visualization methods in various scenarios. The survey results will provide insights for future multi-granularity and multi-variable geodata information visualization and communication using these two methods.

Keywords: geodata visualization, map-based dashboard, storytelling map, web-based mapping

1 Introduction

The volume and the complexity of various data are rapidly increasing as the progress of digitalization. To solve the problem with low data readability caused by data overload and to reveal the hidden information of various data, Keim (2010) proposed visual analytics leveraging the strengths of human and computer data processing, for a better understanding of information. Map-based dashboard and storytelling map are two innovative geovisualization methods, which support the public to gain geographical knowledge and boost the geo-information dissemination. More specifically, map-based dashboards and storytelling maps are dedicated to the

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communication of organized and systematic geo-information in an intuitive design.

Few (2006) described a dashboard as "a visual display of the most important information needed to achieve one or more objectives that have been consolidated on a single computer screen so it can be monitored and understood at a glance". Dashboard is widely used to visualize geo-data. For instance, a map-based dashboard (Cao et al., 2017) has been designed to uncover spatiotemporal patterns and detect the anomaly of urban traffic.

In terms of visual storytelling, comparatively, Kosara and Mackinlay (2013) pointed out that "a story is an ordered sequence of steps, each of which can contain words, images, visualizations, video, or any combination thereof". Chen et al. (2018) proposed a concept of a story slice, being a "structured representation of a finding or a combination of findings or, generally, an information construction obtained from original data in the course of analysis". The story creation process focuses on organizing the findings, rather than states and steps, into meaningful layouts.

The abovementioned storytelling methods have been widely implemented in the interactive geodata exploration. Schell et al. (2007) illustrated the correlation between socioeconomic and infant mortality in different income countries by storytelling. Lundblad and Jern (2012) build a snapshot-based mechanism to capture stories on performance indicators stored in the World dataBank, such as demographics, healthcare, and economics. However, there is a further need of research on how to build, interpret and evaluate narratives for geo-spatial visualizations (Tong et al., 2018).

In this study, we aim to outline the scopes of map-based dashboards and storytelling maps, identify their design space, evaluate their visual elements, and discuss the feasibilities of different insights communication. More specifically, we conduct the survey in three steps: 1) we collect and select the state-of-the-art scientific samples in a defined iterative scheme; 2) we design a framework for the comparative survey with four categories and 12 subcategories; 3) we present and discuss the preliminary results. The findings help future studies for a better design of those two visualization methods to serve their purposes.

2 Survey Methodology

An iterative searching scheme is designed to collect relevant map-based dashboard and storytelling map samples. The scheme consists of three main steps: keywords defining, searching from databases, preliminary results filtering. The results of each step serve as feedback to the previous steps, which means we adjust the keywords, databases and filtering criteria according to the findings iteratively. Figure 1 shows the iterative collection process with the query keywords, databases and the numbers of results. Specifically, the sources of the samplings are (1) academic databases and Google Scholar, (2) the references of the related research papers, (3) research papers in the domain review, (4) research papers from Google Alerts[1] push, (5) online media[2] and blog[3], (6) Tableau Public[4], (7) Google search and Google image search. We search the related materials with the query keywords, e.g. "dashboard" AND "traffic" OR "education", "map" AND "storytelling". A set of filters is applied to find the relevant, mature, and typical samples of various backgrounds and designs. Firstly, the content must include geographical information. Secondly, the sample should be mature and completed, which means it serves for clear purposes, has a coherent design and is publicly available. Thirdly, we want to cover a wide range of scenarios and designs. Thus, the samples shared too many similarities are excluded.

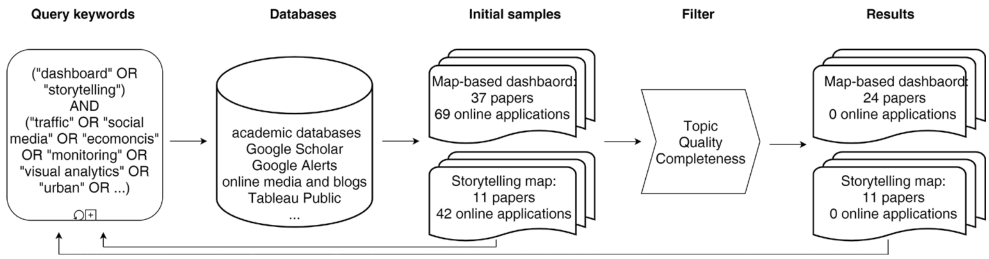

Figure 1: The flowchart shows the iterative scheme for the sample collection. After every searching loop, the fund results help to update the query keywords to expend the searching scope. The searching is conducted iteratively until enough results are found.

Until the time of the paper writing, a total number of 106 map-based dashboards and 53 storytelling maps were captured from the initial searching. Among these, a lot of the samples are web applications. For example, the stories published by online newspapers and examples from Tableau Public. However, these sample are often without any explanation of the design purposes, data selection and processing. Therefore, we exclude the online samples and focus on academic papers.

[1] https://www.google.com/alerts
[2] https://www.washingtonpost.com/
[3] http://www.visualisingdata.com/
[4] https://public.tableau.com/en-us/s/

3 The framework design

Both map-based dashboard and storytelling map cover a wide range from purpose, design and data feature. Moreover, the purpose, and data feature influence largely the interface and interaction design. However, it is not clear what types of interfaces and interactions serve a specific purpose and data feature better. To tackle this issue, we design a framework for categorizing the map-based dashboards and storytelling maps systematically. The framework is shown in Table 1, consists of four categories, i.e., *purpose*, *user interface*, *content* and *evaluation*. Each category has several subcategories. Following the framework, we measure and document the collected samples, compare the differences between map-based dashboard and storytelling map, and identify the advantages and disadvantages of both visualization methods.

Table 1: The framework design for the comparative study.

Category	Item	Description
Purpose	Analysis	Revealing hidden insight
	Data management	Providing visual data filtering, selection, updating, import and export services
	Decision making	Offering a collection of multi-dimensional information
	Monitoring	Detecting the changing of data, alerting of the anomaly
	Learning	Spreading and communicating information
User interface	Visual elements	The visual components, e.g. map, toolbar, table
	Interactions	The interactions for users, e.g. clicking, dragging, filtering, ordering
	Layout	The arrangement of the visual elements, e.g. map-centered, multi-page
Content	Data	The source, scale, spatial coverage, format and privacy of data
	Data processing methods	Data cleaning, projection, interpolation, aggregation, modeling, mining and etc.
Evaluation	Expert feedbacks	The interviews with the domain experts, normally including the quality, efficiency and effectiveness assessment
	User test	The task-solving effectiveness and user satisfaction

4 Preliminary results

To analyze the design space (visual elements and interactions) of map-based dashboard and storytelling map, we applied the parallel set chart. Figure 2 presents the percentage and correlation of purposes, elements, interactions from the 35 map-based dashboards and storytelling maps.

To be more specific, most of the map-based dashboards serve for data analysis. Filtering, selecting, highlighting and zooming are common and useful interactions for dashboard. Some innovative elements are included in the design, such as glyph, parallel coordinates, calendar view, cartogram, sankey diagram. Moreover, dashboards for analytical purposes are with more engaging interactions than other purposes. Highlighting, ranking, and ordering are helpful for decision-making and monitoring, but not often implemented.

In contrast to dashboard, storytelling map serves mainly for learning purposes. The overview maps are applied to give the rough spatial information. Also, a lot of static visualizations, e.g., text and images, are included in the storytelling maps. The storytelling maps with decision making and monitoring purposes have more interactions. Besides, 3D scene is especially used in storytelling maps, not in map-based dashboards.

In most of the map-based dashboards and storytelling maps, maps are used as supportive tools to present the spatial information. The interactions with

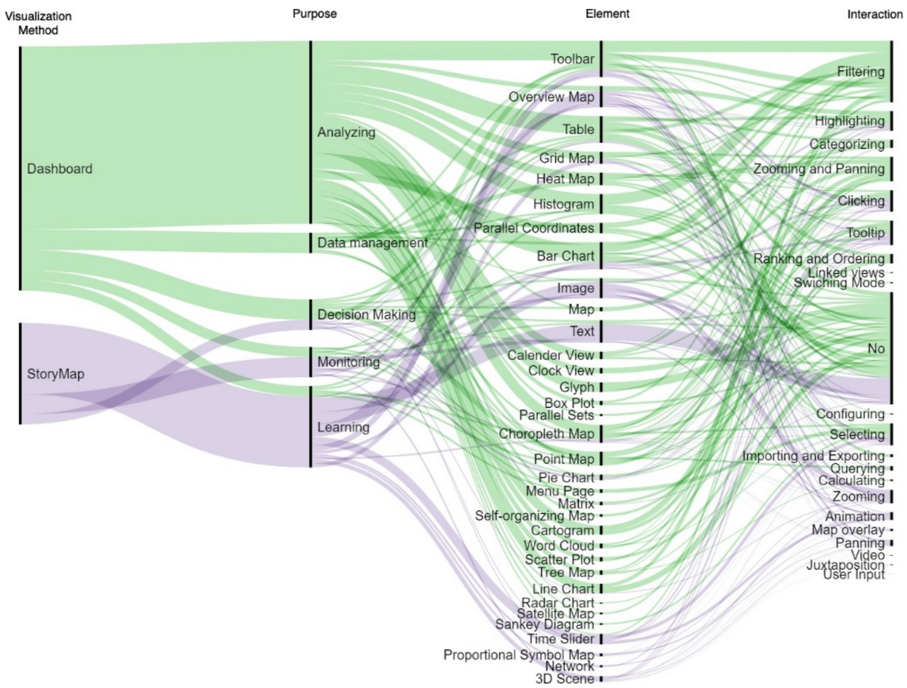

Figure 2: The parallel set chart illustrates the design space and the correlations among features using the collected samples of map-based dashboards.

low engagement interaction, i.e., clicking, zooming, panning, and hovering, are integrated with the maps. Moreover, if maps are linked with other elements, more knowledge will be revealed. For instance, a map with a time slider can convey both spatial and temporal patterns more intuitively.

5 Conclusions and Outlook

The proposed searching scheme and the framework helped us to collect and categorize the samples. The preliminary results provide some insights into the map-based dashboard and storytelling map features and characteristics. However, more work needs to be done in the future: 1) refine the framework for the comparative study and analyze in-depth of each characteristic, 2) search for more samples of both visualization methods, 3) identify the advantages and disadvantages of the two methods in various application scenarios, 4) propose design guidelines for these two visualization methods.

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Interactive Web-based 3D Solar Shadow Map

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Abstract. Urban areas are characterized by a complex topography of buildings, terrain, vegetation and temporary structures, which, depending on their extent, geometry, geographic location and daytime, cast shadow on their surroundings. Given the importance of sunlight for various groups of interest and tasks, we argue that a comprehensive, accessible, and intuitive way of predicting its availability is surprisingly lacking. In our research, we investigate how to enable the visual communication of urban solar conditions for various real-world usage scenarios like finding a sunny spot in the vicinity, parking a solar car in the sun, or taking a photograph of a particular building in a favorable light. Furthermore, since such activities span over time, a visualization of shadow motion is desired. A web-based prototype is being created in order to evaluate technical feasibility as well as user acceptance.

Keywords. Interactive map, 3D, Realtime, Sun, Shadow, LBS, WebGL, CityGML, Three.js, Shader, Open Data, Smart cities, Exploration

1. Introduction

Figure 1. Actual footage of the 3D interactive web-based solar shadow map. This shows Vienna on September 25th at 13:50 with precise sun position, rendered at 60 fps in the browser. (© Basemap: Mapbox & OSM Contr., 3D buildings: CC BY 4.0 Stadt Wien – data.wien.gv.at)

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The Sun is a prerequisite for life on Earth. It impacts overall temperature, plants' growth rates and photovoltaic energy production, up to health and mental conditions in humans (Mead 2012). By building an interactive, browser-accessible map, based on open 3D data (terrain, buildings and vegetation), we want to make humans understand sun/shadow conditions and allow them to plan and act accordingly. For any time, at any location, from any perspective. To allow required temporal and spatial freedom that enables interactive exploration of solar shadows within a 3D environment, a client-side approach is obvious.

In order to minimize entry- and compatibility-barriers (i.e., we want to cover modern location-aware mobile devices, as well as classic desktop computers) while at the same time maximizing accessibility (i.e., no installation, instant access, streamed data), we decided to build upon web-technologies. This strategy, however, given the vast amount of data and the aim to achieve interactive frame rates in contrast to browsers' reduced access to GPU power and memory, creates a potential performance bottleneck.

2. Method

Initially, available tools were researched in regards for their adaptability or extensibility. *Cesium*, *Mapzen*, *OSM Buildings* and *ArcGIS*[1] were evaluated and eventually considered impractical for the task: They were either too bloated, not "real" 3D (i.e., "2.5D") or closed source and therefore not editable and extensible. We therefore decided to initiate an implementation from scratch, based on the lightweight high performance Javascript WebGL based 3D engine *Three.js*[2] – capable of producing real time (60 fps) visualizations as depicted in *Figure 1*.

2.1. Data

The geometries required for accurately calculating the lighting situation in an urban environment need to be combined from different data sources, in different formats, often in different coordinate reference systems. This in turn requires a powerful and scalable pipeline to incorporate all relevant aspects to render solar shadows, with the eventual aim of creating a flexible system that will be working globally and for any city that provides 3D models of its buildings and other potentially relevant layers of information.

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[1] https://cesiumjs.org, https://www.mapzen.com, https://osmbuildings.org, https://developers.arcgis.com

[2] https://threejs.org

Starting out with worldwide terrain data as well as building and vegetation data of Vienna, any occluding structure should eventually be added to the system. Gröger & Plümer (2012) define different levels of detail (LoD) for 3D building models, whereas LoD1 represents blocks without roof structure while LoD2 also contains the latter. LoD3 enhances this by integrating "architectural models with detailed wall and roof structures, balconies, bays and projections" (Gröger & Plümer 2012).

Biljecki et al. (2017) discuss the qualitative impact of LoD on shadows. His conclusion, however, is based on a procedurally created city model. The city of Vienna provides an LoD2 model which we are currently using as Vienna has many pointy roofs: An abstraction as extruded blocks would intuitively lose significant detail. We plan, however, to integrate LoD1 in Vienna as well and research differences in the shadow visualizations between the two levels – based on a real-world scenario.

New York and Berlin offer data of similar quality and are to be added next. Other occluders, including clouds and atmospheric conditions might be added in a later stage, according to available data.

2.2. Map

A web-based interactive map is currently being built that combines 3D terrain data, 3D building data, tree cadasters and a basemap. The map prototype is draggable and zoomable, dynamically loading required resources, covering the whole earth. Its basemap and terrain are streamed from tile-servers. Terrain elevation is based on RGB-encoded height. A GPU vertex shader displaces 3D-planes accordingly. After this process, the terrain is also able to cast and receive shadows, further contributing to an encompassing and realistic rendering. Performance is convincing and fast enough to render a significant part of Vienna in realtime on a 2016 MacBook Pro as shown in *Figure 2*. The map will be freely available on https://shadowmap.org – which will also be the starting point for further user testing.

Figure 2. Shadow simulation of Vienna's central districts. Due to its 3+1 dimensional nature, zoom, perspective and time can be defined by the user without any constraint. Hereby, users are able to even investigate shadow situations on building facades at sunrise or sunset – a scenario that can't be covered by 2D server-generated imagery. (© Basemap: Mapbox & OSM Contributors, 3D buildings: CC BY 4.0 Stadt Wien – data.wien.gv.at)

2.3. Location based services

By employing the current location, one is able to immediately grasp the shadow situation in nearby surroundings. A person with just a few minutes of spare time can effortlessly find the closest spot to enjoy their lunch break in the sun. The driver of a solar car could request sunny parking spots within the next 3 blocks.

Thinking ahead, even routing could be tuned based on a sun/shadow-scenario: A person walking a longer distance through the city during a hot midsummer evening would most probably prefer a route through a shady neighborhood. Vice versa the route for a solar car. Comparable scenarios are considered for further investigation.

2.4. Time integration, shadow accumulation

Most human activities take place over a period of time, not in a temporal instant, causing solar shadows to move. Miranda et al. (2018) argue the importance of shadow simulation in urban design and introduce efficient algorithms to render time-integrated shadows that span an arbitrary timeframe.

While maintaining high quality visualizations, their application, however, is limited to offline usage and targeted towards professionals like city planners and architects.

In our solution, the factor of moving shadows is incorporated by integrating the sun's motion that covers arbitrary timeframes within a given day, as shown in *Figure 3*. Shadows are accumulated by projecting shadows from astronomically precise sun positions (Agafonkin 2009) spanning the desired timeframe. For every sampling point, a shadow is rendered using *shadow mapping* (Williams 1978) – in our case a filtered, thereby higher quality version of it (Fernando 2005). In contrast to *polygonal shadow volumes*, *shadow mapping* also works for curved occluders on curved surfaces which is a fundamental requirement in our endeavor since we utilize non-planar terrain. The accumulated shadow visualization is generated by multiplying the light intensity by $1/N$ (N = number of sampling points) while simultaneously rendering all hereby created shadow maps. N directly affects quality and speed of the rendering. *Figure 3* uses five sampling points. We plan to enhance real-time performance by "baking" those generated shadow maps into the scene and introducing constraints on time and perspective to compensate.

Figure 3. Burggarten, a well-known park in the center of Vienna, late afternoon of September 14th, 2019. Accumulated shadows over the period of one hour. 3D buildings based on LoD 2 DXF models. Trees based on Vienna's open data tree catastre. (© Basemap: Mapbox & OSM Contributors, 3D buildings: CC BY 4.0 Stadt Wien – data.wien.gv.at)

3. Findings

Vienna provides a CityGML and DXF (LoD2) dataset of buildings via its open data initiative. By conversion and lossy 3D model compression, the file size of the metadata pruned model could be brought down from 1.42 GB to 47 MB without sacrificing image and data quality. Vienna's tree cadaster on the other hand is a massive single >100 MB JSON file, covering metadata and location of 199.826 trees, requiring prior processing and tiling to become computable. While these optimizations are desirable in general, they become crucial in a web-context: The often redundant, heterogenous data sources need to be compressed and minimized in order to reduce loading times and also integrated in a way performant enough to allow 3D real time web-based visualization.

4. Conclusion

To realize an interactive 3D web-based solar shadow map, various technical hurdles need to be overcome. The combination of 3D buildings, 3D terrain and vegetation with the aim to reach worldwide coverage – supporting arbitrary points in time and in space – is challenging. Even more in a web environment and the aim to be mobile ready. However, at the current state of our prototype, we are on our way to prove feasibility. Next step will be the finalization of the UI as well as the deployment of our prototype on shadowmap.org followed by user experience testing and feedback evaluation.

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Concerns on Design and Performance of a Local and Global Dynamic Map

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Abstract. Current real-time data collection systems for urban transportation and mobility allow enhancing digital maps with up-to-date situational information. This information is of great interest for short-term navigation and route planning as well as for medium- to long-term mobility data analysis, as it provides a finer time-varying detail of the urban movement infrastructure. In this work, we present our ongoing work to design a representation of a unique urban movement space graph as a local and global dynamic map approach. We address the concerns that must be considered when handling different scales of geographic areas inside a city, according to the application.

Keywords. Dynamic map, Spatial, Graph databases

1. Introduction

Digital representations of both transport networks and movement data collected by any sensing technique need to be stored in efficient electronic formats if we aim to use them for navigation or short-term mobility planning purposes. How they are stored and indexed, in fact, will impact the read and write access times, as well as the performance of spatial or temporal joins of any kind.

Digital maps of several levels of detail are used to represent the city infrastructure devoted to transportation purposes. Current extended sensing and data collection techniques allow measuring and reporting the real demand of this infrastructure and what is happening at large scale. These digital maps can be of interest from a first-person view, locally (the moving vehicle, passenger or citizen), or from a third person view, globally (a city mobility manager or a transportation planner authority).

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Several works have addressed the computational challenges of storing and querying records that represent locations, movements and trajectories, like Evans et al. (2013). Research on the concept of a Local Dynamic Map (LDM) has been mainly oriented to automotive navigational purposes, e.g., Shimada et al. (2015) and Eiter et al. (2019). The purpose of LDM is to provide the nearest location information to moving agents as they move. The most known approach consists of four different layers, from the most static to the most dynamic. To our knowledge, no other authors have tried to use the same map for a Global use. Thus, we present the concept of the Local and Global Dynamic Map (LGDM).

2. Problem statement and research objectives

We envision that the extension of the same Dynamic Map to Global applications may feed high level transportation planning purposes. The main challenge that arises when considering the LGDM is scalability. Thus, we find the need to evaluate the response time and graph behavior when it comes to perform basic operations both locally and globally. For evaluation, we choose the geometric map-matching as one of the most frequently used basic operations. This operation associates a vehicle position to an element on the digital transportation infrastructure map. Being aware of the limitations will allow creating a graph model with optimum performance for global and local analysis.

The main research objectives of the present on-going work are two-fold. First, we aim to define a consistent graph model to represent the urban road infrastructure as a time-varying dynamic map for local and global use. Secondly, we seek to evaluate the implications of the size of the graph (in terms of number of nodes) when computing the needed operations so as to develop the most suitable graph partitioning method. These main objectives are built upon some partial objectives: the study of options to build the network from raw OpenStreetMap (OSM) data (OpenStreetMap contributors 2018) and the integration between a real-time feed of vehicle locations and the network map.

3. Methodology and preliminary results

In our research, we have chosen Neo4j as a graph database management system for its lower learning curve. For an overview of different graph data base frameworks, we refer the reader to work published by Kumar Kaliyar (2015). We have chosen OSM as the transportation network data source, and the SUMO simulation framework, (Lopez et al. 2018), for creating synthetic vehicle movement data.

The transportation infrastructure network is a directed graph, represented by a set of nodes and vertices, associated by a collection of numerical and categorical properties. To import this data from OSM, we have evaluated different alternatives.

- **Osm2po**, (Moeller 2018), is a converter and routing engine. It allows filtering from OSM attributes to build a routable network. Then, we import its output manually into Neo4j. We have tested two variants: representing ways as nodes or as relations. The first variant adds complexity to the network since the number of nodes is significantly higher, but it is more flexible when querying the graph.
- **Spatial plugin for Neo4j**. This option avoids the need to pre-process the OSM file. The spatial functions it provides make the process easier and faster. However, the way of representing the information has been found less intuitive. In addition, intersections are not easily identified, thus limiting some route analysis.
- Additional tools such as https://github.com/neo4j-contrib/osm

In order to simulate the generation of vehicle positioning traces that can be matched onto the network we use the SUMO traffic microsimulation tool. The output of SUMO is a Floating Car Data (FCD) xml file. The TRaCI interface enables the access to a running simulation and allows reading all variables describing vehicle behavior online from our Python code. The most valuable information obtained is the location of a given vehicle at each simulation step.

Afterwards, we need to store this data into the Neo4j graph database where the OSM network has been previously loaded. After evaluating some different drivers to interact with Neo4j from our Python code, we chose the official Neo4j Python driver. At each simulation step, a reference vehicle is taken as the *ego-vehicle*. Step by step, a new node is created at each time instant in Neo4j, adding all the attributes that the TRaCI commands extract. Then, we apply a geometric map-matching, which consists of assigning the network node closest to the vehicle position by creating a new relation (*LOCATED_IN*) between the nodes in Neo4j.

TraCI slows down the simulation speed and there are several factors that condition its performance such as 1) the number of TraCI function calls per simulation step; 2) the types of TraCI functions being called; 3) the computation within the TraCI script; and 4) client language. Moreover, there are also other estimations related to the response time and the client language already given in the documentation.

To make the evaluation and compare different cases of the complexity of the matching process according to the size of the network, we record: the initial, final and middle simulation step times and the average step duration, as well as the total duration of the simulation and the number of elements in the database. Two simulation-related figures are also given: real-time factor and updates per second (UPS). Real time factor represents the relation *simulated time / computation time*. UPS (updates per second) denotes the number of vehicles that were simulated on average per second of computation time. Two different cases have been evaluated simulating 100 steps with a step-length of 0.1s, in 7 executions each, linearly increasing the number of nodes in the database, thus enlarging the geographical area considered:

Case 1: Response time of the simulation with map-matching of vehicle. In this case, for the evaluation of the response time of the simulation, the first approach has been simulating several times the script with the complete simulation. This way, the number of elements in the database increased linearly since the number of nodes was every time the same (Table 1).

Trial	Nodes	Relations	Duration [ms]	Real time factor	UPS	Average step [s]	Final step [s]	Initial step [s]	Middle step [s]
A	263447	284412	65760	1.55	74.55	0.64	0.68	0.78	0.65
B	263543	284415	111684	0.91	43.90	1.11	1.12	1.34	1.08
C	263639	284418	152837	0.66	32.07	1.54	1.58	1.70	1.60
D	263735	284421	196572	0.51	24.94	2.00	2.02	2.11	2.00
E	263831	284424	240646	0.42	20.37	2.46	2.47	2.58	2.50
F	263927	284427	283675	0.35	17.28	2.91	2.96	2.94	2.88
G	264023	284430	330335	0.30	14.84	3.40	3.38	3.52	3.42
H	264119	284433	14779	6.90	331.75	0.12	0.11	0.19	0.11

*H = without map-matching

Table 1. Measurements obtained in case 1 with 100 steps simulation and step-length of 0.1s.

Case 2: Response time evaluation with map-matching and first approach to build an egocentric network. The next evaluated case has been the simulation with the map-matching considering the distance between nodes and the first approach defined to build an egocentric network. Once again, the simulation script has been simulated several times to increase gradually the elements in the database. As an initial method to represent an ego-centered graph, the vehicle with 'id=0' has been chosen to characterize the Ego-car and new relations have been generated. First, the *ego-vehicle* has been related to the cartography (*EGO_LOCATED*) with the same map-matching approach. Then, to analyze the vehicles that are around the ego-car a new *NEAR* relation has been created considering the distance that exists between them in each time step (Table 2).

Trial	Nodes	Relations	Duration [ms]	Real time factor	UPS	Average step [s]	Final step [s]	Initial step [s]	Middle step [s]
A	263447	284412	131822	0.77	37.19	1.34	1.29	1.41	1.32
B	263639	284482	219489	0.46	22.33	2.25	2.24	2.31	2.28
C	263831	284552	305190	0.33	16.06	3.14	3.13	3.24	3.14
D	264023	284622	395011	0.25	12.41	4.08	4.37	4.21	4.06
E	264215	284692	481976	0.21	10.17	4.99	5.01	5.13	4.98
F	264407	284762	562707	0.18	8.71	5.81	5.83	5.93	5.77
G	264599	284832	660792	0.15	7.41	6.85	6.66	6.78	6.75

Table 2. Measurements obtained in case 2 with 100 steps simulation and step-length 0.1s.

4. Conclusions

Several conclusions have been obtained so far: on the one hand, the time needed for each step increases with the number of elements in the database. On the other hand, the initial step duration is, in general, bigger than the others. Also, in the first case, the simulation has been executed an extra time but without the map-matching approach (just creating a new node for each step). So, this was the case where the biggest number of elements was in the database. However, the response time decreased considerably in both cases. For instance, comparing the values obtained for this execution case (Trial H) and the first one (Trial A), can be seen that the time values are in general 5 times smaller. Besides, it should be highlighted that this is the best case since, if compared with the other trials, this difference increases. Considering how the map-matching method affects the response time of the simulation, it is still pending to make tests with other methods and compare the response times.

Finally, considering the second simulation case evaluated, as expected, the response time in general increased. This is both affected by the increase in the number of elements and the extra queries added to create the relations.

As a future work, both simulation cases will be tested with different geospatial databases to analyze and compare the graph considering the size and performance of the system. These preliminary conclusions will be extended to decide optimal network partition strategies according to response-time requirements for real-time applications of the LGDM.

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Cartographic Visualisation of Data Measured by Field Harvesters

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Abstract. Yield is one of the primary concerns for farmers, as it is the basis for their income and, among other impacts, influences subsidies and taxes. Field harvesters equipped with sensors and a GNSS (Global Navigation Satellite System) receiver provide detailed and spatially localised values, where the measurements from such sensors need to be filtered and subject to further processing, including interpolation, for follow-up visualisation, analysis and interpretation. These data, their processing and their application are some of the aspects of the precision agriculture concept. This paper describes the individual steps of processing the data acquired by harvesters, which especially include the spatial filtering of these data and their interpolation. We also proposed a scheme that summarises cartographic visualisation methods for these data (final data, as well as data from different processing steps). Methods of processing and cartographic visualisation were verified in the example of the Pivovárka field (Rostěnice farm, Czech Republic). Both 2D and 3D cartographic visualisations were created. Future development of the proposed concept is discussed in the conclusions.

Keywords. Cartographic visualisation, filtration, harvester measurement, precision agriculture, yield map.

1. Introduction

The main goals of precision agriculture (or precision farming) are, in general, the minimisation of negative impacts on the environment on the one hand and the maximisation of economic profit on the other. Geospatial information is highly valuable for these purposes. Therefore, using geospatial data provided by remote sensing and Global Navigation Satellite Systems (GNSS), as well as through their synthesis and analysis, farmers can more precisely determine what inputs to put exactly where and in what quantities. Conventional farming assumes that each field is a homogeneous area. Alternatively, precision farming techniques count and rely on the heterogeneity of a plot, and it is defined in terms of so-called yield productivity zones that reveal areas with lower and higher yields. Thus, an important

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way to collect geospatial data within the scope of precision agriculture is by field harvesters with yield monitors. Yield monitoring typically consists of a mass flow sensor and a GNSS device for geo-referencing the harvesters' measurements. Therefore, such harvesters use a GNSS to create a yield map of the field being harvested. Data from field harvesters represent the most detailed, as well as the most credible source of yield information. These data on crop yield can be used to determine variable rate treatments.

In this study, we describe the individual steps of processing the data acquired by harvesters, which especially include the spatial filtering of these data and their interpolation. We proposed a scheme that summarises cartographic visualisation methods for these data, and these methods were verified using a case study.

2. Related research

The effectiveness of decision-making in precision agriculture can be improved by integrating current monitoring technologies with Geographic Information System (GIS), GNSS and sensors. These technologies allow connection to the inner sphere of our spatial cognition via direct interaction with a new generation of cartographic visualizations. Cartography in its actual form is a unique instinctive multi-dimensional tool, which can be used in research, analyses, and communication of geospatial data (MacEachren, 1995).

The cartographic visualisation in precision agriculture is a topic that has not been extensively analysed and relatively too little is still known about how maps may be used effectively in this domain. Some papers (i.e. Kubíček et al., 2013; Štampach, Kubíček and Herman et al., 2015) deal with cartographic visualization of static sensors and their meteorological measurements. Charvát et al. (2018) describe visualization of yield productivity zones prediction derived from remote sensing data and agricultural machinery monitoring through interactive cartographic visualizations.

The papers that focus on the yield mapping from field harvesters data focus only on the issue of data processing in the GIS environment (Leroux et al., 2018; Zagórda and Walczykova, 2018). No existing articles or publications are directly concerned with the application of cartographic visualization to visualize this data.

Cartographic visualizations of this data are not covered by any reviewed papers or publications. Various cartographic visualisation methods are used in different steps of processing the data measured by field harvesters. These include exploration of the raw data (see section 3.1), their filtering (section 3.2), especially when using local filters, their selection and use of interpolation algorithms (section 3.3).

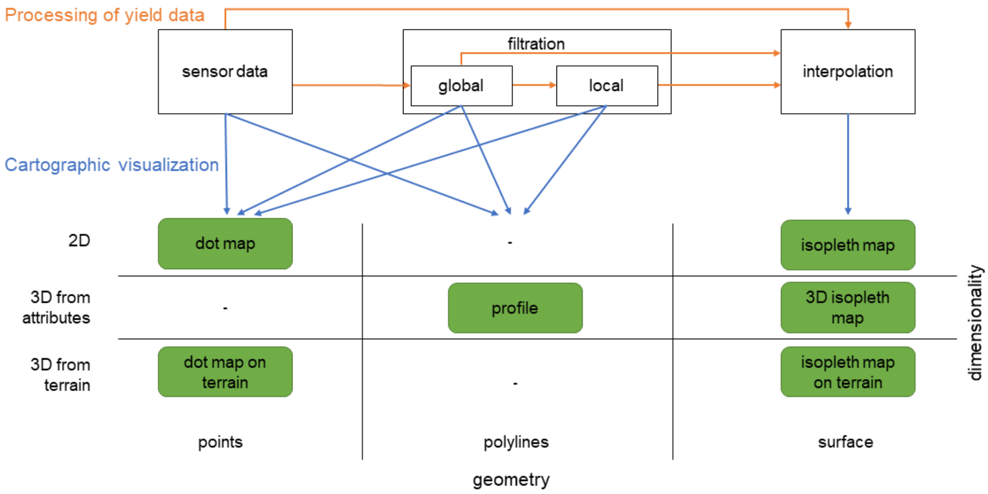

Figure 1. Overview of yield data processing and their cartographic visualization.

3. Materials and methods

This section describes the methodology of spatial data processing when creating cartographic visualisations of yield.

3.1. Sensors data

As mentioned above, the data measured by field harvesters represents the most detailed and credible source of yield information. Regardless, field harvesters provide measurements with some errors and inaccuracies. These biases in data corrupt the results, meaning, for example, that soil cannot be cultivated correctly. As suggested by Arslan and Colvin (2002) or Blackmore and Moore (1999), such errors might arise for the following reasons, for example, the occurrence of unexpected events during the harvesting process, leading to unusual behaviour on the part of the machine; the trajectory of the field harvester; and errors caused by incorrect calibration of the yield monitor.

3.2. Filtering of yield data

The main aim of data *filtration* is to remove the above-mentioned bias and refine the yield estimation. This issue was previously addressed, for example, by Gozdowski, Samborski and Dobers (2010); Spekken, Anselmi and Molin (2013); and Leroux et al. (2018). The processing of sensor data can be divided into two steps—global filtering and local filtering—as follows. Global filtering removes non-credible values within the whole dataset using the statistical analysis of measurement values and related attributes. Local filtering focuses afterwards on some parts of the dataset at a higher level of detail, and it is mostly based on the neighbourhood of data point values.

Global filtering uses statistical (non-spatial) methods for detecting non-credible yield values. Global filters detect incorrect outliers based on the range of possible yield values, the speed of a field harvester and the direction of harvesting. Meanwhile, *local filtering* handles the data in greater detail, and it is based on differences between neighbouring measurements or patterns. Local filtering brings the most precise results regarding domain knowledge, e.g. measurements, data processing and yield history, as well as knowledge of the data, the situation and of the problematics in general. Local filtering often comprises a set of subjective methods (points are excluded manually).

3.3. Interpolation

Continuous yield maps are created by different interpolation methods. The most commonly used methods include *Inverse Distance Weighting* (IDW), *Simple Kriging* and *Ordinary Kriging* (Souza et al., 2016). Continuous yield maps, in general, can be used for the comparison and evaluation of sensor measurements that were obtained directly from the field harvester and processed by global and local filters. Continuous yield maps can also be used in other analyses within precision farming, such as when comparing the measured yield with that predicted from yield productivity zones based on remote sensing.

4. Use case

Data acquisition was conducted in 2017 at the Pivovárka field, which is farmed by the Rostěnice cooperative farm (Czech Republic; N49.105 E16.882). Data were measured by a CASE IH AXIAL FLOW 9120 field harvester equipped with an AFS Pro 700 monitoring. The measurements were of Global Navigation System of Systems–Real-Time Kinematics (GNSS–RTK) quality, i.e. they provided a spatial resolution of less than 0.1 m. Measurements were taken continuously each second at an average speed of 1.55 m.s-1, which was recommended as optimal at the Rostěnice Farm for cereal harvesting by the above-mentioned field harvester.

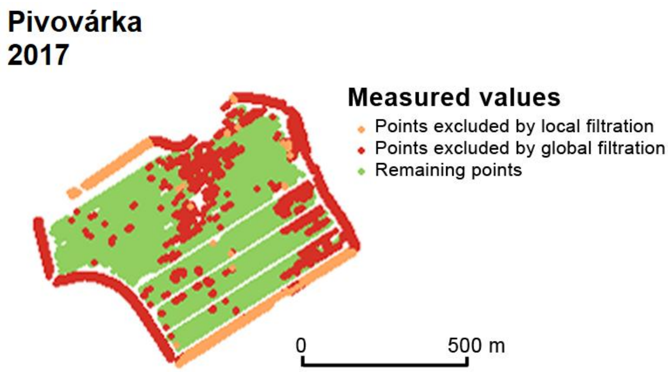

Figure 2. Dot maps depicting excluded and remaining points during filtration.

The data were first filtered through so-called global filters and then by local filters (see Figure 2). The results of both filtration steps were analysed and compared with each other and with measured (raw) data (see Figure 3). For interpolation, the Simple Kriging method was used, because the measured values had normal distributions, were stationary and did not show any significant trends, so the preconditions were met. The parameters of the interpolations of each model were computed utilizing the Exploratory Spatial Data Analysis in the ArcGIS 10.6 software.

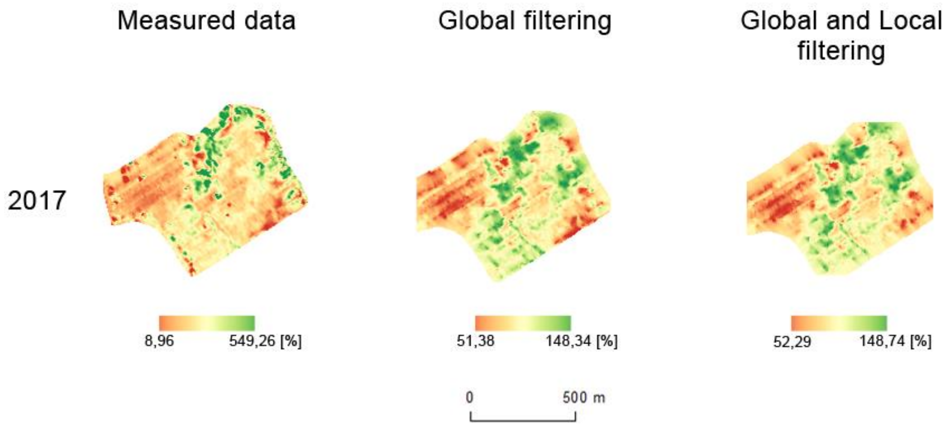

Figure 3. Isopleth maps generated from different stages of data processing.

Figure 4 shows the role of topography. A narrow valley is an area with significantly higher yields than the average of the field. The conducted measurements showed that yields in such a narrow valley within a field might reach more than 150% of the average for the whole field.

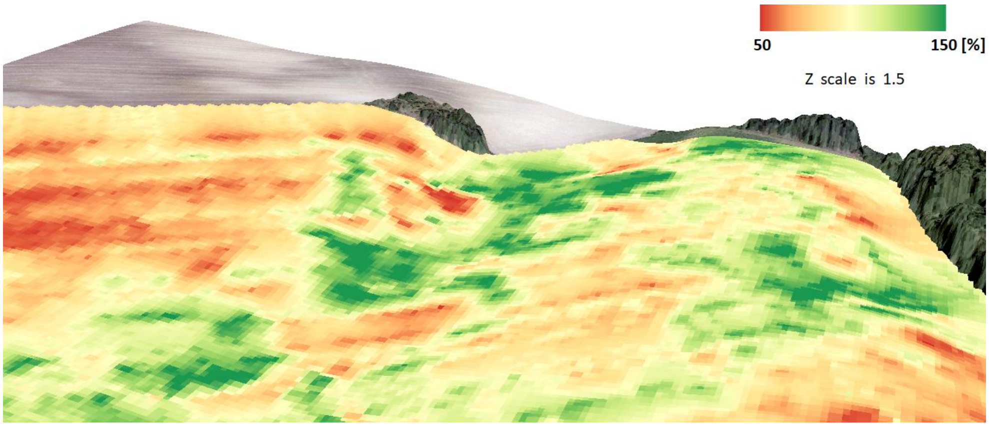

Figure 4. Isopleth map of the measurements processed by global and local filtering for the Pivovárka field in 2017 and draped on the digital terrain model.

5. Discussion

For the depiction of yield maps, 3D visualisation is particularly suitable, because it primarily enables the understanding of the relationship between topography and yield values and patterns. Other benefits of 3D visualisation, as summarised by Shepherd (2008), such as more space for displaying additional data variables and a more familiar view of spaces, also apply here. The third dimension (the Z-axis) can represent altitude (yield data are then displayed on the digital terrain model as texture), or it can show the distribution of values for a particular attribute (in this case yield values). Benefits of 3D visualization of yield data briefly mentioned only Charvát et al. (2018).

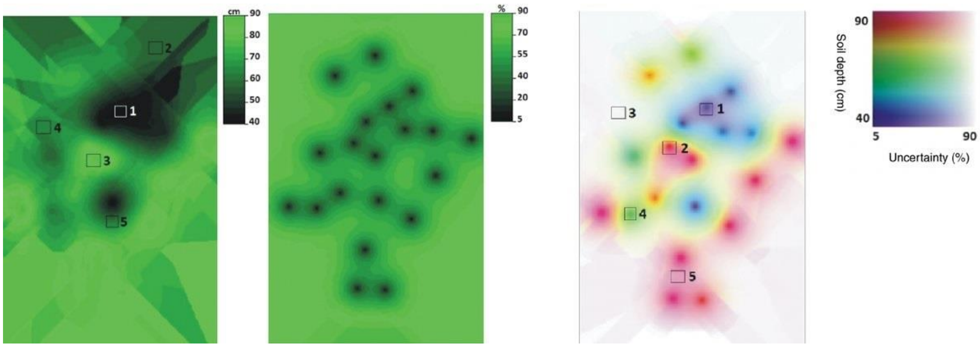

Figure 5. Examples pair of maps compared (left) and bivariate colour scale (right). Source: Kubíček and Šašinka (2011).

Uncertainty is another of potentially critical factors of yield data visualization, which is not addressed in previous studies. Approach, which was originally proposed for visualization of soil sampling data and tested on users by Kubíček and Šašinka (2011), can be transferred also on yield data. Both bivariate colour scales and pair of maps can be used for this purpose (see Figure 5), however, verifying which of these methods is more suitable for visualizations of yield data and uncertainty in these data may be the subject of further research

6. Conclusions and future work

Various methods of cartographic visualisation are important in the processing and interpretation of yield data, and in precision agriculture in general. This paper illustrates the use of cartographic visualisation to filter and present detailed geospatial yield data. Examples of different types of cartographic visualisation were created from data measured by a harvester in the Pivovárka field.

Future work will follow three directions: an extension of the described approach to different fields and data from different harvests; an application of these data and visualisations in more complex analysis (both machine processing and visual analysis); and, finally, user evaluation of designed visualisations and their variants.

Regarding usability research, different aspects of cartographic visualisation should be examined. These aspects in the case of 3D visualisations include, for example, the level of interactivity of visualisations (static perspective views versus interactive visualisations), the effect of different Z scales or different colour schemes in general.

Future usability research focusing on yield maps and related cartographic visualizations is very important because it is obvious that these cartographic visualizations must be not only legible but also understandable also for readers that are experts in their specialisation, in this case for agronomist or farmers.

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A 3D Routing Service for Indoor Environments

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Abstract.

Large and complex buildings with substantial numbers of visitors require fast and effective navigation support to help first-time and infrequent guests to easily find their destination and avoid stressful situations. Most existing solutions are based on in-situ localization and routing, therefore requiring expensive indoor positioning infrastructure. In contrast, the objective of this research is the development of a cheap and easily deployable indoor routing service that visitors can use to plan the route to their destination before their visit. It visualizes both the interior space of a building and its users' individual routing paths in a virtual 3D environment. The proposed solution is entirely based on open source tools and has no installation requirements for the user. Its functionality is demonstrated in a building at the Aalborg University Copenhagen campus. This kind of ex-situ 3D digital navigation promises to help users gain a better understanding of the explored environment, and to improve people's cognitive spatial maps when combined with animated stimuli and landmarks.

Keywords. 3D navigation, indoor routing, 3D modeling, animation, landmarks

1. Introduction

The increased complexity of the contemporary urban environment has led to the widespread adoption of digital navigation systems for pedestrians in outdoor environments. However, even though people spend most of their time in indoor environments of growing structural complexity and scale, the use of indoor routing services is still limited due to three main reasons: the lack

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of navigational organization in the interior of buildings, the need of addressing vertical connectivity issues and the existence of light objects such as furniture. Furthermore, existing solutions rely on mobile devices to display step-by-step routing instructions, which in turn depend on infrastructure for precise indoor positioning that needs to be deployed throughout the whole building.

The research presented here proposes an indoor routing service that motivates the future visitor of a building to memorize the desired routing path by using visually attractive stimuli: 3D virtual navigation, animations and landmarks. Instead of revealing the complexity of the building, the study deconstructs it to its basic components (floor slabs, open and closed spaces), highlighting its landmarks (i.e., unique and easily identifiable features in the indoor environment, such as reception desks or pieces of art) in a predefined routing network to all points of interest for its guests. The objective of the presented work is the prototype development of a comprehensive, yet affordable routing service with 3D visualizations. The next steps for this research include the experimental evaluation of the effectiveness of the above-mentioned visual stimuli and a comparative study against an in-situ online routing service.

2. Related Work

Dealing with the challenges of developing indoor routing services, Diakité and Zlatanova (2018) introduce the Flexible Space Subdivision framework that describes a realistic, non-abstractive 3D indoor space with dynamic scene changes and automatic identification of suitable navigational spaces. Following a more abstract approach, Jamali et al. (2017) show an automated method for 3D modeling of indoor navigation structured in cells without gaps between them. It relies only on geometrical and topological relationships, without spatial semantics. Particularly, the 3D model is considered as primal graph, while the indoor navigation network is generated by connecting surveyed benchmarks as dual nodes through a Delaunay triangulation. In contrast, the Indoor Emergency Spatial Model (Tashakkori et al. 2015) includes 3D indoor architectural and semantic information for advanced situational awareness in emergency response cases.

3. Conceptual Design

The study proposes an indoor navigation service in a virtual 3D environment for the calculation of routing paths between two points that allows users to plan the route to their destination before their physical visit. In order to support the user in memorizing the results and navigate independently in the corresponding spaces, cues enhancing spatial memory and orientation skills are being investigated. Imageability, which defines the probability of a space of '*evoking a strong image in any given observer*' (Lynch, 1960, p.9), is a fundamental component in wayfinding processes, while 3D models, landmarks and animations are of great importance in 'absorbing' spatial information before starting the physical research of the host places. Specifically, according to Xu et al. (2013), 3D models are more powerful than a 2D map in complicated indoor spaces because of the accuracy of their description, offering contextual information and representing not only the object and its location but also horizontal and vertical mobility with adequacy and realism.

Furthermore, Fallah et al. (2013) indicate that human navigation relies on landmarks, while Sharkawi, Ujang, and Abdul-Rahman (2008) notice that landmarks are easier recognizable in 3D models due to their high visual correspondence to real-world objects and increase the navigational value of the 3D map. Bederson and Boltman (1999, p.1) support that '*animation improves users' ability to reconstruct the information space*', while technologies for 3D visualization and interactive animation offer benefits regarding management and access of large information spaces (Robertson, Mackinlay, and Card 1991). Based on these considerations, the study develops an indoor routing service with these basic cues aiming at having guests prepare their routes before their visit. Additionally, the main characteristics of the building model are examined through a requirements analysis inspired by the Topographic Space of Brown et al. (2013), aiming to a more effective and understandable space for route planning accommodation. The building model as a means that provides topographic space information should fulfill various requirements dependent on the navigation tasks, the navigation environment, the users, the modes of locomotion and the scenario (Brown et al, 2013) providing consistent and complete description of its captured components. Regarding the technical requirements, the service should be technically robust, cheap, easy and quick to develop based on existing components. From the user's perspective, it should be easy to use, providing an attractive user interface running in a web browser without any installation requirements.

4. Implementation and Preliminary Results

The prototype is based on the case study of a building at Aalborg University in Copenhagen and consists of three elements: the 3D model, the network and the web service. Since there was no 3D model of the building available, a model has been generated by using the building's blueprints and extracting the three-dimensional volumes of its slabs and closed spaces in CAD format.

The 3D model is finally converted to CityGML and 3D Cesium Tiles for the web service using the FME Data Integration Platform.

The routing network has also been generated as a CAD 3D diagram representing all open and closed spaces. It is a graph model with connected edges among the decision points for each floor. Since this graph does not support routing yet, PostgreSQL with PostGIS and pgRouting has been used for the routing. To the best of our knowledge, this is the first application of pgRouting for 3D indoor routing applications.

Even though pgRouting does not support routing in 3D, the applied methodology relies on its original concept that the data need to be 'noded' in order to create a useful topology. In other words, a node needs to be where an intersection is formed and all path segments need to be broken at the intersection, '*assuming that you can navigate from any of these segments to any other segment via that intersection*.' (pgRouting Concepts — pgRouting Manual (2.6) n.d.). Consequently, each floor and vertical mobility graph is imported into the database as separate table storing its geometrical features in two-dimensional lines and the elevation in a separate attribute field. This approach allows building the routing topology and creating the table with the decision points for the network data by the corresponding queries of the pgRouting extension. Having achieved the routing calculations for each floor separately, all the data are combined in two final tables, one for the decision points and one for the path segments of the whole building. Points that are sufficiently close together between a floor and the vertical mobility intersection are found and connected accordingly. As a result, the so far disconnected two-dimensional graphs are converted to 'noded' data with three-dimensional topology.

Cesium JS has been used for the visualization of the routing path in the 3D virtual environment since it allows simultaneous visualization of the building, the routing path and the start and ending points (Figure 1). The 3D building model is supported in the service in the 3D Cesium Tiles format, while the route path is calculated on the fly in an SQL query based on users' input. The communication between the service and the database is achieved through PHP. Moreover, it offers various easy-to-implement, performant animation techniques (Figure 1) providing a user-friendly interface, which also allows the user to choose whether to use stairs or not, as shown in Figure 2. Lastly, the web service visualizes selected landmarks both in written instructions and on the 3D map for memory and vision initiations and guides the user through them, suggesting the easier recognition of the spaces.

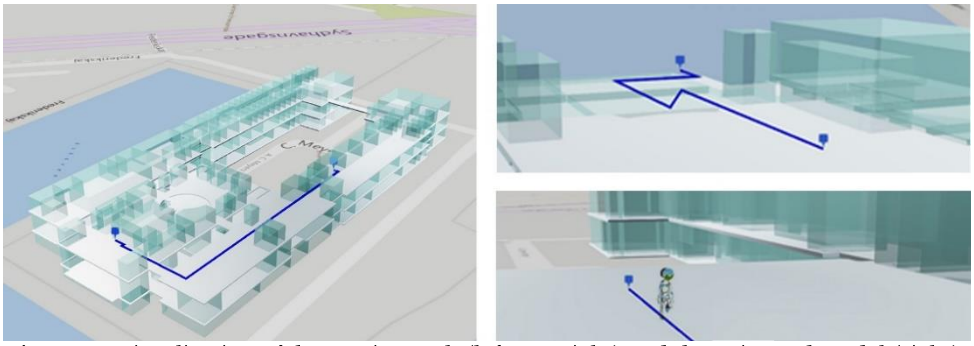

Figure 1. Visualization of the routing path (left, top right) and the animated model (right)

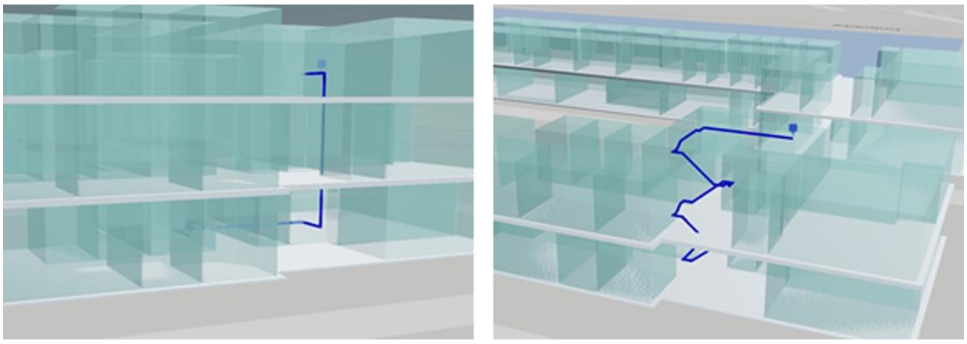

Figure 2. Routing between the same points using the elevator (left) and the stairs (right).

5. Conclusions and Future Work

This study suggests the development of more flexible and easily deployable indoor routing services that provide a tool for unfamiliar visitors in order to reduce the insecurity of navigating in complex indoor spaces. The research examines potential cues that affect spatial perception and orientation and attempts their implementation in the development of a routing web service with promising results for the preparation of the future visitors of complicated buildings. Based on the literature review, 3D digital navigation, animated stimuli and landmarks improve the initial perception of the host spaces, while their advantages in the preparation of the visitors and their performances in wayfinding will be explored in future work. The proposed service can easily be deployed based on floor plans or existing 3D CAD models.

Future work will focus on user and field experiments in the university campus to evaluate its performance against in-situ solutions, not only regarding the navigation performance, but also concerning the users' understanding of the building. Considering future development of the service, support for mobile devices and the inclusion of semantic information from the 3D model, such as conditionally accessible spaces or opening hours of specific rooms, are currently under consideration.

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Adapting the Type of Indoor Route Instruction to the Decision Point

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Abstract. In this study, an online survey was executed in which participants had to indicate how good they found the type of route instruction that was shown on an indoor decision point. results show that the preference for route instruction types differs per decision point category. These preliminary results will be validated in a real life experiment with an adapted mobile wayfinding aid.

Keywords. Indoor wayfinding, route instruction type, Location based system

1. Introduction

When you have to go to a meeting, you can easily find your way to the office building, but as soon as you enter, it is up to you to find the meeting room. This is because outdoors, mobile navigation aids (e.g. Google maps) are widely used, but indoors this is not yet common practice. One of the reasons for this is that most indoor environments are more complex than outdoors, for example because of the third dimension (i.e. staircases, elevators) (Giudice, Walton, & Worboys, 2010). Because of this complexity, indoor environments could benefit from more intuitive wayfinding systems, which impose a low cognitive load on the user. A more intuitive route guidance could be facilitated by providing the right amount of information at a specific place and time. To this end, adapted mobile wayfinding aids are being developed which adapt their characteristics to the context (Reichenbacher, 2003).

One possible adaptive aspect of wayfinding aids is the type of route instruction (e.g. map, photo, text,…). Every type of route instruction has specific characteristics which have a different effect on the induced cognitive load.

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Text instructions have the advantage of imposing low cognitive load on the users, but the disadvantage is that they can only give a limited amount of information. Photos show a lot of landmark information, which can improve orientation, but the large amount of information to be interpreted can cause a rise in cognitive load. Maps can also induce a high cognitive load, because the perspective of the user has to be translated to the map (Chittaro & Burigat, 2005). Similar to photos, 3D-visualizations also show a lot of information and this type tends to be favored by participants (Kray, Elting, Laakso, & Coors, 2003). Additionally, every instruction type has a certain generation cost. Text and symbols are easily generated, but photos require more resources. Map instructions can be deduced from the floorplan and 3D simulations from the building information model (BIM), but both should be extended with realistic colors and materials (Lertlakkhanakul, Li, Choi, & Bu, 2009; Puikkonen, Sarjanoja, Haveri, Huhtala, & Häkkilä, 2009). In this research is determined which type of route instruction is preferred at which decision point in order to implement these findings in an adaptive mobile wayfinding aid.

2. Methods

2.1. Types of Route Instruction and Online Survey

The case study building of the online survey is the iGent tower in Ghent (Belgium), a modern office building that facilitates the installation of a location based system (LBS) as several location sensors can be mounted to the ceiling. In this building, ten routes were recorded on video. First of all, the route instructions for these ten routes were designed in several types. *Figure 1* shows six of these types, the remaining four are obtained by placing the text instruction below the images or videos.

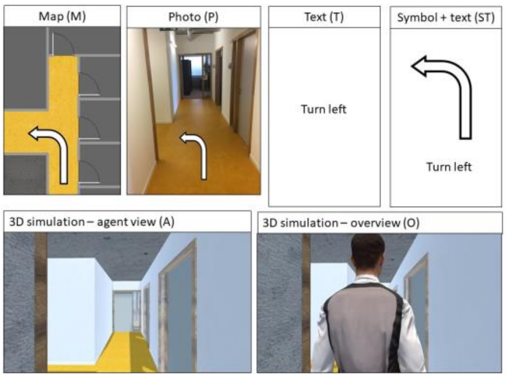


Figure 1. Instruction types.

During the online survey, participants watched the ten route videos and with every new route, a different instruction type was used. The order of the routes and instruction types were randomized. At every decision point along the routes, the route video paused and participants had to rate on a seven-grade likert scale how good they found the type of route instruction that was shown on that decision point.

2.2. Statistical Analysis

In the statistical analysis, the decision points are first categorized according to the action of the route instruction. Next, one-tailed pairwise mann-whitney U tests with Bonferroni correction are used to analyze which types of route instructions received higher ratings for each of these categories. This way, the best type of route instruction is determined for every group of decision points.

3. Results

The preliminary results are summarized in *Table 1*. For every category of decision points, an example of the recommended route instruction type is visualized: Photo + text instructions were preferred at decision points to change levels and take turns, 3D-simulations + text received higher ratings at the central decision point and symbols + text at starts end endings of a route.

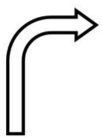
Changing levels	Taking turns
 Take the stairs to the 10th floor	 Turn left
Starting and ending a route	**Central decision point**
 The office is the first one on the right	 Go straightforward

Table 1. Overview of best route instruction types per decision point category

4. Discussion and Future Research

Generally, the photo instructions with text got the highest ratings, but when symbols with textual instructions are considered (e.g. because of their low generation cost), they are best used to start or end a route. This might be explained by a lack of landmarks. As mentioned in the introduction, photos have the advantage to enable a fast recognition of landmarks. However, in this case study building, not many landmarks are present in the hallways, as is often the case in indoor environments (Mast, Jian, & Zhekova, 2012). When no landmarks have to be recognized, a textual instruction can convey the wayfinding information with a lower cognitive load than a photo instruction. For example, it is easier to interpret the text instruction 'the office is the second door on the right' than a photo with the same message. At the other groups of decision points, more landmarks are present: the pictogram of the staircases can be recognized on a photo and at the crossings a photo gives more support than text to take turns. Most landmarks are present at the central decision point where several hallways cross. The type that gives the most complete information, 3D simulations, received higher ratings at this decision point.

The results of the online survey will be validated with a real life experiment. This validation is important in cartographic usability research, as both methods have limitations. By triangulating the results, findings can be confirmed and new issues can be detected (Roth et al., 2017). To this end, a mobile wayfinding aid has been developed, which implements the findings of the online survey by adapting the type of route instruction to the decision point. The turn-by-turn instructions of the wayfinding aid will be automatically shown at the right location. To enable this location awareness, the system uses the ultra-wideband sensors, implemented in the ceiling of the case study building. This way, it will be easier for participants to know they are still on the right track, compared to a system where they need to swipe to the next instruction. During the experiment, participants will wear a mobile eye tracker in order to measure their eye movements. This gaze data will give an indication of the cognitive load, induced by the mobile route instructions. Consequently, it will be analyzed if the adapted route instructions induce lower cognitive load than non-adapted route instructions.

5. Conclusion

To guide people indoors, adaptive mobile wayfinding aids are being developed, which adapt the given route information to the user and the environment. In this study an online survey was conducted to investigate how the type of route instruction can be adapted to the decision point. this research showed that different types of route instructions are preferred at different categories of decision points: text to start or end a route, 3D simulations for central crossings and photos for other decision points. These preliminary results will be validated in a real life experiment, to test if adapted route instructions ease wayfinding.

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Developing Cognitively Simple Wayfinding Systems: A Mixed Method Approach

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Abstract. Existing indoor navigation systems are not well adapted to their users. Our goal is to substantially improve the wayfinding experience for the users of those systems by adapting the routes that people are guided along to more cognitively simple routes. Guiding people along routes that adhere better to their cognitive processes could ease the wayfinder in the indoor environment. This paper identifies the aspects that should be included in a cognitively motivated route planning algorithm by using a mixed method approach. In this approach, the results of a focus group and an online survey are combined. The validation of the results in a real life experiment is subject of ongoing work. From the focus group discussions, it could be concluded that wayfinding complexity has to be considered at different levels: the global and the local level. Moreover, results of the online survey show that geometric simplicity and visual information at decision points is of substantial importance when studying wayfinding complexity in indoor environments. The implementation of these results in a cognitively motivated route planning algorithm could be a valuable improvement of indoor navigation support.

Keywords. Indoor navigation, Cognition, Routing algorithm

1. Introduction

Navigation is a complex process which involves planning and decision-making. Previous research has showed that particular characteristics of the indoor environment, in contrast to outdoor environments, impedes successful navigation in this environment (e.g. changing floors, complex decision points, the fewer options to monitor landmarks) (Ohno *et al.* 1999, Hölscher *et al.* 2006, Carlson *et al.* 2010).

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Although several attempts are made to guide people in such complex environments, these systems are not yet common practice. Possibly because the existing indoor navigation systems are not well adapted to their users. Route planning in existing navigation systems are often limited by distance or travel time optimization algorithms (e.g. Kwan and Lee 2005, Thill *et al.* 2011) although people not always prefer the shortest path (Golledge 1999). Routes that correspond to the cognitive model of the navigator are easier to comprehend. These more intuitive and easier-to-follow routes reduce the risk of getting lost, require a smaller wayfinding effort, guide in recalling routes and are overall perceived as more comfortable (Vanclooster *et al.* 2014). Moreover, these systems do not just have to provide the (shortest) route from origin to destination, they have to guide the user on the route while easing the user and avoiding confusion. By adapting the path algorithms in these systems, and guiding them along the paths that adhere better to cognitive processes, the user experience could substantially be approved.

To get a better understanding of the complex cognitive processes during navigation and to select the aspects that should be implemented in a routing algorithm that calculates such routes, a mixed method approach was applied. This mixed method approach combines quantitative and qualitative research techniques. This combination help the researcher to explore and generate new ideas, but also helps to develop the study design of the subsequent studies (Freitas *et al.* 1998, Breen 2006). Moreover, the combination of techniques enables the interpretation of the results (Safari and Fakouri 2016). Hence, the qualitative and quantitative research techniques complement and validate each other to support triangulation of the data to obtain more solid conclusions (Ooms *et al.* 2017). In this research, a focus group discussion, an online survey and a real life experiment are combined and we will elaborate the application of this approach in this paper.

2. Methodology

2.1. Focus Group

In this first study, the exploratory focus group, the discussions were guided by a rotating wheel according to the so-called GPS-method which was developed by the Flanders District of Creativity. The group of participants comprised academic researchers and experts with different background (i.e. Psychology, Geography and Architectural Design). A pilot study was conducted to evaluate the method and design a detailed time scheme. The moderator guided the discussions and tracked the time while a second research was taking notes. The session took around 3 hours and consisted of an introduction, an exploratory open discussion and proceeded with more structured discussions resulting in a selection and a concluding discussion on the most prominent concepts that where brought up during the previous discussions.

2.2. Online survey

Based on the results of the focus group, multiple situations with specific local characteristics likely inducing confusion and discomfort (e.g. specific intersections, different stair cases, different door types) were selected. Videos of these specific situations were recorded from the navigator's perspective in various complex buildings (i.e. university hospital and three different university campus buildings) differing both in geometric complexity as in appearance. The survey was published on Amazon Mechanical Turk. In the online survey, videos of these situations were shown to the participants, as if they were navigating through the building. After watching the video, participants were asked to rank their comfort and confusion level about the recorded situation on a 5-point Likert-scale and they had to specify their motives for their ranking. Both the ranking and the open-ended questions where compared to the characteristics depicted in the videos.

2.3. Experiment

Since body-movement and the real-world perceptions, which have a substantial impact on information processing and spatial decision making (Schwarzkopf and Stülpnagel 2013), are excluded in these well-controlled lab environments of the previous studies, a real-life experiment will be executed to validate previous findings. The developed study design is in line with the experiment design of previous wayfinding studies (Hölscher *et al.* 2005, 2009). Eye tracking data of participants guided through different complex buildings along different paths (i.e. shortest path and fewest turn path) will be recorded. Performance measures (e.g. duration, stops, errors), eye tracking measures (e.g. fixation number, fixating duration) and annotations of the accompanying researcher, which are all measures indicating complexity and cognitive load, will be compared across the different paths and its decision points. This analysis will allow us to determine complex routes and to identify the environmental characteristics increasing the perceived complexity. Moreover, it will lead to an understanding how and in which occasions people make wayfinding errors.

3. Results

As expected, the results of the focus group discussions provided a broad overview of the elements to be regarded when studying wayfinding. The results confirmed the findings in literature: preferred wayfinding strategies

(Hölscher *et al.* 2006), the environmental characteristics of Weisman (Weisman 1981) and the usability hotspots of a complex building (Hölscher *et al.* 2006) were discussed and thus are of importance when studying wayfinding. Moreover, results indicate that route complexity has to be considered at different levels: local level (i.e. at decision points) and global level (i.e. legibility of the building).

Therefore, a selection of local environmental characteristics raised in the focus group discussions were selected to be tested in the online survey. The results of the online survey show that visibility, visual clutter and geometric simplicity are of substantial importance when evaluating comfort and confusion level, and thus the complexity of indoor navigation situations.

4. Conclusion

In this paper, a mixed method approach was applied to study indoor wayfinding processes in the indoor environment aiming at adapting existing navigation systems according to the findings. The applied mixed method approach combines qualitative and quantitative research techniques. In the initial exploratory phase (i.e. focus group), the researchers explored the issues related to indoor navigation and wayfinding. Consequently, this leaded to an adequate research design of the subsequent studies (i.e. online survey and experiment). Moreover, by combining the results of both the qualitative and quantitative studies the results of the focus group could be validated while the results of the online survey could be interpreted using the results of the focus group. To validate the findings of the two previous studies, a real-life experiment is being conducted. The validation and interpretation of the results of the different studies using the results of the other studies will lead to a coherent and well-founded conclusion of the elements to be included in cognitively motivated wayfinding support. The implementation of these findings in a route planning algorithm would substantially improve the existing systems.

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Towards a User-Oriented Indoor Navigation System in Railway Stations

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Abstract. User demand has always been a driving force of indoor navigation research. In this study, we propose to conceptualise a user-oriented indoor navigation system, with the aim of improving user experience on indoor navigation in railway stations. We firstly conducted a series of stakeholder workshops to identify the most crucial future challenges towards a user-oriented indoor navigation system. Based on the findings from the workshops, a user study in Vienna central railway station was carried out to find out group-specific user needs. In the end, we will conceptualise a holistic indoor navigation system, considering group-specific user needs and technological innovations.

Keywords. Indoor Navigation, User Study, Railway Station, LBS

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1. Introduction

Recent years have witnessed a trend in LBS research from outdoor environment alone to indoors as well (Huang et al. 2018). Navigation in indoor environments, e.g., shopping malls, museums, airports, and railway stations, caught researchers' attention, not only because of the developments of indoor positioning and indoor spatial data modelling (Huang et al. 2018), but also due to the increasing demand from the users. However, users vary dramatically in their age, gender, demographics, culture, and spatial ability, which all influence navigation behaviour and their perception of navigation guidance (Roth et al. 2017, Roth 2013, Keehner et al. 2008, Castelli et al. 2008). It is, therefore, necessary to identify user groups and investigate their special needs. Researchers have emphasised on user-centred design (Haklay & Tobn 2003, Norman 1988) and developed a user-oriented indoor navigation system in venues such as museums (Kaulich et al. 2017, Tscai et al. 2017).

As an important multifunctional indoor environment, many indoor navigation studies are dedicated to railway stations (Tabata et al. 2015, Fall et al. 2012), nevertheless, most of them focused only on indoor positioning. Current indoor navigation systems in railway stations are mostly distance-based and providing turn-by-turn instructions, which do not allow an overview and draw too much of users' attention. In order to improve user experience on indoor navigation in railway stations, we aim at conceptualising a user-oriented indoor navigation system. Aiming at tackling this issue, we focus on three research questions:

1 What are the most crucial challenges towards a user-oriented indoor navigation system in railway stations?

2 What are user group-specific needs towards an indoor navigation system in railway stations?

3 Can we conceptualise a holistic indoor navigation system, considering group-specific user needs and technological innovations?

2. Stakeholder Workshop

2.1. Methodology

To identify the most crucial future challenges towards a user-oriented indoor navigation system, a series of stakeholder workshops were conducted with representatives from the Austrian Federal Railways (OEBB). Participants' professional backgrounds and responsibilities ranged from diversity management, market management, communications, technology, to infrastructure, yet, all were engaged in developing an indoor navigation system of the future. Workshops were conducted to specify the different user groups of railway stations, to discuss their needs and requirements, and to identify usual and unusual activities at railway stations. At the same time, workshops were conducted to get insights into existing infrastructural as well as technological contexts.

Each workshop started with a short introduction to the workshop's goals. Participants were then invited to discuss and share their perspectives. Notes were taken during the discussions, which were used at the end of each workshop to jointly prioritize the findings.

2.2. Results

Based on the workshops, we identified a list of requirements that a future indoor navigation system for railway stations should consider (Fian et al. 2019):

- diversity criteria of existing and potential user groups as well as their group-specific needs
- connecting existing navigational aids available at railway stations, such as signs, floor plans, landmarks, colour coding system, and tactile guidance system in the physical environment, as well as applications on mobile devices
- potential innovative technological solutions for indoor navigation services
- existing and potential data sources
- the varying degrees of railway stations' complexities for indoor navigation

3. User Study in Vienna Central Railway Station

3.1. Methodology

In order to study group-specific needs in more depth and to assess the quality of available navigational aids at railway stations, a user study in Vienna Central Railway Station was conducted.

The aim of this study was to examine the navigation behaviour of different user groups and to identify their group-specific needs at railway stations. Using a multi-methodological research design that combined behaviour-related measures (eye movements using mobile eye-tracking, documentation of chosen walk paths, distances and walking times in the building) as well as data from semi-structured interviews and qualitative data using think-aloud-method, we wanted to identify factors that facilitate or impede participants' navigation at railway stations.

Based on the information provided by Austrian Federal Railways (OEBB), we firstly identified the major user groups. Our sample for the user study consisted of 36 participants, including 18 women and 18 men. The average age was 41 years (SD = 20.5), with the youngest subject 18 years and the oldest 79 years old. They were characterised by high diversity in aspects of age, gender, mobility restrictions, familiarity with the train station and ethnic background. We chose Vienna central railway station as our experiment venue, because of its complexity and the digital services available there. Participants had to complete an ecologically valid use case including ten different search tasks that represent usual activities at railway stations (e.g. finding ticket machine, toilet) as well as unusual activities (e.g. finding hairdresser, flower shop). In addition to usual guides (e.g. signs, floor plans, staff, etc.), participants were instructed to complete some of the tasks by using a prototypical indoor navigation app by OEBB. *Figure 1* illustrates the flow of the tasks and the distribution of the tasks accomplished with or without using the app.

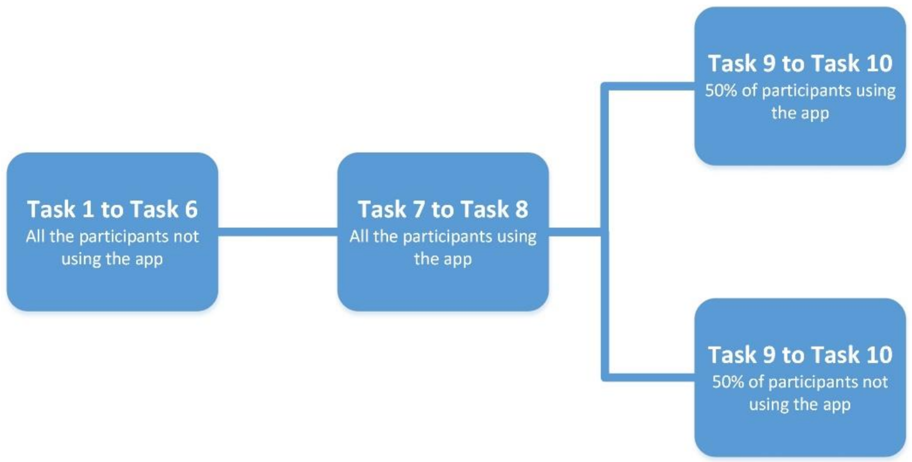

Figure 1. The distribution of the tasks accomplished with or without using the app.

3.2. Preliminary Results

The preliminary results of this study showed that the user group of older participants differed in their navigation behaviour from those of younger participants. While younger participants more efficiently used the navigation app to quickly find targets (*Figure 2*), older participants more often showed difficulties in properly using the app, which led to detours and therefore to long search times (*Figure 3*). Compared to the user group of younger participants, older participants in general showed preferences for analogue indoor navigation guidance.

Figure 2a Figure 2b

Figure 2. Example of trajectories of younger participants (<30) without using the app (2a), compared to using the app (2b) (Fian et al. 2019).

Figure 3a Figure 3b

Figure 3. Example of trajectories of older participants (>60) without using the app (3a), compared to using the app (3b) (Fian et al. 2019).

4. Conclusion and Outlook

While the majority of younger participants were able to efficiently use both analogue and digital aids for quickly gaining an overview at the railway station and to complete the navigation tasks efficiently, older participants had problems finding their way in the railway station, especially when using the indoor navigation app. Thus, a user-oriented indoor navigation system in railway stations should consist of two parts: the navigational aids in the physical environment, and the navigation services on mobile devices. In accordance with the feedback given by the older participants, improvements on the navigational aids to ensure simple orientation at the railway station are needed: more salient and thus more effective placement of floor plans (e.g.

entrance areas, hot spots), user-friendly designed floor plans, and info screens.

In order to improve the navigation services on mobile devices, we plan to conceptualise a holistic indoor navigation system for railway stations, concerning technological innovations. We plan to model user profiles, based on the information in the ticketing system (users' demographic data, preferences, etc.), in the navigation system (movement behaviour, etc.), and their social media accounts. We will consider a railway station as a system of various processes. Thus, we are going to investigate the detailed infrastructures of railway stations and their functions and build a functional ontology of the integrated system. With this, we aim to enhance the user experience on indoor navigation in railway stations.

Acknowledgement

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Adapting Navigation Support to Location Information Quality: A Human Centered Approach

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Abstract. Variations in the quality of location information can negatively affect the users of pedestrian navigation support systems (PNSS). Current approaches to handle these variations mainly focus on improving the quality of location information by improving sensor technology and improving localization algorithms. This research introduces a different approach called "Adaptation to Quality" that adapts the behavior and output of the navigation application to the level of quality. Rather than treating location quality variations as exceptions or trying to improve the quality of location information, adaptation to quality focuses on still providing continuous navigation support even when the location quality is very low or when location information is no longer available. We carried out a series of experiments to investigate ways to facilitate Adaptation to Quality. This paper summarizes the findings and insights.

Keywords. Pedestrian navigation, Location information quality, GPS, Human-centered, Application behavior and output

1. Introduction

Pedestrian navigation support systems (PNSS) have completely changed the modus pedestrians used to find their way in unknown areas. Variations in the quality of location information however make it sometimes difficult or challenging to rely on wayfinding using PNSS. This can have negative impacts on user experience and on user trust on navigation applications. Current approaches to handle this variation in the quality of location information mostly focus on sensors or the processing that calculates positional information from raw measurements. Common strategies of this type include improving the sensor technology (e.g. integrating better clocks into GPS receivers, designing better chips, receivers, and antennas), fusing sen-

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sor data (e.g. combining WiFi and GPS data) and developing better algorithms (e.g. by including contextual factors to eliminate unreachable positions). Due to these efforts, the average quality of positional information has continuously been increasing over recent years but new approaches to pedestrian navigation such as electrical muscle simulation (Pfeiffer et al. 2015) and haptic feedback (Pielot & Boll 2010) require much higher quality as they rely on high quality location information to trigger instructions. Despite these improvements, there still are and most likely always will be situations where location sensing will either produce low-quality location information or fail to provide location information at all. Such situations can be caused, for example, by technical failures, by user mistakes, or by the inherent dependency of sensors on contextual factors. The latter aspect refers to situations such as strong magnetic interference, difficult weather conditions and urban canyons, which can result in the complete loss or very low-quality location information.

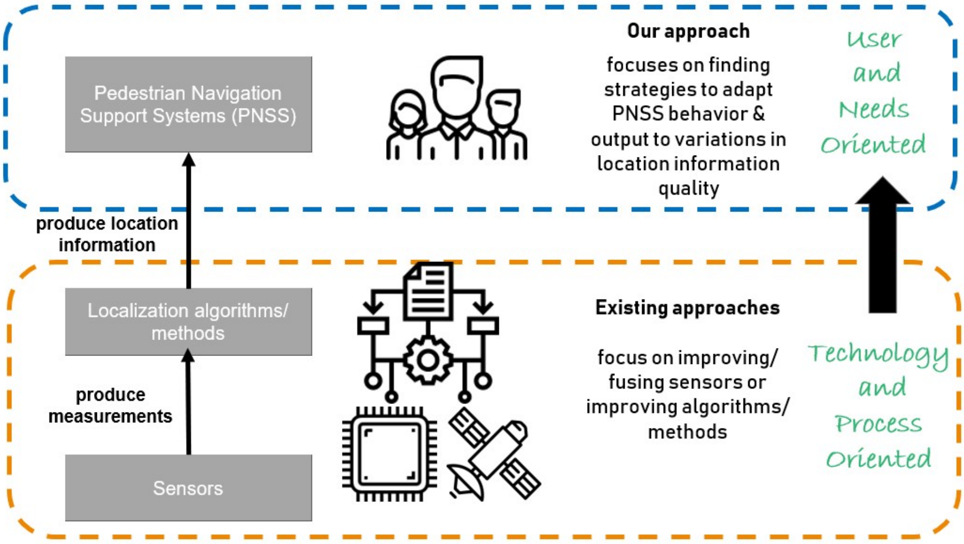

Figure 1. "Adaptation to Quality" focuses on adapting the behavior and output of the PNSS to the level of location information quality rather than on improving sensors or localization algorithms.

This research focused on investigating a new and complementary approach called "Adaptation to Quality" in solving this problem. "Adaptation to Quality" adapts the behavior and output of a PNSS to the location quality to continue to support the user rather than stopping support or exposing erratic behavior due to location quality variations. This new approach complements existing ones operating on the sensor or processing level. Our research focuses on the navigation support layer, and puts special emphasis on the interaction between the PNSS and the user (see *Figure* 1).

2. Related Work

Mobile pedestrian navigation support systems highly depend on the positional information from various sensors. In outdoor environments, the main source is satellite-based positioning information obtained from global navigation satellite systems (GNSS) such as the Unites State's Global Positioning System (GPS) and Russia's Globalnaya Navigazionnaya Sputnikovaya Sistema (GLONASS). In addition to GNSS, PNSS also use other sensors of smartphones such the accelerometer, gyroscope (Pei et al. 2013), WiFi (LaMarca et al. 2005) and the mobile network (Fang 2012). Many factors such as multipath reflections, interferences, weather conditions and user related factors however cause variations in the quality of location information produced by these sensors. Consequently, the quality of location information can vary from very accurate and timely information to no information at all (Ranasinghe & Kray 2018). One approach to handle this problem is by improving sensor technology. For example, by developing better chips, antenna designs and receivers (Blunck et al. 2011). Also, the development of receivers with multi-constellation capabilities (Zhu et al. 2018) has enabled receiving signals from more than one satellite systems. Fusing sensors is also another method used for improving the accuracy and availability of positional information. For example, GNSS is often combined with inertial navigation (Godha et al. 2006). Apart from improving and fusing sensors, current systems also improve localization algorithms to improve the quality of location information (Zhu et al. 2018), (Reuper et al. 2018). All these existing approaches, improving sensors, fusing sensors and improving algorithms focus on improving the quality of location information. However, there are still situations caused by various factors that hard to model that positioning systems produce low quality location information (or no information).

3. Facilitating Navigation Adaptive to Location Information Quality: Methods and Outcomes

In previous work, we conducted a series of experiments and employed a combination of methods to investigate ways to facilitate navigation adaptive to location information quality (cf. *Figure* 2). This section briefly summarizes these methods and the findings in order to relate and discuss how these individual experiments contribute to the overall aim of finding ways to facilitate navigation adaptive to location information quality.

3.1. Methods

Understanding location information quality is crucial to understand how to deal with quality. We first conducted a thorough literature analysis of location quality to identify, to analyze and to characterize the aspects of location quality, factors causing quality variations and the existing approaches for dealing these factors (cf. *Figure* 2). Understanding users is integral to design human centered strategies to deal with quality variations. We conducted three user experiments for this purpose (Study 1, 2 \& 3 - cf. *Figure* 2). Study 1 investigated the impact of low-quality location situations on PNSS users, user strategies and needs of users when facing quality variations using a field-based user study (N=21) that exposed users to three types of location quality variations (low accuracy, no coverage and delay). Study 2 and study 3 investigated the use of visualizations to support users when facing low quality location information. Study 2 introduced two new visualizations to communicate location uncertainty and to assist users with landmark-based visualizations based on the level of quality of location information. The efficacy of the two new visualizations were compared to the state of the art using a field-based user study (N=18). Study 3 (lab-based, (N=52)) investigated the cross-cultural differences in how users perceive visualizations of location uncertainty. Finally, we developed a framework (LUIF for "location uncertainty injection framework") for designing and evaluating strategies to adapt the behavior and output of a PNSS to location quality variations.

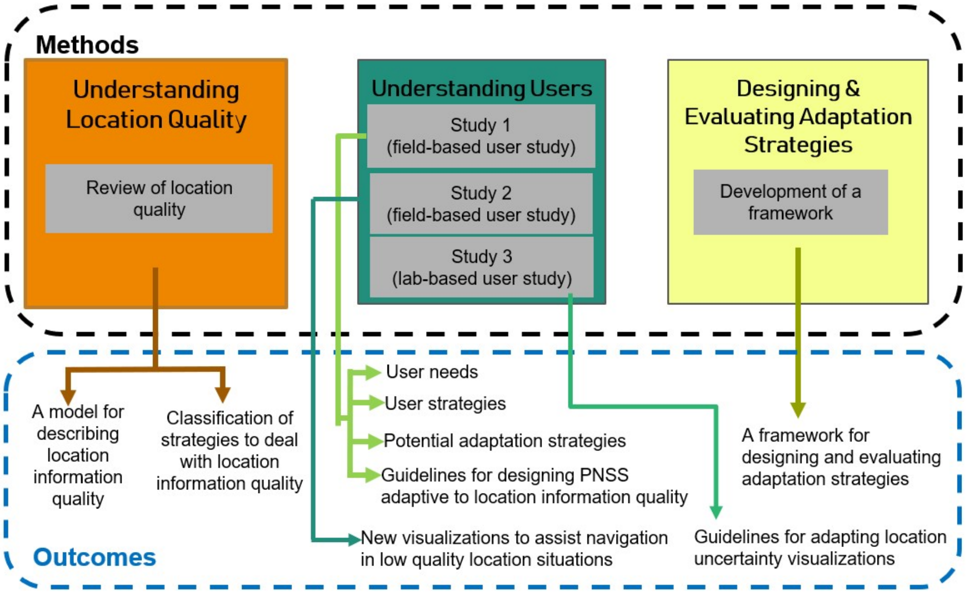

Figure 2. Facilitating navigation adaptive to location information quality: methods and outcomes.

Details of the literature review, study 1 and study 2 can be found in (Ranasinghe & Kray 2018), (Ranasinghe et al. 2018b) and (Ranasinghe et al. 2019a) respectively. Study 3 is described in more detail in (Ranasinghe et al. 2018a) and (Ranasinghe & Kray 2016). Further details of the framework are available in (Ranasinghe et al. 2019b).

3.2. Results and Implications

The literature review on location information quality resulted in two contributions: a model for describing quality of location information (cf. *Figure* 3); and a classification of strategies for dealing with quality variations (cf. *Figure* 4). The former describes location quality as a multi-faceted concept that includes seven aspects of quality (cf. *Figure* 3). These aspects were further categorized into two dimensions, spatial and temporal. Spatial dimension of location quality includes, accuracy, precision, granularity, coverage and conflicts whereas the temporal dimension consists of update rate and recency.

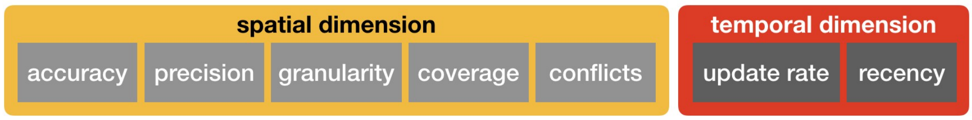

Figure 3. A model for describing location information quality (Ranasinghe & Kray 2018)

Designers of location sensing systems can use the quality model as a standard vocabulary to report and describe the quality of location information of their systems. This makes it easier and useful for the designers of PNSS to plan for and design adaptation strategies. Usually, location sensing system designers report the accuracy of their systems but rarely the other aspects of quality. It is also useful to report under what conditions the reported quality applies. This in turn helps designers of adaptation strategies to compare location sensing systems and to design adaptation strategies at different levels (eg. sensor level, algorithm level, application level). Use of a standard vocabulary to report quality also makes it easier to evaluate and benchmark location sensing systems. This is helpful in selecting suitable location sensing systems for PNSS as well as to identify future research directions. An interesting future research direction along this line is to develop a central platform for reporting quality of location sensing systems. Currently, there is a large volume of research on better location sensing and improving the quality of location information. For example, there is a lot of research on mitigating the impact of multipath reflections on WiFi based positioning. Many sensor and algorithm level approaches have been introduced. The current means of reporting the quality of the location information produced by these approaches is through the corresponding publications. This makes it practically difficult to compare those approaches along different dimensions (for example, comparing the accuracy of WiFi fingerprinting based approaches). A common platform for reporting the quality, preferably together with the source data and other settings would make it easier to benchmark location sensing systems, compare them and to identify future research directions.

The classification of existing strategies for dealing with the variations of location quality categorizes the existing approaches into three classes: sensor level adaptation, algorithm level adaptation and application level adaptation. These classes are organized in three levels and are also aligned with the popular software engineering model for ubiquitous applications, the Location Stack (Hightower et al. 2002). Designers and developers of PNSS can use the classification of existing strategies to design strategies for avoiding problems due to quality variations or to design strategies for dealing with quality variations on three levels that are aligned with the Location-Stack model (Hightower et al. 2002). This classification implies that application level adaptation strategies can be planned and designed in the three top layers of the LocationStack, intentions, activities and contextual fusion.

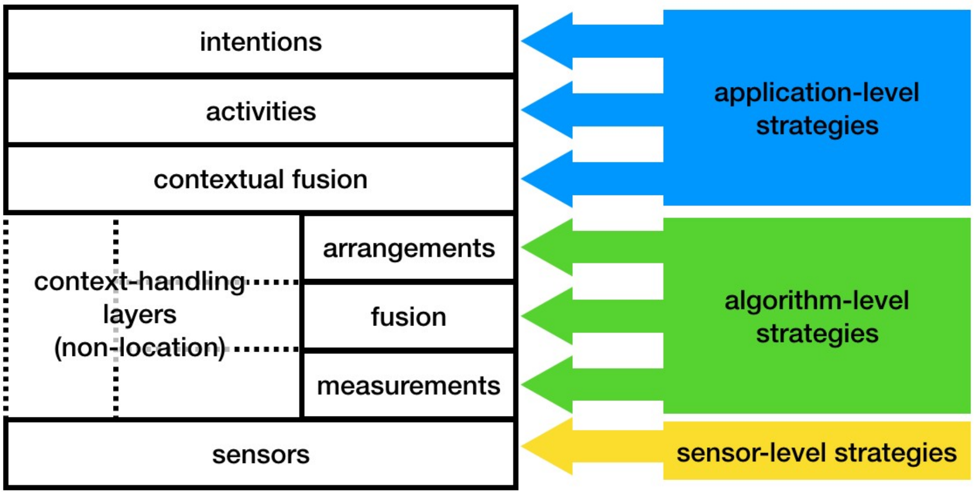

Figure 4. Classification of strategies (right) to deal with location quality variations (Ranasighe & Kray 2018) aligned with the Location Stack (Hightower et al. 2002).

This classification also provides a basis for benchmarking PNSS. For example, to see what PNSS provide adaptation at all three levels (sensor, algorithm, application) or what PNSS provide adaptation strategies at all three application layers of the location stack (intentions, activities and contextual fusion). Furthermore, this classification can be used as a basis for benchmarking adaptation strategies for different aspects of quality. For example, to compare the adaptation strategies (sensor level, algorithm level, application level) for no coverage. It will also be useful to dig deeper into each class and identify subcategories of strategies in each class. Extending the classification to other types of positional information (eg. orientation, speed), to other types of contextual information or even to other types of LBSs would be an interesting future research direction.

Study 1 (Ranasinghe et al. 2018b) showed that user performance, user experience and user trust in the navigation application are negatively affected by location quality variations. The degree of impact of these variations on users varied a lot based on different factors such as personal navigation techniques, situation, type of quality variation and the magnitude of the problem. The study revealed five principle user strategies to deal with low quality location information : (a) slow down and pay more attention until the location quality is good; (b) ignore the location marker but keep referencing the map to assist navigation; (c) walk back to a known location and start to reorient and navigate from there; (d) asking from someone; and (e) use local information such as 'you are here' maps. Study 1 also identified four classes of user needs in situations of low location quality (detailed in (Ranasinghe et al. 2018b)): (a) notification about the problem; (b) rendering; (c) more information; and (d) ability to control the options and offline support.

Based on the results of study 1, we derived four application level adaptation strategies and guidelines for designing PNSS adaptive to location information quality: (a) notifying about the problem; (b) emphasizing landmarks along the suggested path; (c) displaying landmarks based on location accuracy; and, (d) asking the user to slow down and pay more attention. Furthermore, based on the results of study 1, we also derived two classes of design guidelines for facilitating adaptation: (a) map and data quality; (b) empowering users. The results imply that maps with high level of detail such as embedded landmarks with on-demand information such as photographs are helpful to users in situations of low location quality. In order to support the differences in users, their navigation strategies, preferences, perceptions, situations, context and severity of the low quality situations, these guidelines recommend designing of different strategies, functionalities and interfaces to cater for a diverse and a large user base and to empower users to select the options to match their requirements.

Figure 5. Visualization of landmarks based on the level of accuracy to support navigation in GNSS degraded situations (Ranasinghe et al. 2019a).

Study 2 (Ranasinghe et al. 2019a) showed that landmark-based visualizations (cf. *Figure* 5) significantly reduced the number of wrong turns, and it helped users to judge their true location in the environment when faced with low-quality location information. In addition, users preferred this new visualization over the existing circular one. Despite its unfamiliarity, the subjective workload (mental and physical) and user experience of landmarks-based visualization were similar to those of more familiar circular visualization. Therefore, we see a great potential of visualizations of landmarks in supporting users in navigation under GPS-degraded situations. We thus encourage further research on using landmarks for this purpose.

Study 3 (Ranasinghe et al. 2018a, Ranasinghe & Kray 2016) studied the existing adaptation strategy of communicating location uncertainty to users and derived guidelines for adapting the visualizations of location uncertainty to the quality of the location information. These guidelines provide instructions on how to adapt the visual representations to modify people's perception to align them with the quality of location information. Designers of PNSS can use these guidelines to better communicate the location uncertainty to the users. Studying the impact of uncertainty visualizations on user perceptions in situ and comparing the results with the lab studies is a promising future research direction. Researchers can also further investigate the impact of uncertainty visualizations on aspects such as navigation performance, physical workload and mental workload. Furthermore, it makes sense to explore how to visualize other aspects of quality such as no coverage and delay and how users understand such visualizations.

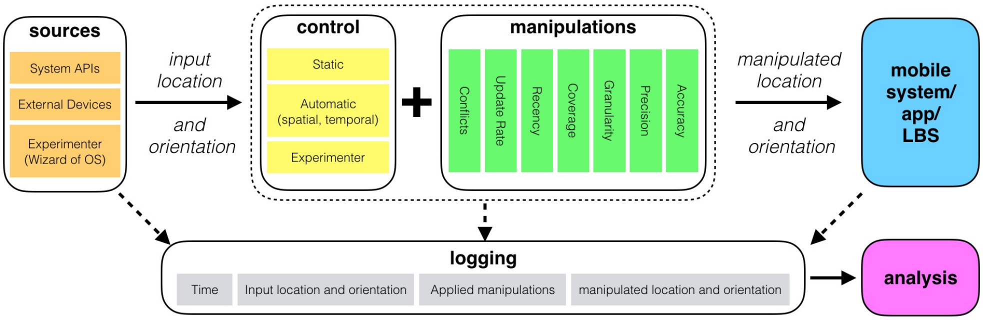

Figure 6. Location uncertainty injection framework (LUIF) for designing and evaluating adaptation strategies in-situ with users (Ranasinghe et al. 2019b).

The proposed framework LUIF - location uncertainty injection framework – (cf. *Figure* 6) (Ranasinghe et al. 2019b) provides a platform for evaluating how PNSS users behave and interact with the application when faced with low-quality location situations in the real world. A preliminary evaluation based on expert reviews confirmed the validity of theoretical and methodological aspects of LUIF. These types of in-the-wild user evaluations also provide useful insights for designing adaptation strategies. For example, they could trigger new insights to the developer that are otherwise undiscoverable. In addition, it can be used as a tool for evaluating adaptation strategies. Since it can be used to evaluate different users under different types of quality variations and in different environments, it facilitates developing further adaptation strategies and comparing them systematically.

Promising future extensions to LUIF include functions such as incorporating experience sampling, dynamic triggers such as social encounters, additional logging such as feelings of users using behavioral sensors and enabling combined manipulations or layered manipulations.

4. Discussion and concluding remarks

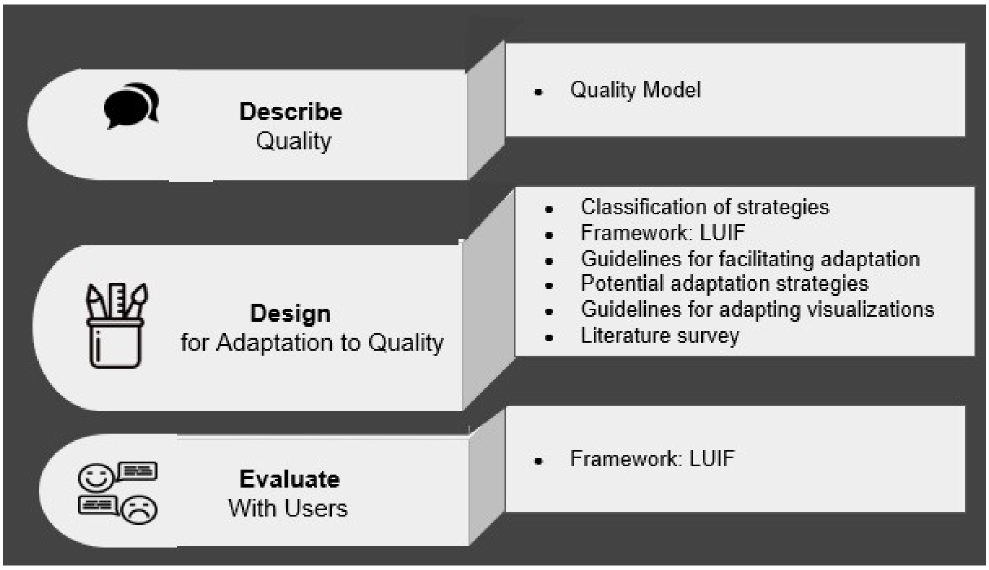

Figure 7. Outcomes of this research provides three types of means to facilitate adaptation to quality: tools for describing, designing and evaluation.

The goal of this research was to find ways to facilitate the development of pedestrian navigation applications that adapt their behavior and output to the level of location information quality in a human-centered way. The outcomes of the series of experiments in this research provides means for this purpose in three ways: (i) tools to describe quality; (ii) a set of tools to design for adaptation to quality; and (iii) a framework to evaluate the designs with users. These are summarized in *Figure* 7.

Based on the outcomes of our research, we can define five pillars that determine successful facilitation of pedestrian navigation support that is adaptive to location information quality (cf. *Figure* 8).

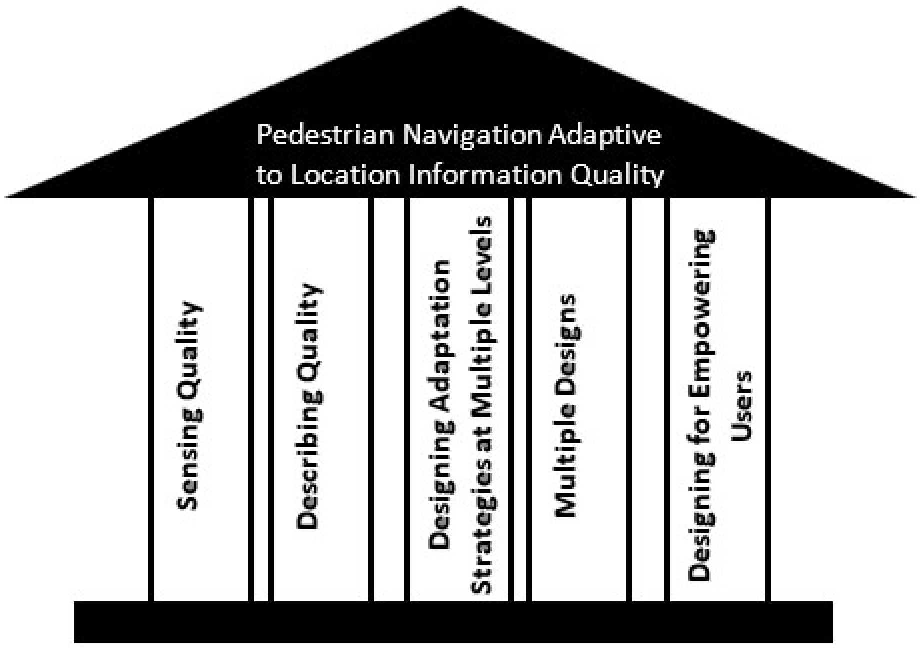

Figure 8. Five pillars of facilitating pedestrian navigation adaptive to location information quality.

Sensing quality is an important factor in determining the effectiveness of adaptation strategies. Applications can have different adaptation strategies for different aspects of quality as well as for different levels of quality of the same aspect. Therefore, sensing quality is required for triggering different adaptation strategies. An explicit description of different quality levels also contributes towards specifying adaptation strategies. For example, identifying what sensor parameters can be used to better describe different aspects of quality and further research on quantifying quality would be highly relevant and useful.

It is also important to research adaptation strategies that can be used when sensing quality accurately is not possible or to find alternative parameters to use when proper sensing of quality is not possible. Dealing with quality variations at the sensor level, algorithm level or application level in isolation would not guarantee navigation support all the time. Consequently, adaptation strategies need to be designed at all the three levels and in combination to ensure better navigation support. Beyond just the accuracy of a system, detailed descriptions of the quality of location information produced by location sensing systems are useful in designing adaptation strategies at multiple levels. Aspects such as granularity and recency or under what conditions the reported quality applies allow for comparing location sensing systems (e.g. to select potential localization techniques) and for designing adaptation strategies at different levels (e.g. sensor level, algorithm level, application level).

Design, realization and practical use of adaptation strategies in PNSS are challenging due to various factors such as individual differences between users, their navigation strategies, perceptions and contextual factors. Ways to overcome this are to improve map and the data quality, to design interfaces and functionalities for a diverse and wider use base, and to empower users to choose options and adaptation strategies that best match their preferences, situations and contexts. Overall, following a user-centered approach for designing and evaluating adaptation strategies could help to address many of the challenges that arise due to these aspects. Further research with users from different age groups or with different backgrounds would also contribute towards developing effective adaptation strategies and guidelines. The same applies for studies on different usage scenarios.

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Prediction of Landmarks Using (Personalised) Decision Trees

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Abstract. Numerous studies claim that personal dimensions - such as *personal interests* or *prior spatial knowledge* - influence landmark selections for wayfinding. Nevertheless, up until now, a computational landmark salience model that includes personal dimensions has not been published. Thus, there has been no comparison possible between a conventional and a personalised model. In this paper, we provide such a comparison: We train two decision tree models - one personalised decision tree model (PdTm) and one conventional (CdTm) without personal information - to determine any differences between these models. We use the trees to predict selections of landmarks of participants in a case study. We evaluate the results and show that although the PdTm reacts sensitively to the personal dimensions it does not predict more landmarks than the CdTm.

Keywords. Landmarks, Decision Trees, Personalisation, Prior Spatial Knowledge, Personal Interests

1. Introduction

Our spatial memory is full of personal landmarks such as my working place or my doctor (Richter and Winter, 2014) or even brightly coloured doors, if it is our own (Lynch, 1960). Humans intuitively use landmarks with personal meaning especially in familiar environments (Sorrows and Hirtle, 1999). While human beings are able to easily provide such personalised landmarks it is much harder to get a routing application to do so. The data collection effort for the provision of personalised landmarks via an application is high and it raises the question if it is justifiable. To find an answer to this question we investigate the hypothesis: A model considering personal

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dimensions is able to correctly predict landmark selections more often than a conventional model without personal dimensions.

There are already a number of studies investigating which dimensions should be considered in such personalised landmark models (Nuhn and Timpf, 2017a, Nuhn and Timpf 2017b). In addition, there are studies showing that decision trees yield good results for landmark identification (Elias, 2006). In this paper we use a personalised decision tree model (PdTm) and a conventional one (CdTm) using the dimensions proposed in Nuhn and Timpf (2017b) to predict the selection of landmarks for route descriptions. We compare the results of a case study applying these models to test the hypothesis that a personalised decision tree model predicts significantly more landmarks than a conventional model. The CdTm is based on so called landmark dimensions (visual, semantic, and structural salience of objects (Sorrows and Hirtle, 1999)). A potential landmark might be salient because of outstanding visual attributes (e.g. colour or height). Visual salience is highly dependent on the surrounding objects. For example a yellow post box in a grey environment is highly salient. An object is semantically salient if it has an outstanding meaning. It might have cultural or historical importance or show explicit marks (Raubal and Winter, 2002). Highly accessible objects with a prominent location (e.g. squares) are structural salient. The PdTm includes, in addition to landmark dimensions, also personal dimensions. There are several personal dimensions influencing landmark salience (Nuhn and Timpf, 2017b). Amongst them: *prior spatial knowledge* and *personal interests* (Nuhn and Timpf, 2017a). Several studies confirm the importance of spatial knowledge for landmark predictions (Hamburger and Röser, 2014, Quesnot and Roche, 2015). Inspired by Siegel and White (1975), Nuhn and Timpf (2017b) introduced four attributes to consider prior spatial knowledge of a traveller: *no knowledge*, *landmark knowledge*, *route knowledge,* and *survey knowledge*. The second important dimension is personal interests, which guides attention and, thus, results in the perception of objects and configurations (Rensink et al., 1997). Personal interests reflect person-specific orientation and provide important categories for action goals in a situation where persons are free to do as they please (Krapp et al., 2014).

In this paper, we first describe the data collection and preparation process for the computational models. Subsequently follows the description of the training of PdTm and CdTm, including the identification of optimised model parameters. Afterwards, the results of the trees on case study data are compared and discussed. The paper closes with conclusions and an outlook on future work.

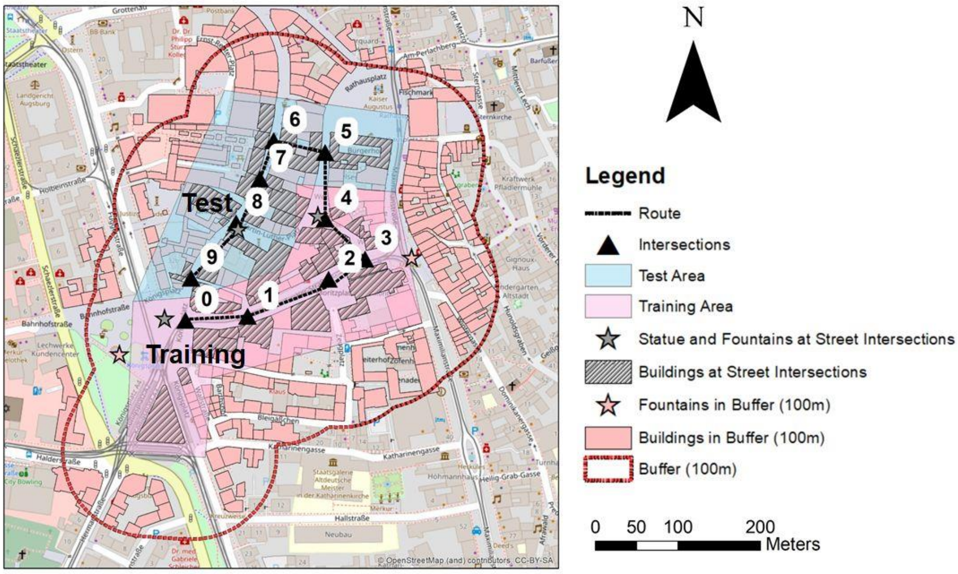

Figure 1. Intersections along the route.

2. Data Collection and Preparation – Case Study

For data collection we chose to concentrate on a route in the inner city of Augsburg because it includes different objects belonging to different topics of personal interests. The route is around 640 meters long and includes 10 street intersections (Figure 1). The objects at the street intersections are 44 buildings, two fountains, and a statue. The modelling of the landmarks for consideration in the trees requires a number of data sources. Additionally to information on the landmark itself we need information on the personal dimensions.

2.1. Landmark Dimensions

Landmark dimensions include information on visual, semantic, and structural dimensions of the objects at the street intersections (Nuhn and Timpf, 2018). In this study we use data from OSM (OpenStreetMap) and an official 3D city model. Further data (mainly visual data, such as colour) was collected during a field study. Objects have salience if they are different from the surrounding objects (e.g. in a 100m buffer as proposed by Raubal and Winter (2002) (Figure 1)). We calculate the salience for the landmark dimensions following the formulas provided in Nuhn and Timpf (2017a, 2018).

2.2. Personal Dimensions

We collected personal dimensions, interest and spatial knowledge, as well as information on landmarks in the framework of a case study. Decision trees need objects for training, which classify as a *landmark* and so called *NALs* (an object which does not classify as a landmark). 51 people participated in the case study, 24 of whom are female. The mean age of the participants is 33.1 years (min = 19, max = 73). 23 participants live in Augsburg, seven of them since their early childhood (age ≤10) or birth, and, thus, are spatially familiar. Six participants are not born in Germany. We use ESRIs Survey123 for data collection. The app allows to create and publish survey forms (Survey123, 2018). For the study, we set up a survey with questions about personal interests, prior spatial knowledge, and about the objects at the street intersections along the route. Participants rate their interest in shopping, culture, historical monuments, and gastronomy on a Likert scale with *no = 1*, *low = 2*, *medium = 3*, *high = 4*, and *very high = 5* items. Participants walked along the route and stated at each street intersection if they have been there before or not. In case they answered affirmative, they are asked about their spatial knowledge in the area of the intersection (landmark, route, or survey knowledge). In case they have never been at the street intersections, the questions include an additional question about no knowledge (Table 1). Afterwards, participants were asked to do their object selections. Survey123 provides photos of the objects at the street intersections. The photos are only intended as an aid for identifying objects in the real environment. Participants are encouraged to look at the real objects to do their selections. Because we assume that direction givers adapt their directions to the expected personal interests and spatial knowledge of the recipient, not to their own preferences, we told participants that they should imagine personally addressed route directions. Based on this assumption they had to select an object they like (landmark) and one object they don't like (NAL) for such a route direction. In total, 47 objects are presented with a mean of 4.7 (min = 4, max = 6) objects per street intersection.

S_{PspK}	Street intersection	Area	ø
1	Yes	Survey	21.9
2		Route	12.1
3		Landmark	8.2
4	No	Survey	0
5		Route	0
6		Landmark	1
7		No	7.8

Table 1. Stages of spatial knowledge and average number of selection.

The result of the study is a corpus of landmarks and NALs. The Survey123-App presented the same objects for landmarks and NALs, which resulted in some cases in the same object being selected for both instructions. For further analysis, only those street intersections were kept where two different objects had been selected for both (landmarks and NALs). This resulted in 503 *landmarks* and the same number of *NALs*. Ratings for topics of interest and information about spatial knowledge for the street intersections are available for all participants.

3. Decision Tree Training

We use the decision tree algorithm CART (Classification and Regression Trees) (Breiman et al., 1984) in this work. CART might grow until it perfectly classifies a data set. However, this may lead to overfitting. In this case the tree tightly fits the data set so well that is is inaccurate in predicting the outcomes of previously unseen data. Decision trees are almost always stopped before they are fully grown to avoid overfitting. There are various parameters that help to decide when to stop growing (Scikit, 2018). The *criterion* measures the quality of the split (available functions are the GINI index (Breiman et al., 1984) or entropy (Quinlan, 1986)). *Splitter* is a method to split the node, it is divided into 'best' or 'random'. The *minSamplesSplit* is the minimum number of samples required to split a tree node, whereas *minSamplesLeaf* is the minimum number of samples required to be at a leaf. Finally, *maxDepth* determines the maximum depth of the tree. There are also other training parameters considering weights for data entries or target variables (*landmark* or *NAL*). We decided not to introduce weights and to restrict ourselves to the five parameters described here.

The input dataset for the trees includes landmark and NALs with values for landmark and personal dimensions. The CdTm considers only the landmark dimensions (visual, semantic, and structural), whereas PdTm considers landmark as well as personal dimensions. The available data is used to train both decision tree models as well as to test them. We divide our data set consisting of data for the 10 street intersections into two sets of equal size: training and test area (Figure 1). The training set includes 252 landmarks and 252 NALs. There are combinations of spatial knowledge and personal interests ratings from the training set not appearing in the test set. In order not to influence the prediction we excluded landmarks with these combinations from the test set. This results in a test set with 232 landmarks. We do not consider NALs for testing, because here we are only interested in landmark prediction.

Parameter	Coarse	PdTm	CdTm	Finer	PdTm	CdTm
Criterion	Gini,Entropy	Entropy	Gini	Gini,Entropy	Gini	Gini
Splitter	Best,Random	Random	Best	Best,Random	Random	Random
minSamplesSplit	[5,10,…,50]	30	5	PdTm: [25,26,..,35] CdTm: [2,3,,10]	34	2
minSamplesLeaf	[5,10,…,50]	5	5	[1,2,...,10]	5	1
maxDepth	[5,10,…,50]	10	5	PdTm: [5,6,..,15] CdTm: [1,2,..,10]	9	4
Average Accuracy [%]		76.78	76.19		77.38	76.19

Table 2. Parameter values for initial coarse grid-search (middle) and for finer grid-search (right).

However, the number of data items for training might be too small to gain reliable results. A solution for this problem is cross-validation (Stone, 1974). We use stratified cross-validation, which divides the data set in disjoint classes with equal class distributions (Kohavi, 1995). According to Borra and Di Ciaccio (2010) a reliable result can be obtained with k=10. A widely used method to identify optimal parameter values for the parameters defined above combines cross-validation with grid-search (Chicco, 2017). We implement the (P/C)dTm as a Toolbox in ESRI's ArcGIS 10.5.1 using Python 2.7.12. In addition, we use statistic packages to train and test the trees (Pedregosa et al., 2011). The packages provide methods for grid-search and cross-validation. We start with a coarse grid-search with 10-fold stratified cross-validation to train the trees. Table 2 shows the initial parameter settings. The coarse grid-search identifies the highest average accuracy for the PdTm for the values in Table 2 with a score of 76.78. The average accuracy for the CdTm is with a value of 76.19 slightly lower. Next, we conduct a finer grid-search, varying the parameters of *minSamplesSplit*, *minSamplesLeaf,* and *maxDepth* around the best values (see Table 2). The accuracy of PdTm improves and reaches a value of 77.38, whereas the accuracy of the CdTm stays the same (76.19). After identifying the best parameters, we build the final decision trees on the training set. Figure 2 and 3 show the resulting trees.

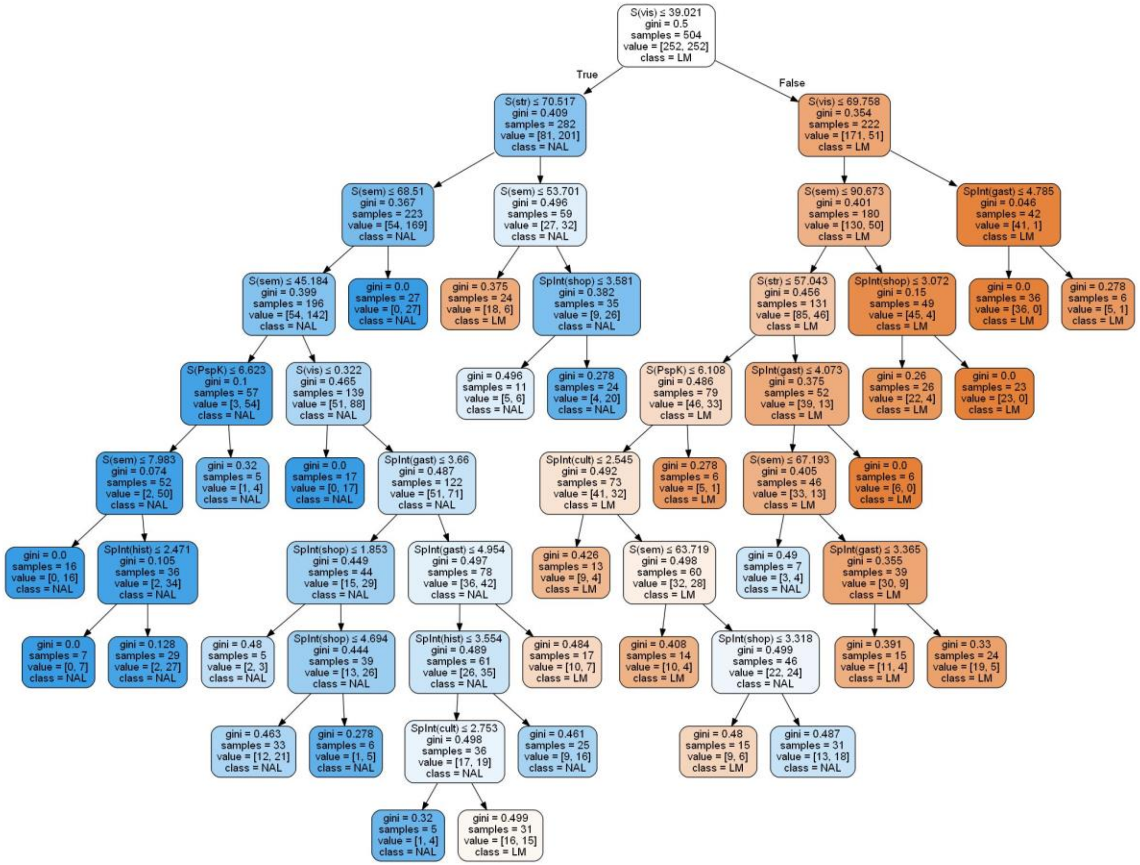

Figure 2. Trained PdTm.

4. Comparison and Discussion of the Results

This section compares the landmarks determined by the trees with landmarks selected by the study participants. We apply our final model with the parameters in Table 2 to the test set. Remember, that we do not consider NALs for testing, because here we are only interested in landmark prediction. A performance measure considering only landmarks is the recall (Buckland and Gey, 1994). The CdTm identifies 157 landmarks of the test set, or a recall of 67.67%, and the PdTm identifies 154 landmarks, or 66.38% recall on the test set. Thus, the CdTm identifies slightly more landmarks than the PdTm. We investigate these findings with a subsequent McNemar's test (McNemar, 1947) to find out whether this difference is significant. The McNemar's test analyses the results of a study where two different models are applied to the same objects. The test operates upon a contingency table, which relies on the fact that both trees are trained on exactly the same training set and evaluated on exactly the same test set (Brownlee, 2018).

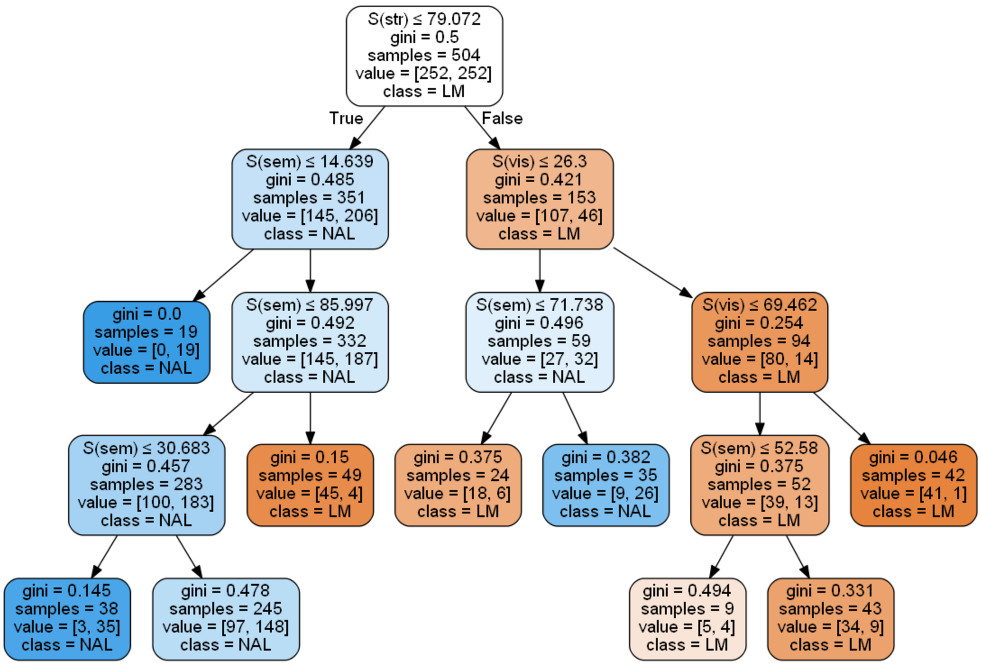

Figure 3. Trained CdTm.

The null hypothesis of McNemar's test claims that the two models have the same error rate (H_0: CdTm = PdTm). In case the null hypothesis is rejected, it suggests that there is evidence to suggest that the two models have different performance (H_A: CdTm ≠PdTm) (Dietterich, 1998). The two-tailed p-value equals 0.810 with a McNemar's test statistic of 0.058. By conventional criteria (significance level of 5%), this difference is considered not to be statistically significant. This means, the CdTm does not identify significantly more landmarks than the personalised model.

The CdTm considers all landmark dimensions (visual, semantic, and structural). The structural dimension appears on the first level in the tree, followed by the semantic and the visual dimension (second level). The tree is sensitive to a change in the input data of semantic, visual, and structural salience (not evaluated further at this point). The ability of CART to use the same dimensions more than once in different parts of the tree is reflected in the CdTm. For example s_{sem} appears in different branches of the tree. First a coarse division of the data in $s_{str} \leq 79.072$ is done on level 1 and a finer division in $s_{sem} \leq 14.639$ follows on level 2. Visual salience also appears more than once. Figure 3 shows, that the tree generates terminal nodes with the same class (e.g. left *NAL*). The algorithm does not stop earlier because *minSamplesSplit*, *minSamplesLeaf*, or *maxDepth* is not reached. Because we determined minSamplesSplit = 2, minSamplesLeaf = 1, and maxDepth = 4 (compare Table 2) the algorithm stops before it can yield all pure leaf nodes. In Figure 3 the terminal node on the left shows 3 samples of the class *Landmark* and 35 samples of class *NAL*. In case decision tree growing would stop already after splitting in Landmark and *NAL* (level 4 in Figure 3) it would produce a terminal node with 100 samples belonging to class *Landmark* and 183 objects belonging to the class *NAL*, which would be far less useful. The terminal node on the right is less pure than the terminal node on the left. It shows 97 samples of the class landmark and 148 samples of the class NAL. Thus, a number of objects which are actually selected as landmarks by the study participants end up in this node and are therefore predicted as NALs. However, the finer grid-search identifies the model parameters of the CdTm in Table 2 as the ones yielding the highest average accuracy. Consequently, we use the CdTm trained on these parameters in this work.

The root node of the PdTm starts with analysing $s_{vis} \leq 39.021$. This fundamental division is followed by s_{str} and s_{vis} on the second level. The PdTm shows sensitivity to the inputs of the landmark dimensions as well as to the inputs of the personal dimensions (not evaluated further at this point). The input values of these dimensions decide if an object becomes a *landmark* or a *NAL*. CART uses also the same dimensions more than once in different parts of PdTm (compare Figure 2). However, most of them appear with the same decision. Only $s_{pInt(cult)}$ behaves differently. It appears twice with similar thresholds but contradictory decisions. Nevertheless, this is comprehensible because whether the PdTm predicts an object as a landmark is also dependent on the values of the other dimensions. The PdTm shows also branches, which generates leaves with the same class, due to the fact that the tree size is dependent on the parameters obtained with the finer grid-search (Table 2).

The PdTm makes a distinction between s_{PspK} = 7 and the other ratings. Table 1 shows the average number of selections of the spatial knowledge ratings at the street intersections. It reveals that study participants did not choose the ratings 4 and 5 at all. In addition, on average only one study participant chose s_{PspK} = 6 at a street intersection. This indicates that these ratings do not influence the splitting of the PdTm. Thus, the distinction between s_{PspK} = 7 (no familiarity at all) and all the other ratings (familiarity) seems to be plausible.

An interesting fact is that the PdTm splits for the personal interests $s_{pInt(cult)}$, $s_{pInt(shop)}$, and $s_{pInt(hist)}$ either between s_{pInt} = 2 and s_{pInt}= 3 or s_{pInt}= 3 and s_{pInt}= 4. This suggests that the tree identifies a difference between a study participant which is interested and which is not. We observe, that the *medium* rating is either assigned to the lower rating or to the higher ratings. This might be explained by *survey optimising* (Krosnick, 1991), which describes an behaviour occurring under cognitive load and when study participants attempt to be fully diligent. Consequently, they try to avoid this effort but they want to answer responsibly (Krosnick, 1991, Krosnick and Fabrigar, 1997). The result is that, the personal interests rating *medium* might be either chosen by a study participant who is actually interested in a topic as well as by a participant who is not. $s_{pInt(gast)}$, on the other hand, is an exception: it splits between *very high* and all the other ratings, suggesting that there is a difference in landmark selection between someone with a very high interest in gastronomy and all the others.

5. Conclusions

In this study we trained two decision trees - one with personal information and one without. We carried out k fold cross-validation with grid-search and determined optimal model parameters. Then, we built the final trees with these parameters and use them to predict selections of landmarks of the participants of a study. We evaluated the results and identified - contrary to our hypothesis - that there is no significant difference between a CdTm and a PdTm. According to these results, we have to reject our hypothesis.

There might be a variety of causes for this result. The most obvious interpretation is that personal dimensions are just not important for landmark selections. This would confirm the findings of Gramann et al. (2017) who also find that directions including information of personal interests associated with landmarks did not perform better than non-personalised directions including irrelevant information about landmarks. However, there might be a number of other reasons for this result:

- **Dimensions.** We considered landmark and personal dimensions. However, there might be missing landmark dimensions influencing the CdTm as well as other dimensions such as e.g. an environmental dimension (Nuhn and Timpf, 2017a).
- **Methods**. Other models, besides decision trees might be useful as well. This includes models inspired by theory (e.g. the model proposed by Raubal and Winter (2002)) as well as other machine learning models.
- **Overall model**. In this work we investigated one overall model to predict landmark selections. Another possible approach could be individual models for each study participant. As study participants might be influenced by individual intangible parameters resulting in individual landmark selections, which might not be covered by an overall approach.

This investigation of possible reasons for the rejection of the hypothesis reveals a number of open research questions for future work. However, we currently have to conclude that the data collection effort for obtaining information on spatial knowledge and personal interests for an applied system might not be justifiable. In case future work will confirm these findings it is most likely sufficient to focus on existing conventional landmark prediction models and to concentrate on their use in applied pedestrian wayfinding applications.

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Landmark Classification for Navigation in Indoor Environments

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Abstract. The representation of indoor environments got the attention of the researchers only recently, and more recently yet the cognitive aspects involved in indoor navigation. The cartography and visualization research group at Federal University of Paraná (UFPR)– Brazil, is investigating some important issues about the indoor representations, such map design, landmark selection and identification and routes formation in these restrict environments and some cognitive aspects related to. This is part of a bigger project named UFPR CampusMap. This paper presents the conclusions of two user experiments in navigation indoor: self-location using QR-Codes and landmarks descriptions using natural languages. These conclusions area addressing important issues on indoor map design, improving the understand of cognition changes and how to implement these considerations on Location Based Services.

Keywords. Indoor Navigation, Orienting, Landmarks.

1. Introduction

Navigation services have become one of the most widely used types of Location-Based Services (LBS) (Basiri et al, 2016). The key for a successful navigation process is a series of processing in the user's mind from the perception and selection of the certain spatial features to serve as reference and the storage of the spatial relations of them in a mental map

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representative of the region. After, different types of knowledge and actions are developed such as self-orientation, self-location, estimation of distances and relative positions. According to Gaunet et al. (2001), the integration and recognition of spatial features configurations are necessary for the people use these reference points as landmarks and choose an appropriate action at each decision point along the route.

However, the selection of objects used as landmarks for navigation is highly dependent of the environment and its restrictions. In outdoor environments people navigate with less features, yet these objects are separated in local and global references, depending on the mental route designed. In indoor environments, there are a great number of both static and mobile objects which can be used as local landmarks, but due to the environment conditions only few global references are available. For this reason, positioning techniques for indoor environments should consider the lack of spatial references in the process of cognitive map creation. In other words, people who navigate in an indoor environment must process a set of small cognitive maps and try to link them somehow.

The diversity of types of indoor environments as museums, libraries and convention centers which have characteristics related to specific human activities, present a set of difficulties that depend of heuristics related to the comprehension of the indoor environment (Bahm and Hirtle, 2017). Many of those characteristics can be defined as landmark elements, so it is important to have descriptions about these elements. In a narrow sense, it is necessary to provide a typology for the indoor landmarks (Sorrows and Hirtle, 1999). In indoor environments, landmarks have the main function of providing information about the point where decisions should be made in relation to a route or even, demarcating the point where the orientation of the navigator changes direction (Viaene et al., 2014). In the context of indoor personal navigation, this paper presents the UFPR CampusMap project, which aims to evaluate different indoor representations, including cognitive aspects related to landmarks selection and the use of natural language to describe these landmarks.

2. Background and Context

2.1. LandMark Selection: Indoor x Outdoor

People associate directions with visual cues, if features are easily recognizable, are based on cognitively salient features and followed by easy-to-follow instructions (Duckham et al., 2010; Basiri et al., 2016). This is interesting in indoor environments because pedestrians have a reduced speed of movement that, in contrast to drivers, allows to see the landmarks with greater clarity (Basiri et al., 2016). When encountering an unknown environment, the visual system uses few features for rapid visual scanning (Oulasvirta et al., 2009 and Marr, 1982). Typically, the features that stand out to the human visual system are selected for different reasons either by the differentiation of the surrounding features or by their own characteristics (Lynch, 1960, Oulasvirta et al., 2009, Quesnot, T., and Roche, 2015). The basic characteristics of these features are processed by the visual system and the topological structure based on their distribution is evaluated to serve as landmarks (Maceachren, 2004; Klippel, 2003). For Caduff and Timpf (2008), features are chosen because of their visual relevance in the scene observed in relation to their surroundings and not only due to their relative contrast or completeness as in Lynch (1960) and MacEachren (2004). Quesnot, T., and Roche (2015) divided the visual protrusion of the features to be taken as reference frames into three classes: perceptual salience, cognitive salience and context salience.

The perceptual salience is measured by the prominence of the feature or the symbol in relation to the others of its surroundings, along the lines of the relative contrast of the Gestalt (MacEachren, 2004). In real environments, the visual prominence depends on the visual variables that compose it and its relative position to the other elements surrounding. According to Schmidt and Delazari (2013), the combination of visual variables attracts the selective attention of the user and stimulates the selection of characteristics or objects and their recording in short-term memory. The cognitive salience, is the degree of distinction of features based on the personal meaning of some features and its can change perception according to the individual's experience and is constantly updated with repeated exposure of the user to an environment. Contextual relevance is related to the relative distribution and orientation of features and objects in space and the relative visibility they assume along the route.

When navigating, pedestrians use at least one feature identification strategy to be used as landmarks (Oulasvirta et al., 2009, Basiri et al., 2016). According to Redish (1999) these strategies are: Random navigation, Taxon navigation, Praxic navigation and two more. The last two strategies are based on the individual's cognitive aspects. In the fourth strategy, people associate directions with visual cues, such as "turn left in church,"; In the last one, people form a mental representation of the environment from one or more specific points to become able to plan routes between any locations within the area (local navigation). These last two approach the more natural interactions that humans use to navigate. When we look at indoor environments, some problems arise. The global orientation becomes impossible because the view of the area is limited and may not be completely observed along the route. The landmarks along the route and potential landmarks can be fixed or mobile and change according to people, their culture and even mood. Fixed points along the route, decision points, are the ones with the greatest potential for implementation in LBS systems, since they tend to have a fixed and unchanging over time. Incorporating them as landmarks into navigation support systems, such as smartphones and vehicular devices, can transform the way users navigate, especially pedestrians.

3. Methods

3.1. Context: UFPR CampusMap Project

The Federal University of Paraná (UFPR) has 26 different Campi in the Parana State, Brazil; what summarize 500 thousand m2 of constructed area distribute in 316 buildings. UFPR has more than 6000 employees, about 40,000 undergraduate students and 6,000 graduate students. The natural unfamiliarity with these spaces has direct impacts in several issues, such as management of resources (humans and materials), Campi infrastructure management, security, and other issues. From this perspective, we have started a Project named UFPR CampusMap (UCM) whose main goal is to implement a Geographic Information System with information from the indoor and outdoor environments. From the main project, different aspects are being addressed in this research, two of them addressed below.

3.1.1 Landmarks evaluation with use of QR-Code for positioning in indoor environments

Oliveira (2014), Ning (2013), Chang et al. (2007) and Basiri, Amirian and Winstanley (2016), developed applications in their studies based on the positioning method using QR-Codes to analyze images. The mobile device camera captures the QR-Code, which is decoded by the system that then presents a map of the place and the user's position. The innovative aspect of our study is the hypothesis that if a user performs recognition of QR-Code codes only in places considered to be reference points, by using the indoor positioning system developed when this in turn shows the user's location, the user will then be able to carry out orientation and navigation tasks based on the positioning information provided. However, the need exists to understand which places are considered to be reference points and which are really used by a user during navigation. It is also of fundamental importance to understand to which categories reference points most used by users belong, so that this information can support decision-making regarding placement of labels in projects or similar applications.

The elements most mentioned by the participants as landmarks are elements that stand out in the environment because of their structures, such as stairways, lifts and decision-making points. We conclude that those structural reference points are most used within an indoor environment to aid navigation and orientation and, therefore, they are the most indicated for affixing QR-Code labels. Through this comparative analysis between two buildings, we found that building's architecture influences the determination of reference points. For example, in the environment that only has two floors, the lift is practically not mentioned as a reference, while in the environment with five floors the lift takes on significant importance for participant orientation.

3.1.2 Landmarks and spatial relations descriptions in indoor environments

The proposal of this experiment was based on the studies of Dogu and Erkip (2000), Schmidt and Delazari (2012), Viaene et al. (2014), Sarot and Delazari (2018), Antunes (2016), Bahm and Hirtle (2017), and Delazari et al. (2017). These studies focus on the determination of mental routes, addressing the level of familiarity with the subject, with the symbology of indoor maps. These researches search for specific places in the maps and how people describe them in natural language for extraction of spatial relations. The experiment conducted at UFPR evaluated the level of familiarity of the subject with the indoor environment, and sought to identify in them the potential landmarks, and the most used spatial relations. The use context of buildings directly affects the choice and frequency of use of a given element as a spatial reference point. When comparing elements that were cited in both buildings evaluated in this research (such as floors, elevator, stairs), it is noticed that the frequency of its use was directly related to the context in which the user was at the moment.

The spatial relations of our research were classified in terms of prepositions, prepositional phrases, adverbs of place, nouns, adjectives, and verbal expressions. The group of spatial relations with the most occurrences (80) (in, on, or at with a male or female definitive article). The second most common group of spatial relations, at 63 occurrences, was in front (of), by the front (of), at the front, with words that fit as prepositional phrases. In third place, with 62 occurrences, was the group next to, near, close to with words that fit as adverbs of place. As the two latter groups had almost the same number of occurrences (63 and 62), the fourth group presenting 56 occurrences: “to the right (of)”, “on the right (of)”, “at the right”, “on the right side of”, “to the left (of)”, “on the left (of)”, “at the left”, “on the left side of”), with words that fit as nouns

4. Conclusions

The objective of these experiments was to contribute to the advancement of orientation and spatial navigation studies in indoor environments, in relation to spatial relations and spatial reference points (SRP), when collected through descriptions in spoken natural language. There is still much to be studied, analyzed and understood when dealing with experiments on humans. The freedom of expression of the natural spoken language makes complex the task of generalizing expressions for computational uses. The understanding of spatial relations of spatial descriptions and spatial reference points (SRP) for the representation of geographic locations leaves gaps to be studied semantically. Therefore, further experiments are needed to conclude that spatial relations and spatial reference points contribute to the representation of geographical locations.

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Off-Route Virtual Landmarks To Help Pedestrian Indoor Navigation

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Abstract. Users of navigational support systems often have difficulties in maintaining attention to instructions and visual representation to establishing a relationship with reality due to cognitive differences and navigation instruction difficulties. In traditional systems, especially in-car navigation systems, the form of instructions and representations help users to complete the goal, but not allow them to learn the way. Navigation support systems limit spatial learning and this becomes more relevant in restricted environments such as indoor navigation. This research presents the proposal of increasing virtual reference points on and off-routes as a way to approximate the creation of routes by algorithms to the way humans interact with reality. For this, an approach of highlighting reference points and topological relationships between them as a way of creating more natural routes than the current systems. The focus is the use of pedestrian support systems in unfamiliar environments using an augmented reality (RA) system on mobile devices. Evaluations will be conducted with volunteers with different backgrounds in two distinct regions of the Brazil.

Keywords. Virtual pedestrian navigation, Augmented Reality Mobile, 3D Cartography

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1. Introduction

The interest in navigation systems for pedestrians (PNS) has grown in recent years, as they become both feasible and popular (Ohm et al., 2016). Pedestrian movement is one of the most basic modes of mobility (Wang, Lo & Liu, 2017).

Car systems are generally based on positioning through the Global Navigation Satellite System (GNSS), or other continuous tracking mode, to provide real-time and on-site route information to the user (Huang et al., 2012). In contrast to the navigation mode in car navigation systems, pedestrians prefer route instructions based on landmarks (Ohm et al., 2016). One difference in pedestrian navigation is that the routes generally include outdoor environments and the passage to indoor environments, which renders systems such as GNSS unfriendly.

Different technological approaches can be used to communicate information about routes, such as maps on mobile devices, voice instructions, 3D representations and images. Even with the voice guiding strategy along with screen based maps, drivers still need to translate auditory information into visual cues, however, which causes an additional cognitive burden (Chung, Pagnini & Langer, 2016). A key prerequisite to designing successful pedestrian services, and delivering these over mobile devices, is to understand the nature of the navigation task and the information requirements of the pedestrian (May et al., 2003). The effectiveness of traditional systems requires a lot of cognitive attention to be effective and this is a problem for the user, since it must focus on the system itself and the path (Chung, Pagnini & Langer, 2016).

In navigation, understanding the spatial relationships between features requires a series of processing in the user's mind that connect what is perceived and what is understood. The most popular way to provide directions for pedestrians is to display maps on handheld devices like personal digital assistants and smartphones. On these devices, the augmented reality becomes more and more popular. Augmented Reality in Mobile Devices (AR) overlays a real image, as the setting for the user's environment, with virtual objects to create a composite view where the user has the feeling that overlapping objects are present in the scene. This give to the user a more natural relation with the ambient, letting to interpretation only those symbols that matter to self- location and to take decision along the route. But in indoor environment the absence of those features to be used as landmark could impair the adequate routing by user. Our hypothesis in this research is that complementary landmarks positioned off-route could work as global reference for indoor navigation using AR on mobile devices. Consequently there will be a reduction of the cognitive demand of reading to highly abstract and elaborate map, interpret and organize the spatial information on short memory and finally translate to visual cues.

2. Route Formation: User's Mind Versus Algorithm

To successfully navigate, people plan their movements using spatial knowledge acquired about the environment and stored on a representative mental map of the area using landmarks at different scales (Vinson, 1999, Schmidt & Delazari, 2013). From the distribution of these points, several types of knowledge and actions are developed such as self-orientation, self-location, estimation of distances and relative positions. These knowledge and actions are constructed from relation between objects and features distributed in space, and which have characteristics that distinguish them from their surroundings (Lynch, 1960). This correlation affects the organization of the internal representation of these same features in the mind of the people, that is, in the cognitive map.

Obviously in this process, initially, few features are highlighted by the human visual system and quickly processed in relation to their essential topological characteristics to work as landmarks. Quesnot & Roche (2015) divided the visual salience of the features to be taken as reference frames into three classes of salience: perceptual, cognitive and context. To Ohm et al. (2016), the visual salience is important for users to find the landmark quickly on the display and the way objects are presented on the display heavily influences the efficiency of self-localization. The accumulation of landmarks and how they are distribute in spatial mental model depends on how the person is exposed to the environment (Dünser et al., 2012).

In the context of AR, the physical world is represented in two components, the physical object or feature and the context in which it is inserted, that is, the other features in its surroundings. The identification of naturally salient features favors the storage of reference points. Therefore, the process of constructing an AR system for PNS that allows the relationship in an improved way between the representing and its represented, which will allow the storage of the feature and its positioning in the cognitive map is necessary.

Alternatives to outdoor navigation were presented Wenig et al. (2017), Schall et al. (2011) and Raubal & Winter (2002). In these papers, strip maps on smartwatches were used to provide folow-the-line representation. Global references were indicated in direction and distance with textual descriptions and pictorial symbols. In the case of indoor navigation, these references cannot usually be seen as in the case of hospitals, universities, shopping malls and other complex structures. Therefore, this research adopts the use of pictorial symbols for user self-location and dynamic symbols for decision-making points along the route.

3. Assessment framework

To investigate the influence of virtual landmarks distribute along the route in indoor environment on users' navigation strategy, we propose a single navigation task, in three different situations, in a complex building of Universidade Federal do Paraná to identify design implications for landmark representation on mobile navigation device using AR.

Our research questions are:

1. What information is needed by pedestrians for indoor navigation purposes (adapted from Ohm et al., 2016)?

2. How landmarks in different points on- and off-route could improve the route and how this could be implemented on routing algorithm?

Our test framework counts with at least 30 volunteers on the campus of the Federal University of Paraná, Curitiba, Brazil, all with background in cartography or correlate areas. We started with two multipurpose buildings that include Docent rooms, laboratories, conference room and classroom. The two first and second floor buildings linked by a smaller building. The connection is made by winding corridors, stairs and an elevator and the entrances are on the sides of the smaller building, as in Figure 1.

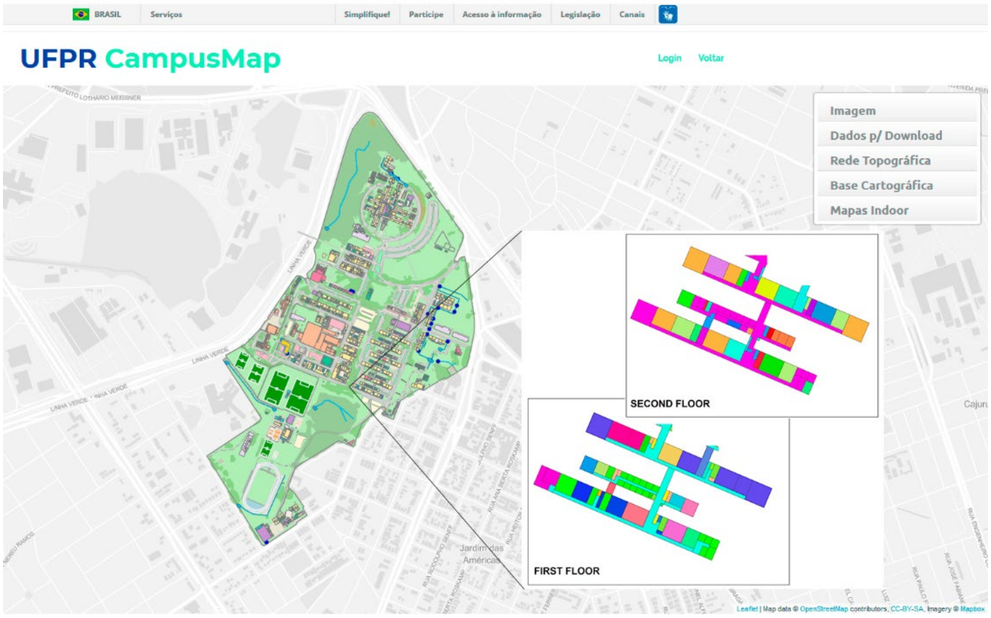


Figure 1. Universidade Federal do Paraná, campus Politécnico and details of the building with indoor map considered.

For user self-location, the developing system presents virtual objects of global references. These are sights or of relevance to the citizens of Curitiba. Points were chosen from four different buffers: locals reference points at out of the building, up to 2km from buildings, from 2 to 6km and over 6km. These distances were empirically selected due to the positioning of these references in the city (Figure 2). The features selected were university's restaurant and medical room, the Botanical Gardens, the Airport, the Telephone Tower, a cable-stayed bridge, a shopping mall near the campus and the city's bus station.

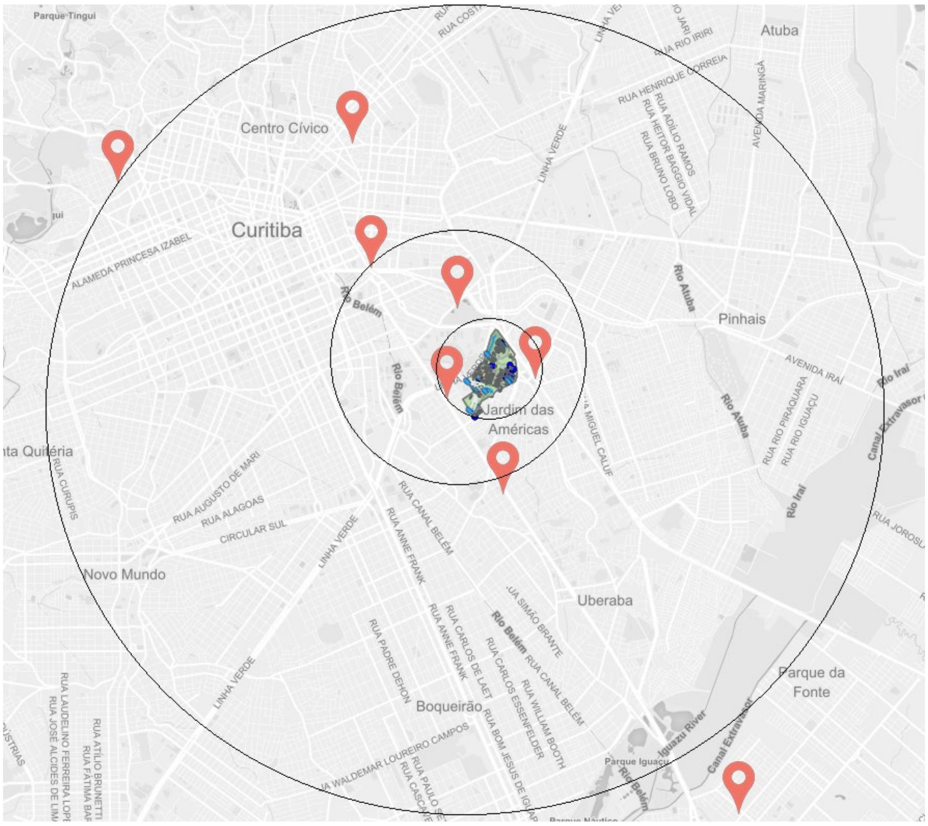
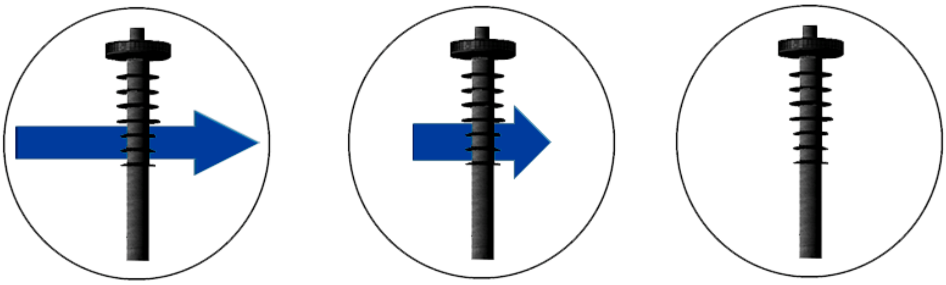


Figure 2. Location of Global References Points selected and the buffers

The system presents these locations as simple pictorial symbols with black outline and transparent background. The elaboration of the symbols themselves is part of research in development by the research group (figure 3a). An important issue is that symbols that are not directly aligned with the smartphone's position but that matter in the selected route receive an additional symbol, an arrow. The length of the arrow varies according to the alignment of the device with the real position of the symbol. Thus, the farther the larger the arrow and the closer the smaller the arrow (figure 3b).

a)



b)

Figure 3. a) Tower icons change from far to close as the smartphone is rotate up to straight direction of where the tower actually is. b) Shows how the global references points are presented in smartphone (under development)

The importance of the symbols mentioned is due to the relative distance between the start and finish points informed by the user and the position of the global reference. In the route formation process, global references can be seen as reference line in user's mind in which the initial self-orientation is determined ().

However, in indoor navigation decisions along the route are strongly based on local landmarks. The problem then becomes that there are no features that stand out in the user's cognitive system and can easily be tied up as route confirmation points. For this reason, we understand that indoor navigation should provide users with more route confirmation points than the turn points provided by current routing algorithms, known as turn-by-turn routes. Therefore, at these points and several other relevant decision making and route confirmation points the system uses dynamic symbols to guide users (figure 4).

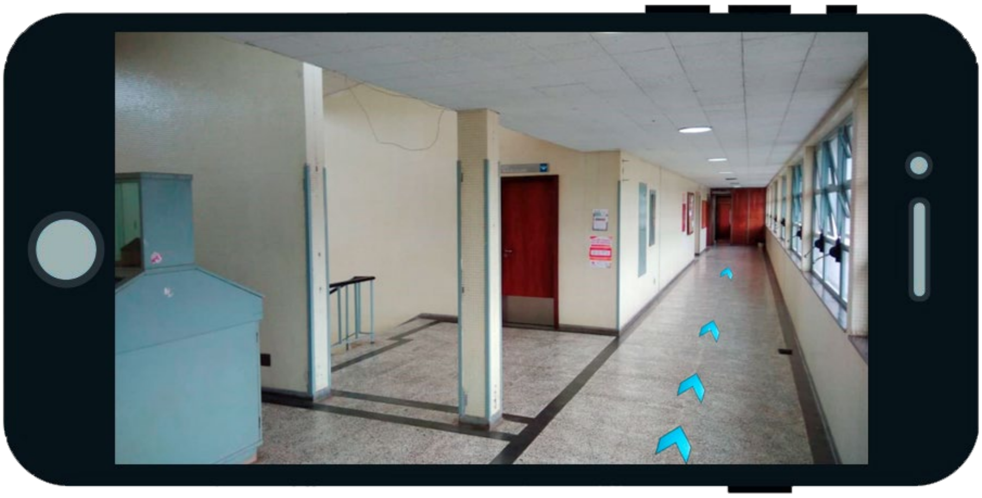


Figure 4. Representation automatically changes to local dynamic representation in decisions points along the route (under development)

The indoor location takes into account the geomagnetic mapping of each floor of the buildings and a refinement by wi-fi is being implemented. This mapping is developed using IndoorAtlas® and consists of evaluating the magnetic and signal oscillations like Wi-Fi inside to create a potential map. This map is free and can be accessed by other systems.

The expected results are empirically based on indoor environment of building universities, where participants were presented to three study situations. The first one is a free route inside the building (exploratory navigation). The second situation, presents two external landmarks well-known in the city, virtually represented as being out of the building, but with their position accessible and indicated in the display during all route. The third situation is a routing algorithm presented on PostGis and the representation of start-to-end line.

To the tests we use the Think Aloud protocol to register what he/she will identify as landmark. Based on Ohm et al. (2016) we will ask to volunteers to identify in detail the information that they think a pedestrian unfamiliar with the area would need in order to navigate those routes successfully. Our device is a smartphone with an Augmented Reality App developed with the ARCore® and the base map is from UFPR Campus Map (Delazari, 2019). In the tests with the Think Aloud protocol we hope to identify a) the semantic and structural relevance of global references as a function of participants' browsing habits and knowledge of the region; b) identify characteristics of the decision-making process at route change points such as the use of dynamic visual variables, degree of symbolic abstraction, cultural aspects such as linguistics and region of origin (the sample group has people from various countries); c) perform the statistical evaluation and validate the solution and point out system improvements. In this moment, the system is under development.

4. Conclusion

The expected conclusions should demonstrate how virtual landmarks could help people to keep their self-orientation in indoor navigations and, specifically, in change from outdoor to indoor ambient to navigate adequately. We expect identify how local culture could influence the descriptions of landmarks and correlate to how people describe their way in order to improve our knowledge about route formation on user mind. Based on this information we intend to propose a new algorithm based routing application. Finally, we expect scientifically contribute to improve personal navigation systems.

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Towards Anonymous Mobility Data Through the Modelling of Spatiotemporal Circadian Rhythms

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Abstract. Recent years have seen an extensive exploration of the potential of mobility data. Mobility data are gathered from personal devices and as technologies advance, so does the volume and variety of data that they gather. Such data, however, bring about increased concern over the potential for revealing sensitive information. Although there have been many methods proposed for protecting mobile data privacy, they come at a price of either limiting data utility or the level of privacy protection. In this work, we present an approach that preserves global mobility-related data properties and at the same time protects privacy. Our preliminary results show that we can enhance the usability of synthesized data while proving no breaches of privacy. Our contribution can be considered as a new mobility modelling method as well as a privacy-protecting algorithm.

Keywords. Human Mobility, Data Privacy, Mobility Modelling

1. Introduction

The availability of movement trajectories has influenced rapid development in human mobility studies. Location data are now extensively collected through ubiquitous devices, such as mobile phones, fitness bracelets and location loggers. The high temporal and spatial resolution of these data unlocks the potential for many applications where human movement is an important factor to consider. Mobility traces have proven their significance, for example, in traffic forecasting, city planning and utilities management.

High data utility comes at a price of privacy disclosure. Simply removing personal details such as a name from a released dataset does not preserve

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privacy, as in many cases a person can still be re-identified from a combination of attributes such as postcode, gender and age. Moreover, due to high uniqueness of human mobility trajectories, aggregation does not improve the privacy of the data and at the same time causes a loss of precision and limits data utility (Fiore et al., 2019). Hence, data accessibility is limited in many countries by laws such as the General Data Protection Regulation (GDPR) (European Parliament, 2016).

The goal of anonymisation is to protect the privacy of individuals and retain the utility of human mobility traces (Fiore et al., 2019). The two most commonly used groups of anonymisation methods are based on 1) k-anonymity and 2) uninformativeness and differential privacy principle (Mir et al., 2013; Fiore et al., 2019). k-anonymity of traces is achieved when a subset of spatiotemporal points of each person is indistinguishable from at least k - 1 other subsets. Nevertheless, it is not clear what k value is considered sufficient for full privacy protection. The anonymisation methods based on the uninformativeness and differential privacy principle assume that data are stored in a database and are accessible only through the limited subset of queries, which are modified to produce noisy outputs. Differential privacy is satisfied when an observer cannot tell when a particular person's data were used to produce a result. However, because the data themselves are not modified, they can be stored in this database but cannot be published. One of the alternative approaches proposed in the literature is to synthesize traces using the original mobility dataset (Mir et al., 2013). Synthesized data preserve global mobility properties, while the individual traces do not contain true information. Therefore, such data can be freely published but analysed only at a collective level.

2. Modelling

In this paper, we present an ongoing work to extend the Differential Privacy - Work Home Extracted REgions (DP-WHERE) model proposed by Mir et al. (2013). It draws probability distributions of various statistical features of human mobility from a dataset. Next, uses them to generate synthetical trajectories which can be freely published. We extend the DP-WHERE model into the DP-WHO-WHEN-WHERE model which includes spatial and temporal aspects of human mobility and captures multiple mobility behaviours. As a result, we improve the modelling process to achieve higher accuracy of the global properties of the mobility-related dataset. Similarly to the DP-WHERE model, derived distributions are modified by a noise creating the DP-WHO-WHEN-WHERE, a differential privacy protection algorithm.

Three aspects of human mobility, further named components, are used as the foundation of the DP-WHO-WHERE-WHEN model (Fig. 2). The first component, WHO (Working HOurs shift groups) is responsible for finding individuals with similar temporal mobility behaviour. The WHERE component controls the spatial aspect of mobility. The last component, WHEN (Work-HomE circadiaN rhythm) controls the temporal aspect of mobility and determines the circadian rhythm of each synthesized group of people.

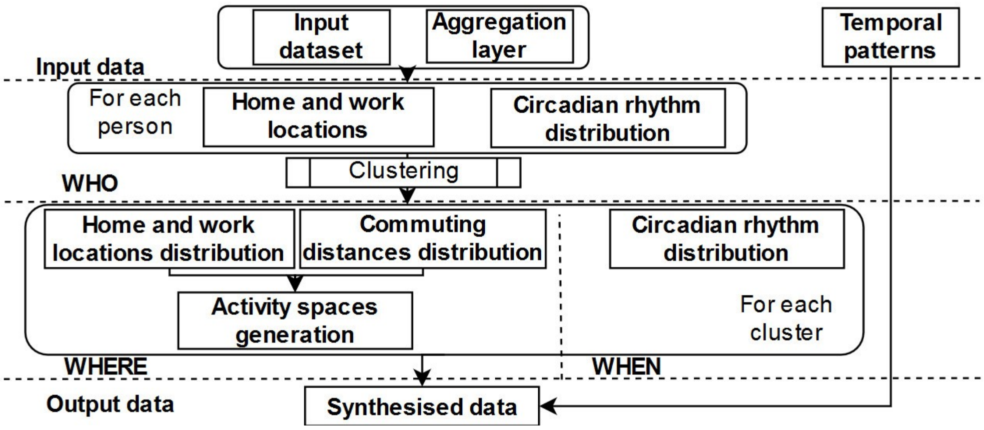

Figure 1. The proposed WHO-WHEN-WHERE modelling process.

The input data are composed of the input dataset, aggregation layer and temporal patterns. The input dataset consists of original mobility traces used to estimate the mobility-related distributions. The aggregation layer (i.e. grid-based partition) is used as a spatial reference for the data. The temporal patterns are used as a temporal reference for synthesised mobility traces. They determine the exact timestamp of a point in the trajectory and reflect the frequency of location updates.

The whole modelling process is repeated the number of times determined by the WHO component. First, home and work locations and the distance between them are determined for each person. These are used to construct his/her parametric activity space (also known as the use of space) in which a person spends most of his/her time. Any place apart from home and work locations inside the activity space is further considered as 'another place'. Next, the person's circadian rhythm (empirical distribution) is drawn from his/her movement and divided into three categories: home, work and other places. These locations have each an assigned probability of a person appearance in a given time of day. It is calculated by counting and normalising the total number of appearances of each person in one of those locations throughout the whole period of the study. Using a clustering algorithm (for example Self-Organising Maps (Bianchi, Rizzi, Sadeghian & Moiso, 2016)) circadian rhythms are grouped to find people with similar temporal patterns of movement. In doing so, the population groups as well as their share in the whole population are determined.

For each cluster WHERE and WHEN components are calculated. First, the algorithm transforms the detected home and work locations into two spatial distributions. Next, a third spatial distribution of median commuting distance (median distance between home and work) is determined. The WHEN component calculates an average circadian rhythm in each cluster.

Mobility traces are synthesised using the distributions from each cluster. The spatial distribution of home locations is used to select the home location for each synthesised trace and the commuting distance is used to determine the distance in which the work location is selected. This step is identical to the original DP-WHERE model (for more information see Isaacman et al., 2012). From these, an activity space is constructed using one of the activity space approximation algorithms.

Each trace is synthesised accordingly to the temporal pattern from the input data. Single spatiotemporal point is generated in a repetitive process as follows: (1) a timestamp is read from the temporal pattern; (2) current location (either home, work or another place) is selected for a given time of day from circadian rhythm distribution; (3) coordinates of that place are read from the activity space. If another place is selected, it is randomly chosen inside the activity space. Coordinates and a timestamp are written as a single record with a random user identifier.

3. Preliminary Results and DIscussion

Number of clusters to synthesize increases computation complexity linearly. Therefore, at this stage of development, we evaluate the model without the clustering process, hence the average of distributions is calculated for the whole input dataset and it can be considered as WHEN-WHERE model. We compare its performance to the WHERE model in two cases (Test Case - TC1 and Test Case 2 - TC2).

TC1 is based on the 5000 mobility traces generated from the New York Taxi Cab and the US Census data for the city of New York. As an aggregation layer for the test case and further calculations, we use census tracts from the Census Bureau's geographic database. To preserve the real distribution of the New York City population, we use census data to calculate home and work locations. Also, we sample New York City cab traces to determine the commuting distances. We randomise each person's circadian rhythm. To eliminate the impact of the temporal aspects on the results, trajectories are synthesized with the same frequency as they were recorded.

For the TC2, we evaluate our model on the real data gathered by Global Positioning System (GPS) loggers from 173 people from the Kingdom of Fife in Scotland. This test case investigated the ability of the evaluated algorithms to capture and model real-life movement flows. To model population mobility, we aggregated the data into a regular grid of 81 x 66 km, divided into 1 x 1 km squares.

For the TCs, we compare hourly population distributions of the input and output datasets using the Earth Mover's Distance (EMD) measure (results shown in Fig. 2). When referenced to the same aggregation layer, quantified similarity of two spatial distributions can be interpreted directly in meters.

Two variants of the WHEN-WHERE model are evaluated, one full and one that does not extend the WHERE component with the activity space. In both cases, we note higher accuracy levels yielded by our model. For the TC1 there is more than 50% of improvement over the WHERE model. The WHEN-WHERE model is more than one kilometre more accurate on mean position error, which is 2272 m for the WHEN-WHERE and 3588 m for the WHERE. For the TC2 the accuracy varies from 2 km for the late evening hours, when most of the people are at home, up to 5 km in the morning. Our model continually performed better than the WHERE model. The WHEN-WHERE model produced at least 12% smaller position error than WHERE. High errors for the morning hours were caused by the gaps in the original GPS data.

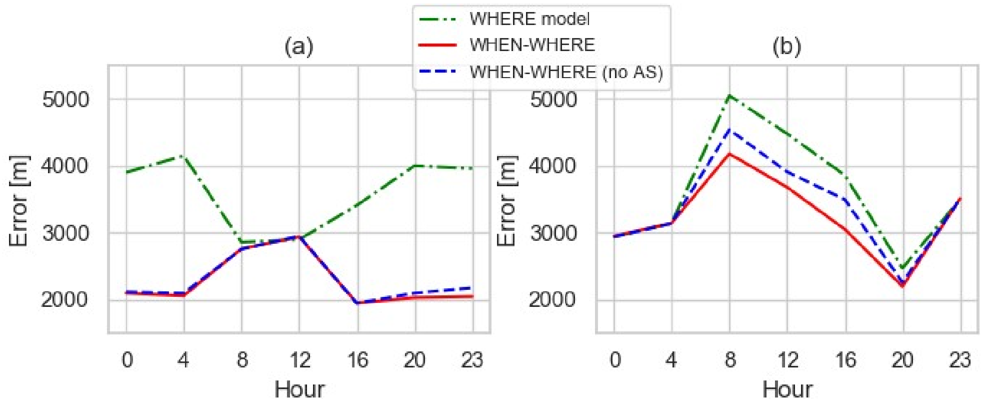

Figure 2. Comparison of the EMD error for datasets synthesised using (a) generated test case and (b) real data.

We measured the individuals' privacy protection by comparing the daily traces found in the original and synthesised data. It is expected that no trajectory would be matched in both datasets, which means that any real trace is included in the synthesised data. We considered trajectories to be identical when they had the same sequence of consecutively visited locations in an individual's daily itinerary. The longest matching sequence appearing in the compared datasets contained three locations for the first test case and two for the second, which stand for 10% and 5,4% of a daily trace, respectively. Furthermore, as a measure of activity spaces similarity, we calculated a number of people whose most frequently visited locations were identical. There were 340 (TC1) and 2 (TC2) people having the same set of the two most frequently visited locations and 5 (TC1) having the same set of the three most frequently visited places.

We compared the performance of the WHERE model and not yet fully developed WHO-WHEN-WHERE model for the synthetic and real data. We demonstrated that our model reaches a higher accuracy than the WHERE model and guarantees no breaches of privacy in published data.

In future work, we plan to introduce the WHO component into the model that will enable us to achieve an even larger accuracy improvement in all the cases. We will also adjust the model to satisfy the requirements of differential privacy. At the current stage, the synthesized mobility traces could be published, but the calculated probability distributions cannot as they breach the privacy.

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Trajectory and Mobility Based Services: A Research Agenda

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Abstract. In light of the definition of- and research agendas for Location Based Services (LBS), this paper first defines Trajectory- and Mobility Based Services (TBS and MBS) which place the trajectory-, mobility- or mobility need of an individual user or a population of users in the center and then presents the problem characteristics and challenges in TBS and MBS for two class of applications: (i) *resource-aware trajectory / mobility services* and (ii) *trajectory based resource infrastructure and operations optimization*. The paper's aim is to 1) implicitly present a work-in-progress research agenda for TBS and MBS, 2) cluster and raise the interests of researchers from different fields and 3) start the process of alternative or complementary characterizations and the process of discovery of new challenges and opportunities in TBS and MBS.

Keywords. Trajectory and Mobility Based Services, resource-aware trajectories, trajectory based infrastructure and operations optimization

1. Introduction

Driven by advances in communication and information technology, such as the increasing availability and accuracy of GPS technology and the miniaturization of wireless communication devices, Location Based Services (LBS) started to gain popularity in the early 2000s and quickly became an integral part of our daily life.

LBS can be defined as computer applications (especially mobile computing applications) that deliver information tailored to the *location* and *context* of the device and the user (Raper et al. 2007; Huang et al. 2018). While it is difficult to determine the number of LBS in existence, by analyzing the location permissions of mobile applications one can conclude that, as of 2014

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Q3, potentially one quarter of the 1 million mobile applications on Google Play Store were LBS (Olmstead and Atkinson 2015). The prominence of LBS is also marked by the growing research activity around LBS: 2019 marks the year of the 15th International Conference on Location Based Services and the publication of the issues of 13th volume of the Journal of Location Base Services.

In contrast to LBS, in this paper Trajectory Based Services (TBS) are defined as services that provide utility to the mobile user tailed to the user's movement *trajectory*. As the movement trajectory of the user describes the mobility of the user, the definition of TBS is extended to Mobility Based Services (MBS) that include services that provide utility to the user tailored to the *mobility* and *mobility needs* of the user. The subtle differences between LBS, TBS and MBS will become more pronounced through the example applications and challenges that the research agenda below outlines.

The utility of trajectory data: Motivated by the promise of smart cities (including their smart transportation systems and services) and the increasingly available, cloud-based, easy-to-use, big data processing frameworks that allow computations to scale, to utilize and monetize these data assets, commercial companies have become increasingly open to share parts of their trajectory data in an anonymized version. For example, Didi Chuxing ("DiDi"), the world's leading mobile transportation platform, has recently announced the worldwide expansion of its GAIA initiative to facilitate data-driven research in transportation (Green Car Congress 2018). Through this initiative, scientists can apply for access to the anonymized GPS trajectory data to explore solutions to traffic challenges including time of arrival estimation, route planning, supply and demand forecasting, transport capacity and congestion management etc. Similarly, while providing a lot less detailed information, primarily due to its high coverage of the population's mobility, in recent years, cellular network data is also increasingly shared by mobile network operators to aid sustainable development (De Montjoye et al. 2014). For example, cellular network data is increasingly used to extract trips, travel modes, travel demand, routes and cumulative flows for travel behavior modelling (Breyer at al. 2018).

Aims: The aim of this paper is three fold. First, in light of this growing availability- and expected utility of trajectory data, the aim of this paper is to present the problem characteristics and challenges in TBS and MBS based on example applications. Second, through this categorical presentation the paper hopes to cluster and raise the interests of researchers from different fields including LBS, geoinformatics, computer science (primarily data management, data mining, and big data processing), transport science (primarily logistics). Finally, through the categorical presentation and engagement of the research communities the paper hopes to start the process of alternative or complementary characterizations and the process of discovery of new challenges and opportunities in TBS and MBS.

Limitations: The herein described research agenda is a personal view of the author that has been formed by working in the field of trajectory and mobility data mining for over a decade and being active in the intersection of the LBS-, spatio-temporal data management- and transport science research communities. For these reasons the research agenda is not comprehensive and should be viewed as work-in-progress.

2. Related Work

Raper at al. (2007) provide a young and somewhat narrower- and Huang et al. (2018) provide and a more mature and wider research agenda for LBS. These research agendas first identify trends in the field and then describe and hierarchically group issues in- and key research challenges of LBS. To some extent, both of these works mention "tracking history", "navigation history" (i.e., trajectories) and "movement patterns" (i.e., mobility patterns) and even state these as possible bases for services (i.e., context), due to the comprehensive nature of these works, trajectories, mobility needs and patterns and their importance for some applications is not sufficiently emphasized. Other works, describe discipline- or field specific aspects of LBS, e.g., Jensen (2002) describes data modelling, indexing and query processing and optimization aspects of LBS from the field of spatio-temporal / moving object data management. Yet other works, draw connections to related disciplines and their research issues, e.g., Jiang and Yao (2006) do not find substantial fundamental differences and a clear-cut boundary between the research issues of LBS and GIScience and foresee a future where the differences and boundary further fades as "GIS functionalities are embedded in tiny sensors and microprocessors." Finally, while Brilingaite et al. (2004) presents key concept and software that discovers routes of a user along with their usage patterns and makes the accumulated routes available to services (i.e., LBS context), the importance of this context is not emphasized (i.e., generic LBS is assumed). In comparison, the present paper focuses on trajectories, mobility needs and patterns and their importance for TBS and MBS and describe- and identify challenges in- two classes of applications.

3. Trajectory and Mobility Based Services

3.1. Example applications

Resource-aware trajectory / mobility services: For a new set of TBS, mobile users need to acquire or collect resources to accomplish their mobility needs. Some example of services and their resources are as follows: 1) routing services that integrate the dynamic availability and cost of parking at different locations; 2) routing services that integrate the need to maintain the connectivity to a vital resource (e.g., wireless communication to a control tower for remote-driving of autonomous vehicles in emergency situations) throughout the trajectory; 3) routing services for electric vehicles that integrate the need to ensure electric operations under on-board energy storage constraints by charging at electric charging infrastructure components (stations or electric road segments) that have dynamic availability / capacity and costs; and 4) electromobility related services that based on the mobility patterns of a user (including driving style and related energy use) and the availability and cost of charging provide optimal charging strategies for the user.

Trajectory based resource infrastructure and operations optimization: Analogous to the above user-centric TBS, one can also define a set of new operator-centric MBS that try to optimized the location and availability of resources for large group of TBS users primarily based on the trajectories or mobility needs of the users. Some example of services, their resources and optimization objective are as follows: 1) services that under a budget constraint find the resource-infrastructure that can guarantee access to- and availability of the resources (e.g., carking / connectivity / electric energy) for most or all of the users given their mobility patterns or needs and 2) services that given a resource-infrastructure with dynamic capacity-constraints (e.g., available parking, network bandwidth, energy supply) find access control policies or pricing schemes that optimize the resource operations (e.g., utilize the resources or balance the demand for the resources) given the users' mobility patterns or needs. The distinction between mobility patterns and needs is crucial. Mobility patterns (e.g., routes) are observed mobility behavior of users, which can rapidly change based on how MBS optimize the resource-infrastructure and its operations and based on what TBS the users use to access the resource-infrastructure. In comparison, mobility needs represent the users' underlying need to reach a destination, which, in comparison, are expected to remain relatively stable.

3.2. Challenging problem characteristics

The ***problem characteristics*** that are associated with these services are rooted in the spatial and spatio-temporal relationship between the trajectories-, mobility patterns and needs of a single or group of users and the location and temporally changing availability and cost of the resources. In particular, in most cases, *the utility of a resource is highly dependent on its spatial relation with the movement trajectory of the user*, e.g., an electrified road segment has just as little benefit to a user with an electric vehicle that has a full battery or have enough battery to reach its final destination where cheap stationary charging is available as the benefit is of cheap parking space at a location that is far away from the destination of the users. Moreover, because users may need to acquire several resources to accomplish their mobility needs but cannot infinitely accumulate resources due to limited storage capacity (i.e., battery), *the utility of a resource is highly dependent on the location and amount of resources that were previously acquired and consumed during the movement trajectory* of the user. Finally, because the resource-infrastructure has to cater for the mobility needs of multiple users that are in competition with one another, *the utility of- or demand for resources is defined by the complex topological relationships between trajectories*. Dealing with these problem characteristics is ***challenging*** and require combinatorial optimization methods that can "untangle the complex topological relationships between a large number of trajectories" and efficiently estimate the utility- and availability of a resource individually and as part of an infrastructure / network.

To better exemplify the challenges and problem characteristics, consider the task of finding the optimal placement / selection of electric road segments to meet the energy demand of battery electric vehicles. In particular, consider the case of heavy freight trucks that cannot be equipped with large enough batteries to cover their energy demand and should be charged while moving in order to reduce their idling time and spread the energy demand on the electric grid (Gidofalvi and Yang 2019, Gidofalvi and Yang 2020). For a fixed electric road infrastructure budget N, the optimization problem can be stated as "Select N unit-length segments in the road network for electrification so that the transport work of the vehicles (vehicle-km traveled) in electric mode (ERS or battery) is maximal." To evaluate a candidate solution requires the ability to efficiently simulate the vehicles' battery state at each point of their trajectory according to an energy storage-, consumption- and charging model. For realistic problem sizes at national / international scale, this requires the processing of billions of trip trajectories, e.g., a fleet of 20,000 trucks produce TBs of GPS trajectories annually. To improve a candidate solution requires the calculation of the *electrification utility* of a segment, which can be defined as the additional transport work that can be carried out in electric mode due to the electrification of the segment. Due to the battery capacity limits of the vehicles, the electrification utility of segments is not independent of one another. In particular, the dependence between the electrification utility of two segments is influenced by the battery states of vehicle whose trajectories directly or indirectly (through other electrified segments) connect the two segments. To find the optimal solution, given a road network with M segments, requires the evaluation of an exponential number of (M choose N) candidate solutions.

4. Conclusion

This work-in-progress paper advocated the importance of trajectories- and mobility needs and patterns for TBS and MBS and described- and identified challenges in- two new classes of applications (*resource-aware trajectory / mobility services* and *trajectory based resource infrastructure and operations optimization*), which was aimed to trigger the interests and future engagement of research communities and the evolution of the research agenda that will hopefully lead to new opportunities and challenges.

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Data-driven Trajectory Prediction and Spatial Variability of Prediction Performance in Maritime Location Based Services

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Abstract. Location-based services in the maritime domain aim to improve efficiency and safety of vessel operations. Predictive functionality can increase the value of these services beyond ordinary visualizations of the current operational picture. Trajectory prediction aims to forecast the future path of vessels and can thus help improve logistics as well as help predict potentially dangerous situations. This paper presents ongoing work on data-driven trajectory prediction that leverages information of past vessel movements to improve prediction results. Preliminary results show that data-driven prediction outperforms baseline approaches, particularly in complex situations. However, results also show a large spatial variability in prediction performance. This indicates that it is impossible to compare the performance of different prediction methods by relying solely on the error statistics reported in publications since every research group uses different data samples from different geographic regions.

Keywords. Computational movement analysis, trajectory prediction, Automatic Identification System

1. Introduction

Methods for extracting useful information from increasingly massive movement data are lagging behind the tracking technology that generates these datasets (Long & Nelson 2013). Frameworks and predictive models for movement data in GIScience therefore are an important research avenue towards understanding, simulating, and predicting movement (Dodge et al. 2016).

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In the maritime sector, for example, all vessels of a certain size are tracked since they are required to carry Automatic Identification System (AIS) receivers. They have to broadcast their information (including location and status) to other vessels and AIS base stations in their vicinity. The resulting AIS data is an important input for location-based services, such as vessel traffic services (VTS).

This work focuses on data-driven vessel trajectory prediction, also known as route estimation (Tu et al. 2018) or future location prediction (Georgiou et al. 2018). In contrast to other moving objects, such as land vehicles and aircraft, ships typically exhibit slow parabolic maneuvers. They cannot stop, turn or reverse abruptly and their movement occurs on a two dimensional plane (Tu et al. 2018). Vessel trajectory prediction methods come in three main classes: physical model-based methods, data-driven methods, and hybrid methods (Tu et al. 2018). Physical model-based methods include linear and kinematic prediction but, particularly kinematic prediction is mostly used in the context of trajectory interpolation rather than prediction (Long 2016, Sang et al. 2016). Data-driven methods are increasingly popular and vary considerably in their approaches and complexity. One type of data-driven methods are map-based approaches using attracting and repelling forces (Vespe et al. 2008). Approaches that are trained using previously observed movement include, for example, Hebbian learning of location changes between grid cells (Bomberger et al. 2006), Ornstein–Uhlenbeck (OU) processes (Vivone et al. 2017), perceptrons and multi-layer perceptrons (MLP) (Zorbas et al. 2015, Valsamis et al. 2017), and neural networks (Gao et al. 2018). The prediction errors reported for different prediction approaches vary significantly. For example, error values range from 153m to 1314m (Valsamis et al. 2017) for 4-minute predictions to 7km (Zorbas et al. 2015) for 1-hour predictions, as listed in Table 1. To the best of our knowledge though, existing approaches (Table 1) all base their evaluations on different regions and do not take into account spatial variability within and between regions.

Paper	Method	Prediction:	4min	5min	10min	15min	20min	30min	60min
Valsamis	Linear		890		2,186		4,256	6,477	
Graser	Linear			520	1,247	1,923			
Wijaya	Similar trajectory				900 [a]				
Graser	Similar trajectory			436	919	1,344			
Graser	Gaussian mixture			582	1,029	1,522			
Zorbas	Perceptron							3,000	7,000
Valsamis	Multi-layer perceptron		153		652		983	1,721	
Valsamis	MLP time series		1,314		1,896		2,102	4,613	

Table 1. Trajectory prediction errors (mean distance error in meters) ([a] median error)

Most works measure prediction error using distance error, that is the distance between predicted position and observed position. Other less common error metrics include cross-track error and along-track error as illustrated in Figure 1. Cross-track error measures the distance between predicted position and the observed trajectory. It thus provides information about how well the prediction reflects the true movement direction. In contrast, along-track error measures the error along the observed trajectory and thus provides information about how well the prediction reflects the true speed.

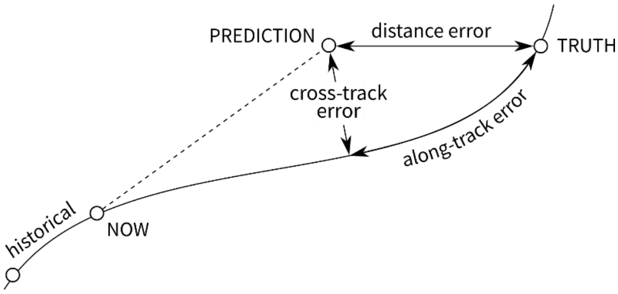


Figure 1. Prediction error measures

The rest of this paper is structured as follows: Section 2 presents preliminary results of our ongoing work on data-driven trajectory prediction with a specific focus on the spatial variability of prediction performance. Finally, Section 3 provides an outlook towards planned future work.

2. Data-driven Vessel Trajectory Prediction

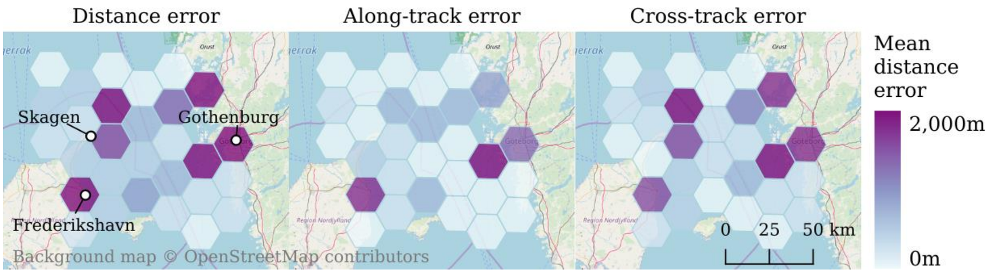
The data-driven prediction approach presented in this work is inspired by Wijaya & Nakamura (2013). It is based on the concept that historical trajectory data provides a sample of potential paths that objects can travel. To predict future locations, we search the historical data for moving objects that were moving along a similar path. While different distance metrics are conceivable to determine similarity, this approach relies on selecting past trajectories of vessels of the same type, located in the same region, and moving in the same direction at similar speeds. Then we determine the locations of those vessels after the defined prediction time frame. The complete algorithm can be summarized as follows:

1. Find n similar trajectories: for a given observed track, identify up to *n* similar trajectory segments that move in the same direction (direction tolerance α_{max}), at similar speed (speed tolerance v_{max} and are at most d_{max} (distance tolerance) meters from the observed track
2. Identify potential future locations: for each identified segment determine where the moving object was located after the given prediction time frame

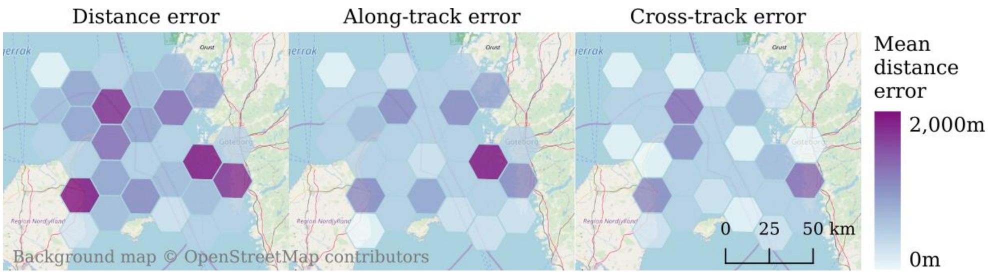
3. Compute the final prediction given the set of potential future locations

If no similar trajectories are found in the historical database, the method falls back to linear prediction. This mostly happens in open areas where vessels do not need to follow shipping lanes and it is therefore less likely to find a trajectory within the distance tolerance.

Linear trajectory prediction is a commonly used base line for comparison (Graser et al. 2018, Valsamis et al. 2017). It is based on the assumption that vessel movements will continue with the last observed direction and speed. Direction and speed can be instantaneous values that are provided by the input data, or alternatively, direction and speed can be computed from consecutive data records.



(a) Linear trajectory prediction errors are highest in coastal regions near Frederikshavn, Skagen, and particularly Gothenburg.



(b) Similar trajectory prediction error distributions show improvements where linear prediction suffers from large cross-track errors.

Figure 2. Spatial distribution of 20 minute trajectory prediction errors based on 3 minutes observations for cargo vessels

Figure 2 shows the cargo vessel trajectory prediction performance for 20-minute predictions in the sea between Denmark and Sweden, near Gothenburg. The largest linear prediction errors (Figure 2a) are observed in coastal regions, particularly near Frederikshavn (Denmark), Skagen (Denmark), and Gothenburg (Sweden). Similar trajectory prediction error distributions (Figure 2b) most notably show improvements where linear prediction suffers from large cross-track errors, indicating that this data-driven prediction method manages to better capture vessel movement directions.

However, not all regions exhibit improvements from data-driven prediction. This is due to the behavior of cargo vessels which tend to travel on straight courses at constant speeds if there are no specific reasons to do otherwise. This behavior is well represented by linear trajectory prediction. It is therefore hard to beat linear prediction performance in these regions.

Particularly in coastal regions, however, there are external reasons for vessels to change course and speed. Therefore, switching from linear to similar trajectory prediction results in better predictions in these areas. In our example, seven regions fall into this category. Replacing linear trajectory prediction with similar trajectory prediction in these regions improves the results for five out of seven regions. The largest improvement is observed near Gothenburg with a mean distance error reduction by 2,252m. The mean improvement over all seven regions is 769m.

3. Conclusions and Outlook

Our work on data-driven vessel trajectory prediction for maritime LBS is still ongoing. The preliminary findings presented here show that even comparatively simple data-driven prediction approaches outperform basic linear prediction in areas of complex movement. Furthermore, our results show how prediction performance varies across different geographic regions. This considerably impacts the interpretation of existing vessel trajectory prediction publications, as well as their potential to inform the selection of prediction methods for future applications. Comparing trajectory prediction errors found in the literature is meaningless without access to the same evaluation data.

In the future, we plan to improve on the data-driven trajectory prediction presented in this paper. In particular, we envision data-driven trajectory prediction methods that make use of movement patterns that can be extracted from massive movement datasets. Depending on the area of interest, vessel movement patterns are furthermore influenced by other factors, such as tides, current, and visibility. Finally, since nearby vessels influence each other's movement, future prediction methods should also take the surrounding traffic situation into account.

Acknowledgements

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Cross-scale Spatial Enrichment of Trajectories for Speeding Up Similarity Computing

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Abstract. Different types of cross-scale analytics have been applied to spatial enrichment and aggregation of trajectories using geographical context sources as both subjects can present different spatial patterns at different scales. This paper clarifies the taxonomy of different types of "cross scale". A conceptual framework is then proposed on summarizing the key components for spatial enrichment of trajectories supporting different cross-scale types. Following a workflow guided by the proposed framework, POIs are used for enrichment of GPS waypoints, in a proof-of-concept case study. The preservation of pairwise trajectory similarity between the raw trajectory and the enriched trajectories is investigated. Empirical results show a good preservation while the time on computing the distance/similarity matrix is significantly reduced. This shows the potential for applications relying on an efficient trajectory clustering strategy.

Keywords. Cross-scale, Spatial Enrichment, Trajectory Modeling

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1. Introduction

Spatial enrichment integrates geographical context and spatial semantics into trajectory modeling, which can simplify querying, analyzing, and mining trajectories. Roads, points of interest (POIs), and places extracted from the raw trajectories are common geographical context resources for trajectory enrichment. However, geographical context commonly involves the issue of *scale* (Goodchild, 2011), that is, the same geographical features may present different patterns while being aggregated at different granularities, leading to one type of modifiable areal unit problems (MAUP, Openshaw, 1977). As the term *scale* refers to different definitions, cross-scale modeling and analysis essentially also refers to different scenarios.

The question thus is how the spatial enrichment and aggregation at different scales can benefit trajectory modeling and analysis. For example, if the enrichment by an external geographical context, such as POIs, at a coarse scale can achieve a similar result as another external geographical context at a fine scale, the former resource may be selected because it may take less computing resource and time.

However, existing frameworks for spatial enrichment of trajectories, such as Yan et al., (2011) and Soares et al. (2019), do not address integrating cross-scale analytics, even though they have otherwise developed a comprehensive understanding of data sources, models, and applications.

This paper starts by clarifying different scenarios of general cross-scale modeling based on one common definition of scale. Two main research objectives are conduced:

- A conceptual framework is proposed for fitting the cross-scale modeling scenarios into spatial enrichment of trajectory analysis.
- Using the framework, a proof-of-concept case study empirically shows that the cross-scale approach can benefit trajectory similarity computing by saving computing time.

2. A Theory of Cross-scale Analysis

2.1. Scale as Spatial Granularity

Based on the taxonomy by Atkinson & Tate (2000), this paper uses the definition of scale as the *spatial extent* rather than the amount of detail. The term further narrows to the aspect of *spatial granularity*, rather than the scales of spatial variance.

2.2. Three Scenarios of Cross-scale

The granularity of spatial subdivision units for spatial analysis can be further categorized into *fixed granularity* and *variable granularity*. Subdivision units with fixed granularity have the same or similar shape and areal size, such as grid tessellations, image pixels, etc. Subdivision units with variable granularity have significantly different areal size from each other. Examples of variable-granularly units are subdivision units by fractal geometry (Jiang & Brandt, 2016) and urban-countryside subdivisions.

The term "*cross-scale analysis*" usually refers to comparing results aggregated at different scales. Regarding the context of two types of granularity, we conceptualize cross-scale analysis as three types of comparisons: *fixed-granularity multi-pass subdivisions, variable-granularity single-pass subdivisions,* and *variable-granularity multi-pass subdivisions*.

Fixed-granularity multi-pass-subdivision modeling as cross-scale analysis (Scenario a, *Figure 1*) uses different fixed-granularity subdivision units in different modeling processes and compares the results, such as empirical studies by Lloyd (2014). Variable-granularity single-pass-subdivision modeling as cross-scale analysis compares results from groups with significantly different geographic areas within the same subdivision. For example, statistical comparisons between cities and rural areas can be categorized as one type of this cross-scale analysis. Variable-granularity multi-pass-subdivision modeling compares results from different passes of variable-granularity single-pass-subdivision modeling by aggregating subdivision units (Scenario b, *Figure 1*), such the modeling by Soleymani et al. (2014).

This paper conducts cross-scale analytics in trajectory modeling applying the variable-granularity multi-pass-subdivision scenario.

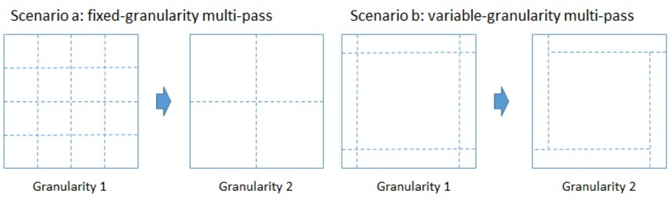

Figure 1. Theoretical models of the existing cross-scale analysis.

3. Methodology

3.1. Variable-granularity Cross-scale Subdivision for Trajectory Modeling

A GPS trajectory can be simplified by aggregating raw waypoints into less representative waypoints after being enriched by places, such as POIs or land use parcels. However, not all POIs or land uses are equally important for trajectory modeling. For example, to model the movement of a truck, small grids can be used for aggregating waypoints within the city centers while larger grids are used for modeling suburban and countryside area.

3.2. Conceptual Framework Overview

We conceptualize cross-scale enrichment as a key processing component for trajectory applications: A subdivision model is extracted from the geographical context and is applied to enrich a trajectory; Waypoints of a trajectory are then enriched by the subdivision units (*Figure 2*). The enriched waypoints can be aggregated into fewer, representative waypoints based on the enriched spatial proximity or semantic proximity for further applications, such as trajectory clustering.

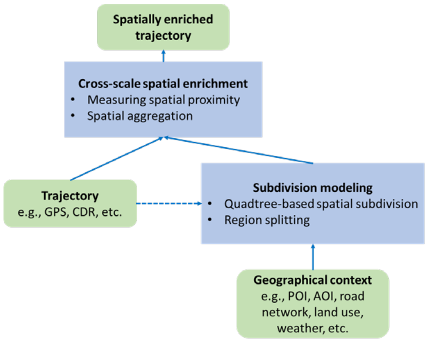

Figure 2. A framework for cross-scale-based spatial enrichment on trajectory

The quadtree scheme is selected for modeling variable-granularity subdivision from a geographical context. Commonly used for spatial indexing, a quadtree splits space into hierarchical, mutually exclusive grid meshes (*quadnodes*) at different levels. Areas with more data are split into smaller quadnodes. An existing quadtree can easily support multi-pass cross-scale analysis, by controlling the threshold of data records for splitting quadnodes into smaller quadnodes.

4. Preliminary Results for Evaluation

As a proof of concept, a pilot empirical study was conducted to illustrate the feasibility of the proposed framework, as well as to explore the tradeoff by using POIs as the geographical context to enrich and aggregate waypoints with the variable-granularity multi-pass cross-scale analysis and investigate if the pairwise similarity between trajectories can still be preserved, towards its further application to cluster big trajectory data sets in an efficient way.

500 sample truck trajectories from a Greece-based fleet management company were randomly selected. The mean trip length regarding the number of waypoints is 263 (SD = 215, MIN = 51, MAX = 1889) and the median time interval of two waypoints is 20 seconds. 4,641,857 OpenStreeMap POIs over Europe were collected, regarding the potential to extend the study for the whole truck trajectory database. Longest Common Substring (LCSS) and Dynamic Time Warping (DTW) are used as the trajectory similarity metrics. The mean center is used as the location of points with the same spatial proximity after enrichment.

Three thresholds were used in quadtree building: 1, 5, and 10 POIs per quadnode. As the benchmark, the cost for calculating 124,750 pairs of LCSS and DTW for the 500 raw trajectories was 7,748.0 seconds and 7,076.0 seconds, respectively. While the pairwise distance is well preserved, the computing time is significantly reduced (*Table 1*).

	LCSS			DTW		
Quadtree splitting threshold	Pearson's r	Spearman's rho	Time (sec.)	Pearson's r	Spearman's rho	Time (sec.)
1	0.65	0.93	878.0	0.82	0.80	1,581.0
5	0.60	0.87	58.9	0.77	0.77	254.0
10	0.56	0.85	28.8	0.79	0.81	157.0

Table 1. Correlations between the pairwise LCSS and DTW of the simplified trajectories and the raw trajectories, respectively. All correlations have a 0.00 p-values significance.

To conclude, our cross-scale waypoint enrichment and aggregation framework enables to speed up related trajectory similarity computing and thus benefit trajectory clustering computing.

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Analyzing performance in Orienteering from movement trajectories and contextual information

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Abstract. This paper presents a framework to automatically analyze the performance of elite orienteers under the consideration of the slope and of a wide-range of vegetation types. We test our approach using data of four different competitions of the European Orienteering Championships 2018. Two use cases of the framework are presented: first, the analysis of the speed and slope on a competition level and second, the analysis of the speed as a function of the vegetation type either on a competition level or on an individual athlete level. The presented framework can be used efficiently across multiple data sets and by coaches and athletes to develop new strategies for training or competitions.

Keywords. orienteering, data analytics, context

1. Introduction

The monitoring of sports activities in amateur and professional settings has become ubiquitous due to the availability of small and low-cost GPS receivers. In orienteering, a sport where an athlete runs at speed from control point to control point using a map and compass, the tracking serves two main purposes: For live coverage of events to make the invisible runners visible for spectators and moderators, and for post-analysis of the athlete performance. In the second case, the availability of high-resolution data, topographic maps, and further contextual data, allows to reconstruct the race, analyze route selection decisions and compare the performance to other competitors (Gasser, 2018).

Despite these advantages, the ubiquity of GPS tracking results in large data quantities requires automated data processing methods for efficient analysis. In orienteering, performance of orienteering athletes based on context data

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focuses mainly on tests under laboratory conditions (Lauenstein, Wehrlin, & Marti, 2013; Zürcher, Clénin G, & Marti, 2005) or in the outside on prepared test courses (Amouzandeh & Karimipour, 2017; Hébert-Losier, Jensen, Mourot, & Holmberg, 2014). Furthermore, studies often do not consider vegetation context in their analysis or only consider few vegetation types (Hébert-Losier et al., 2014). For further information on related work, we refer to the review done by (Amouzandeh, Karimipour, Chavoshi, & Tveite, 2016).

Here we present a framework to analyze the performance of orienteers in competitions under the consideration of a large variety of vegetation types and the slope of the terrain. Our framework provides the means to compare the vegetation type dependent performance to athletes of the same race.

2. Methods

To analyze the context dependent performance of elite orienteers, raw tracks are enriched with context data. We assume that the individual trackpoints consist of timestamps, geographic coordinates and the current speed. Vegetation data comes from the same topographic maps that are used by the orienteers during competition. These orienteering maps provide information about control points.

For the context integration, we represent vegetation and terrain type information as polygons or lines, and the tracking data as a set of trajectory segments by connecting consecutive tracking points of the same athlete. To join the line segments with the context information, we perform the following data preparation steps:

- **Streets**: Streets are encoded as a line geometry. To account for imperfect GPS accuracy, we apply a 10m buffer around all road types.
- **Overlapping vegetation**: The geometries of the available vegetation data can overlap. To enable the association of a trajectory segment with a unique context type, we define a matching hierarchy[1] and associate each trajectory segment only with the vegetation type with the highest priority.
- **Non-unique relations**: Each trajectory segment can span over multiple vegetation types. To associate line segments with a unique vegetation type, we split the trajectory segments whenever they cross the boundary between two polygons. Therefore, a new tracking point is created at the

[1] Vegetation types (see footnote 6) ordered by their priority (20 = highest priority). Priorities are printed in boldface - 1:405; 2:401; 3:402; 4:403; 5:404; 6:310; 7:407; 8:409; 9:414; 10:406; 11:408; 12:410; 13:411; 14:508; 15:507; 16:506; 17:505; 18:504; 19:503; 20:502

boundary of the polygons, and it is associated with the average speed of the two original trackpoints.

- **Slope information**: Every trackpoint is associated with the elevation information from the digital elevation model swissALTI3D[2] with 2m resolution. The slope of every segment is calculated as $\frac{h_{i+1}-h_i}{dist(t_{t+1},t_i)}$, where h_i is the height of the i^{th} trackpoint and $dist(\cdot,\cdot)$ calculates the Euclidean distance between two trackpoints.

The line segments can then be associated with the context type using a simple spatial join. The result of this process is that each trajectory segment is associated with information about the vegetation type, the average speed and the average slope.

3. Case Study

To test the framework, we apply the segmentation method described in section 2 to four different competitions of male elites, which all took place during the European Orienteering Championships 2018 (EOC18) in Ticino, Switzerland[3] (Table 1).

Competition	Carona (c1)	Serpiano (c2)	Capriasca (c3)	Capriasca (c4)
Date / Weather	08.05.2018 / dry	09.05.2018 / dry	12.05.2018 / dry	13.05.2018 /dry
Type	Middle quali	Middle final	Relay	Long
Tracks	10	19	52	31
Segments	3692	18545	55414	78864

Table 1. Orienteering Data Sources of EOC2018

Tracking data from the EOC18 was recorded per competition and athlete with a sampling rate of 3 seconds using GNS 3301 receivers and are available online[4]. We discarded invalid tracks (e.g. multiple large jumps) based on visual inspection, parsed all tracks in a PostgreSQL database with PostGIS extension, and deleted all points that were recorded before the first or after the last control point. Furthermore, we deleted all trackpoints with implausible running speed (> 8 m/s) and points that are not within the competition area. As a source for the vegetation data we used the official competition maps that were provided in the OCAD format by the EOC18 organizers. The maps are based on the schema of the International Orienteering Federation (IOF). We exported vegetation and terrain type including their geometry as a shapefile

2 https://shop.swisstopo.admin.ch/en/products/height_models/alti3D

3 http://www.eoc2018.ch/eoc2018/news.html

4 https://www.tulospalvelu.fi/gps/?year=2018

and merged underrepresented categories with similar ones (IOF terrain type code[5] in parentheses), e.g., we merged paved area (501) into wide road (502). Furthermore, the forest (405) is not explicitly drawn on the map but corresponds to the background color. Therefore, we define all areas that do not explicitly belong to IOF-categories as forest (405).

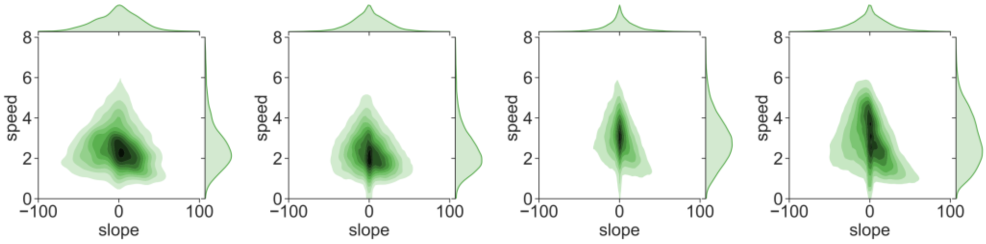

Figure 1. Speed-slope distribution for the different competitions (L to R: c1, c2, c3, c4; speed in m/s, slope in %).

3.1. Speed vs. Slope

Figure 1 shows the joint distribution of running speed and slopes of all segments for the different competitions as well as their marginal distributions. The joint distribution shows the expected correlation between running speed and slope. However, this dependency is not linear but shows an optimal slope between -3% and -7% depending on the competition.

3.2. Speed vs. Environment Type

Figure 2 shows a box plot to visualize the speed distribution of all segments depending on the vegetation type. The plot is from Capriasca (c4) and consists of fast segments (slope between -25% and 5 %, and median speed > 3 m/s). The median values show that the better the ground (streets) the better the performance. While indistinct marsh (310) shows unexpectedly good values, easy to run forest (405) shows unexpectedly bad values compared to paths, roads and open areas. Vegetation resulted mostly in worse performance. An additional value for orienteers is the possibility to compare their performance to their peers. Figure 2 shows the median of the best athlete (blue) and the median speed of a randomly selected athlete (pink) as line plot for every vegetation type. The graph demonstrates that the best athlete

avoided less distinct small footpaths (507) and performed dominantly in difficult to run terrain like undergrowth vegetation (409). The figure shows that

5 https://www.fiso.it/_files/f_media/2018/02/15021.pdf

the selected athlete (pink), performs significantly worse in (409) and also on footpaths (505).

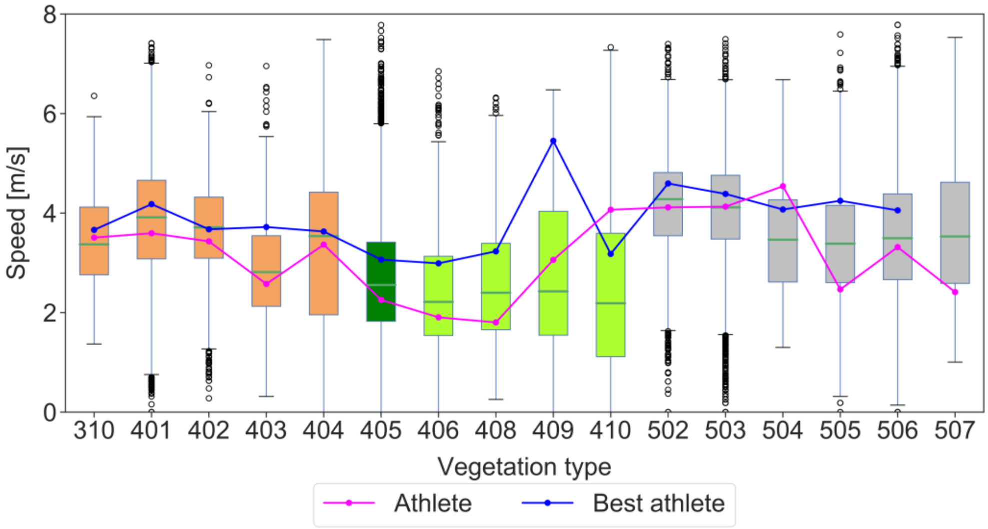

Figure 2. Speed vs. vegetation type[6] by the terrain codes of IOF from Capriasca (c4)

Comparing all four competitions in that way, shows if and where an individual runner has significant deficits. Such findings are important insights for future competition strategies and training plans for coaches and athletes.

4. Discussion and Outlook

The presented approach allows analyzing running speed of all or individual athletes depending on the environment type and slope on a large scale. The automated analysis has the potential to generate new insights for context dependent performance in orienteering. Furthermore, the possibilities to reconstruct the competition and to compare the context dependent performance of individual athletes allows to optimize training sessions and to create better strategies for future competitions.

The possibility to process tracking data of competitions on a large scale and in realtime can revolutionize the experience of spectators in front of the television and on site.

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[6] **Open Areas**: (310) Indistinct marsh, (401) Open land, (402) Open land with scattered trees, (403) Rough open land, (404) Rough open land with scattered trees / **Forest**: (405) / **Forest Vegetation:** (406) Vegetation, slow running, (407) Vegetation, slow running, good visibility (408) Vegetation, walk, (409) Vegetation, walk, good visibility, (410) Vegetation, fight / **Street**: (502) Wide road, (503) Road, (504) Vehicle track, (505) Footpath, (506) Small footpath, (507) Less distinct small footpath

Most analyses have been made so far based on GPS, slope and environment. Future work could take more context into account such as human biological and cognitive factors, and further environmental factors. This results in an infinite number of further research possibilities in the field of orienteering.

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Demand Forecasting of a Public Bike-Sharing System Reflecting Dynamic Spatial Data

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Abstract. Bike sharing is booming in Korea as a leisure traffic mode, but its original purpose was to reduce traffic congestion. This study developed a demand forecasting model for bike sharing connected to a subway station. For accurate demand forecasting, we used various kinds of data to reflect the spatial distribution of travel demand. We used machine learning method as prediction model, and random forest had the best predictive result.

Key words. Public Bike-sharing System, Social Media, Random Forest

1. Introduction

Bike-sharing systems are one of the useful solutions for traffic congestion and last-mile problem in urban transportation systems (Xu et al., 2018). Also, since the MaaS (Mobility as a Service) model emerged as a global trend, the status of bike sharing is increasing.

We aimed to develop a demand-forecasting model for bike sharing near subway stations, which are familiar to users as public transportation. Lots of temporal and spatial data are required for accurate demand forecasting, but previous studies were biased toward one side of the data. Time-focused studies made predictions mainly using weather data (Campbell et al., 2016 ; Gebhart and Noland, 2014), and space-focused studies considered only the influence of the static state (Faghih-Imani et al., 2014).

New forms of micro-level data have been found to contain rich information about place semantics and individual interactions with the physical world (Liu et al., 2015). In this paper we actively used various kinds of data to overcome the limitations of previous studies. In order to index the diversity of space in terms of time, we used social media data and used real-time smart-card data to consider linkage with public transportation.

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2. Research Methods

2.1. Influential Factors

The factors affecting public bicycle demand can be classified into weather, public transportation, and land use. Unlike other traffic modes, weather influences the use of bicycles, so various types of data, such as temperature, humidity, wind speed, rainfall, and snowfall, were collected.

Public transportation factors were constructed using smart card data, which record the number of people who get off at subway station near a bike dock. They may use a public bike for the last mile to final destination.

Finally, we collected land-use factors reflecting the dynamic state of space by time zone. After defining a purpose for a public-bike trip, we collected data corresponding to each rental demand. The bike-trip purposes were divided into work, school, home, and recreational trips. These were selected by referring to Household Travel Surveys (HTS) items. In order to reflect the dynamic state of space, we extracted demand quantities for each trip purpose and then multiplied the distribution by the time period.

Work, school, and home trips were based on the distribution chart of departure times for each purpose provided by HTS. Table 1 shows the distribution of departure times by trip purpose. For example, demand for work trips by time zone was calculated by multiplying the number of employees in a district by the distribution value by time zone provided by HTS. In the same way, we calculated school trip was by using the number of students, and home trips were calculated using population (ages 15 to 64).

Time zone	0-1h	....	7-8h	8-9h	....	12-13h	....	18-19h	19-20h	....
Work trip	0.1%	....	32.7%	36.4%	....	0.7%	....	0.2%	0.1%	....
School trip	0.0%	....	26.9%	54.1%	....	0.5%	....	0.1%	0.0%	....
Home trip	0.2%	....	0.2%	0.3%	....	2.4%	....	21.5%	14.9%	....

Table 1. Departure time distribution by trip purpose (HTS in Korea, 2018).

However, the distribution of recreational trips, unlike other trips, which had an approximate trend, differed by POI (Point Of Interest). So we used check-in data provided by Google Place to figure out the distribution by time. Since check-in data is not accurate data reflecting the real world, standardization is required. For example, place A has more visitors than B in reality, but B may have more check-in data, because social media is user-dependent data. Another thing to consider is distance; since many bike docks can be adjacent to the same POI, we calculated the distance from dock to POI as a weight value. For a shorter distance, the more demand is calculated.

2.2. Prediction Model based on Machine Learning

There are various methods for machine learning to predict demand. In this study, bicycle demand was predicted by using random forest and gradient boosting, which has proved to be effective in various data sets of classification and regression problems.

Both algorithms use a decision tree as a basic element for constructing a model, and it is an ensemble technique that creates a powerful model by grouping several decision trees. Decision trees have an advantage of being fast, and easy to explain, because visualization is possible. Random Forest uses aggregation as a model-combining method. Gradient boosting compensates for the error in the binary tree by using a boosting method that gradually increases the model to be used. The overall analytical process is illustrated in Figure 1.

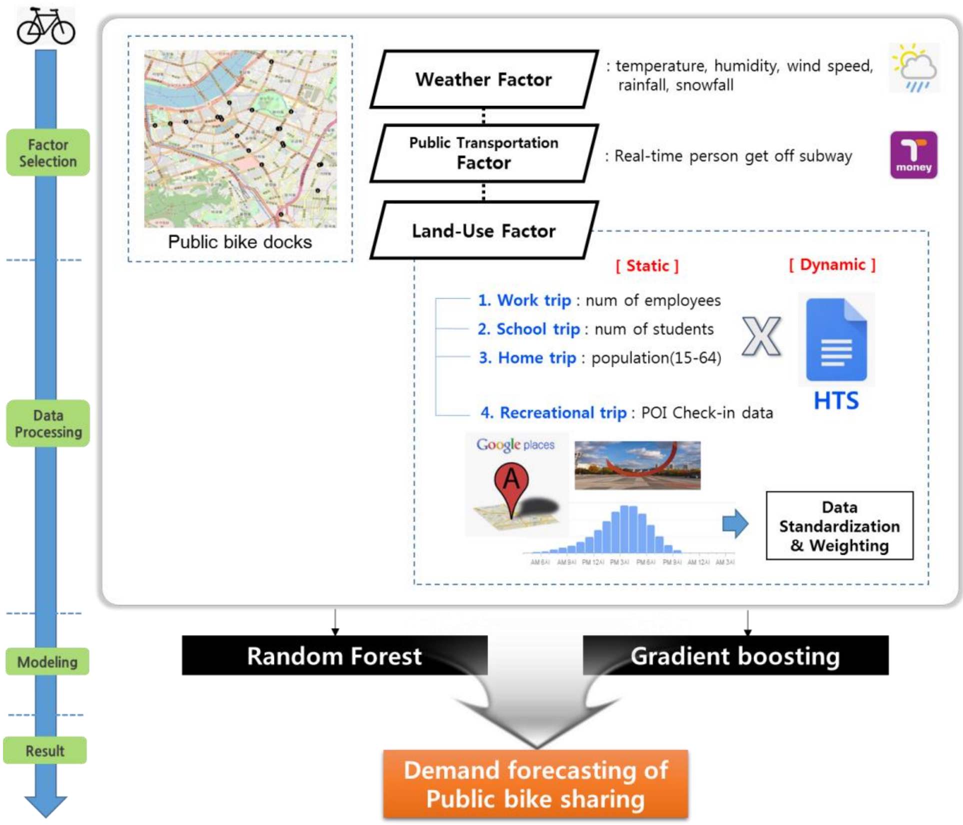

Figure 1. Study flow chart.

2.3. Accuracy assessment

In order to evaluate the performance of the proposed prediction model, we selected Root Mean Squared Logarithmic Error(RMSLE) as the evaluation parameter shown in Equation(1).

$$\text{RMSLE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(\log(p_i+1)-\log(a_i+1))^2} \qquad (1)$$

where n is the number of hours in the test set ; p_i is predicted count ; a_i is the actual count ; And $\log(x)$ is the natural logarithm.

This method gives a penalty to underestimated items rather than overvalued items, and the closer the value is to 0, the higher the precision. Also, in order to measure the generalization performance, we did k-fold cross validation to learn multiple models by repeatedly dividing the data.

3. Experiment and Result

The experimental area was limited to Songpa-gu, Seoul, and the rental history of 20 public bike docks near a subway station was analyzed. Songpa-gu has a variety of densely populated residential and business areas, close to the bike-riding Han River and parks, so is a good place to analyze bike demand.

From September to December 2018, 130,783 items of rental-history data were collected for four months. Figure 2 provides the detailed of data. The data for days 1-24 of a month were used as train data and data for days 25-30(31) were used as test data. Data were collected on an hour-by-hour basis and classified as weekday or weekend.

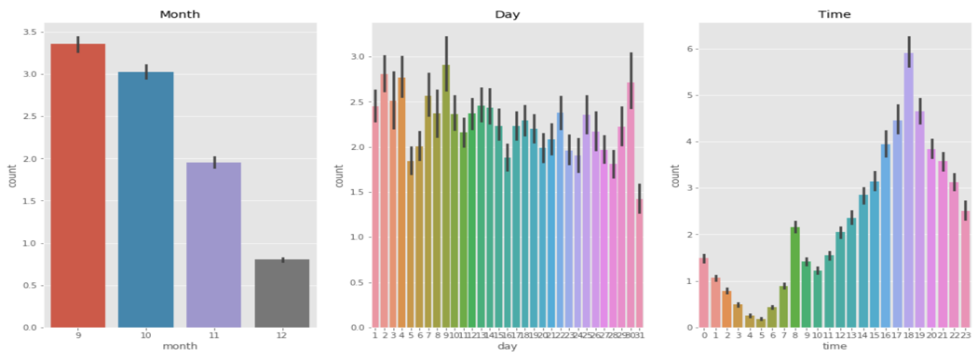

Figure 2. Rental history of public bike in research area

Experimental results show that the demand forecast using Random Forest is 0.1440 for RMSLE and 0.3258 for prediction through Gradient Boosting.

Random Forest's prediction performance is better. In addition, the model that reflects the dynamic state of public transportation and space works better than the model that uses only weather information. Table 2 shows the RMSLE results for each model.

Models	Random Forest	Gradient Boosting
(Weather + Public Transport + Land use) factors	0.1440	0.3258
(Weather + Public Transport) factors	0.2806	0.4053
(Weather) factors	0.4544	0.4588

Table 2. RMSLE result of different models

4. Conclusion

This study developed a demand forecasting model for bike sharing near subway stations using machine learning. Spatial and temporal data were introduced into the forecasting demand. In particular, various kinds of data such as smart cards and social media data were used to reflect the spatial distribution of travel demand. By integrating those data with general information, the method can be predicted more accurately bike-sharing demand.

Spatial and temporal data has information that static data does not have, which allows decision-makers to gain new insights. Especially user-created content on social media provides details for topics such as customer satisfaction, and travel behavior (Welch et al., 2019). In a future study, we plan to develop customized demand-prediction models by analyzing user opinions composed of unstructured data from social networks.

Acknowledgement

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Automatic incident detection along freeways using spatiotemporal Bluetooth data

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Abstract. Magnetic induction loop detector technology is considered as the traditional and reliable sensors for monitoring the traffic flow at freeways. These detectors are used to monitor traffic on freeways, and many automatic incident detection models have been developed based on this detector data. However, the magnetic induction loop detectors installation is complicated and expensive. This research focuses on a special group of cross-sectional sensors, Bluetooth readers, as a "low-cost" replacement for loop detectors. In this work, a novel deep-learning algorithm was developed to automatically detect incidents in an unsupervised fashion based on Geotagged Bluetooth readings only. Preliminary experiments show promising results in correctly detecting road incidents.

Keywords. Geotagged Big-Data, GIS-based urban analytics, Deep-learning, Automatic Incident Detection

1. Introduction

With the rise of the information era, cities start to integrate various physical devices (Internet of Things) to optimize the efficiency of city operations and services, and to connect citizens. These cities are commonly categorized as Smart Cities. Smart city technology allows city officials to interact directly with the city's infrastructure, and to monitor what is happening in the city. One of the critical needs for such interaction is transportation. In today's urban environment, the ability to forecast future traffic conditions, like travel time, speed and flow, are crucial. This is vital information not just for the benefit of traveler's route planning but also for city authorities who seek to know in real-time the reason for temporal congestion at a route node, whether it is a recurring congestion pattern or incident congestion.

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Automatic incident detection (AID) along freeways is a challenging task due to the prominent level of variance in traffic behavior. The needed data collection and its processing require expensive resources allocation for freeway sensor installation and for their continuous operating. Although radar and video detection technologies for traffic monitoring have been implemented in several urban transportation management systems, magnetic induction loop detector technology continues to be common (Williams et al., 2007), and for many years, they are considered as the traditional and reliable sensors for monitoring the traffic flow at freeways. However, the magnetic loop detectors installation is complicated and expensive.

This research focuses on a special group of cross-sectional sensors, which has the ability to receive data only from a sample of the vehicles at the cross-section and to re-identify these vehicles at other cross-sections over the traffic network. The type of sensors that this research will mostly refer to is the Bluetooth readers, since this is a relatively innovative technology for traffic sensing with a grown potential to have a high penetration rate: most navigation/entertainment systems in vehicles today are equipped with Bluetooth sensors, meaning that approximately 15-20% of all vehicles are documented in the Bluetooth reader network. Those sensors are easy to deploy, and their privacy issues can be addressed (Friesen et al., 2015). In this study we formulate the problem of incident detection as anomaly detection in Big-Data, and solve it with a deep-learning algorithm, DeepAID, we developed. Deep-learning is known to perform better than traditional machine-learning methods when it comes to large volumes of data, as will be presented in the promising preliminary results.

2. Methodology

Traffic incidents are anomalies compared to usual hour traffic, thus the problem of incident detection can be transformed into the anomaly detection problem. This means that it can be described as a task where the goal is to model the time-series data and, given this model, find regions where the predicted values are too different from the actual ones. Thus, the method developed in this research for AID for freeways is based on anomaly detection, known as an unsupervised learning methodology, and the use of the data provided by Bluetooth sensors. Such learning methodology does not require incident information (a.k.a. Labels) to train and build the model. The algorithm developed in this research, depicted in Figure 1, is based on CNP (Conditional Neural Process). CNPs are inspired by the flexibility of stochastic processes, such as Gaussian processes, but are structured as neural networks (Garnelo et al., 2018).

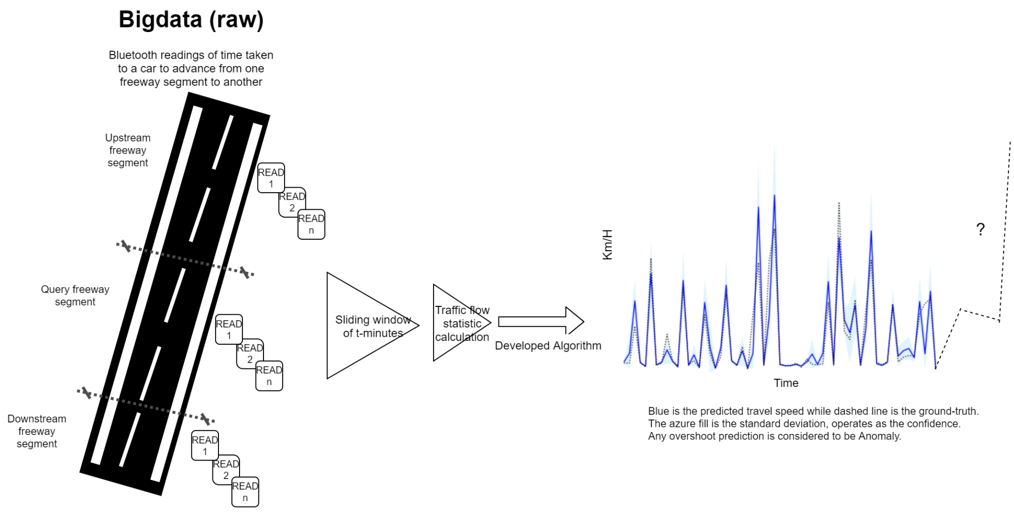

Figure 1. A high-level depiction of the automatic road incident detection algorithm.

The algorithm flow, depicted in Figure 1, is given as follows:

1) Raw samples (Travel Time) are bucketed into windows of size t-minutes.
2) Each window, i.e., context-point, is aggregated by its speed and the traffic flow. Spatiotemporal statistics are calculated, as follows:
    a. Time of the day measured in 1 minute time intervals, t.
    b. Velocity in query segment during the time interval t.
    c. Relative change of velocity in the query segment with respect to the previous time interval.
    d. Relative change of velocity with respect to upstream.
    e. Relative change of velocity with respect to downstream.
    f. Relative change of velocity with respect to upstream at the previous time interval.
    g. Relative change of velocity with respect to downstream at the previous time interval.
3) The inputs for the algorithm are C number of context points, at the current segment; supposedly, the more the context points the more confident model with the prediction.
4) The algorithm forecasts T number of target points (context-points in the future) with their confidence; any target point in the current segment that is out of the confidence interval is considered an anomaly. Since an overshoot anomaly exceeds the confidence interval, a consecutive set of overshoot anomalies is an unambiguous measure for an incident because incidents cause unexpected slowdowns. Figure 2 depicts an example of a consecutive set of overshoot anomalies, indicating a road incident at the red circle.

The algorithm exploits neural processes in a way that models Big-Data - like Bluetooth spatiotemporal sensory readings - in order to detect freeway incidents automatically. Some of the algorithm novelties include:

1) Not posed to pre-determined input or output lengths but offering dynamic input and output sizes.
2) Model interpretability – the model's output mean and STD velocity values are easy to visualize.
3) Unsupervised training methodology (no labels are needed).

3. Preliminary Results

The algorithm was tested and analyzed on real traffic data collected by Bluetooth sensor readers placed along the Ayalon Highway, Tel-Aviv, Israel. The freeway traffic flow was aggregated by its raw speeds [km/hour] measured by the Bluetooth sensors in time-windows of size 1 minute. The data were collected during August 2017, and corresponds to an 11 km segment that is divided into 7 sections, quantified in millions of Bluetooth readings. Respectively, some traffic incidents during that month were recorded by the freeway operator, and were used to assess the algorithm quality in automatically detecting road incidents. The algorithm analysis was performed on several case studies, the most important one depicted in Figure 2, using 5 central cross-sections due to the need for data corresponding to the downstream and upstream sections. In Figure 2, the green line corresponds to the algorithm input (context, ground truth); the blue line depicts the algorithm output (context and target prediction); the dashed black line depicts the ground truth speed flow; the light blue buffer depicts the prediction confidence (in STD). It is apparent that the developed algorithm qualitatively models anomalies with high confidence values, clearly showing road incidents.

4. Conclusions and Future Work

This research presents an algorithm that structures spatio-temporal descriptors as neural-networks, DeepAID, to mine and interpret road incidents by learning to differentiate between the normal to the abnormal. This algorithm opens new opportunities in road incident detection based on travel time and other spatiotemporal data. It shows that Bluetooth sensors can be used to automatically detect road incidents on freeways without the use of other data. Further research is required in order to model trends in time more precisely.

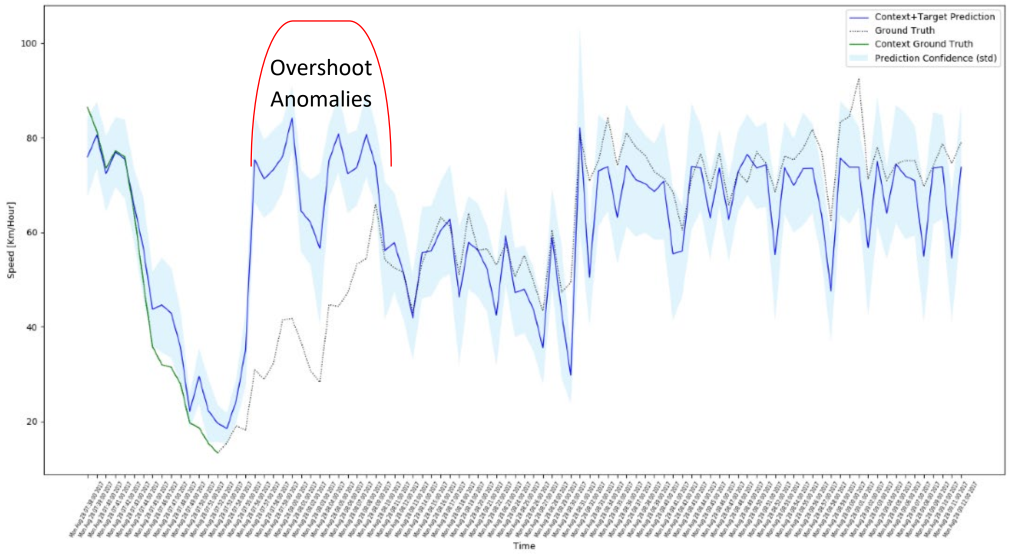

Figure 2. Automatic road incident detection and model generalization – the algorithm detects an incident (in red) caused by car accident along a testing freeway segment. The traffic slowdown afterward is reflected with consecutive set of overshoot anomalies. Moreover, it successfully models and predicts traffic flow on never-seen freeway segment data.

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Time-distance Accessibility of Public Transport considering In-vehicle Crowding based on Smart card data

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Abstract. In this study, we propose the time-distance accessibility of public transport considering in-vehicle crowding. It is an indicator that measures how easy to reach other areas by travel times. The time-distance includes not only general factors such as in-vehicle time, out-of-vehicle time, and transfer penalties but also feelings of exhaustion due to in-vehicle crowding level. The crowding was computed by smart card data. We analyzed the accessibility of public transport in the Seoul city by using the proposed index.

Keywords. Public transport, Accessibility, Time-distance, Smart card, Crowding

1. Introduction

The time-distance accessibility is an indicator that measures how easy to reach other areas by travel times (Lee et al. 2014). The time-distance of public transport includes in-vehicle time, out-of-vehicle time. It may include psychological burden caused by transfer called transfer penalty. Some studies have shown that passengers experience longer travel time than their actual travel time if the crowding level in a vehicle is high (Wardman & Whelan 2011, Tirachini et al. 2013, Jenelius 2018).

In this study, we propose the time-distance accessibility of public transport considering in-vehicle crowding. As the automated fare collection system was introduced and the use of smart cards became common, the calculation of the number of passengers in a vehicle became easier. We computed

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crowding level of each vehicle using smart card data, and analyzed the time-distance accessibility of public transport in the Seoul city.

2. Methodology

The time-distance accessibility considering in-vehicle crowding is defined as Eq. 1. The A_i is a accessibility of zone i, T_{ij}^* is a relative time-distance from zone i to j, n is the total number of zones.

$$A_i = -\sum_{j(j\neq i)}^{n} T_{ij}^* \qquad \text{Eq. 1}$$

The time-distance T_{ij} is composed of the sum of the total in-vehicle time T_{ij}^{In}, total walking time T_{ij}^{Walk}, total waiting time T_{ij}^{Wait}, and total transfer penalty T_{ij}^{P}. The total transfer penalty is calculated by multiplying the number of transfers by the time value of the psychological burden.

$$T_{ij} = T_{ij}^{In} + T_{ij}^{Walk} + T_{ij}^{Wait} + T_{ij}^{P} \qquad \text{Eq. 2}$$

The relative time-distance T_{ij}^* is the deviation of T_{ij} from the average time-distance $\bar{T}_{X^k}$ of all (o,d) pairs within the same distance class with (i,j). The (o,d) set X^k is classified by the integer distance class k calculated by rounding off the distance function $\ell(o,d)$.

$$T_{ij}^* = T_{ij} - \bar{T}_{X^k}, \quad (i,j) \in X^k \qquad \text{Eq. 3}$$

$$X^k = \{(o,d) \,|\, \lfloor \ell(o,d) + 0.5 \rfloor = k\}, \qquad k \in \mathbb{Z} \qquad \text{Eq. 4}$$

If the relative time-distance from zone i to j is negative, it means that the travel time of (i,j) is faster than the average travel time of same distance class. Therefore, the smaller the relative time-distance, the higher the accessibility.

The total in-vehicle time T_{ij}^{In} including crowding is shown in Eq. 5. It is calculated by multiplying an in-vehicle time $t_{ij,m}^{In}$ for each route by a time multiplier $\beta_{ij,m}^{In}$ according to the crowding level of that route m.

$$T_{ij}^{In} = \sum_m (\beta_{ij,m}^{In} \times t_{ij,m}^{In}) \qquad \text{Eq. 5}$$

Table 1. An example of smart card data.

Card_ID	Boarding_time	Boarding_Stop_ID	Arrival_time	Arrival_Stop_ID	Route_ID	Vehicle_ID
1	07:00	100	07:20	200	1000	1
2	07:10	100	07:30	200	1000	2
3	07:00	100	08:00	500	1000	1

The crowding level is calculated using smart card data. The smart card data store records of individual passengers such as boarding / arrival time, station and vehicle. The *table 1* is an example of smart card data. Passengers 1 and 2 arrived at station 200 using route 1000 and passenger 2 used the next vehicle of passenger 1. Also, passengers 1 and 3 used the same vehicle, and passenger 3 stayed longer in that vehicle.

The occupancy of each vehicle can be calculated, and dividing by the capacity can calculate the crowding level. However, unlike the occupancy of bus, the calculation of occupancy of subway is complex. This is because the tagging of smart card in the subway takes place on platforms, not on vehicles. We are currently studying a methodology for estimating the occupancy of subway.

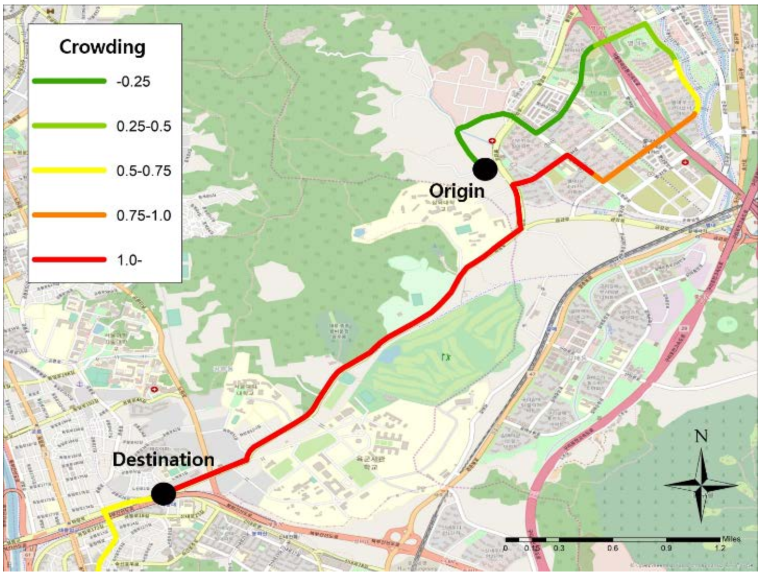

Figure 1. The crowding in a specific bus route at the morning peak in Seoul city.

3. Results

Due to the limitation of estimating the number of passengers in a train, we analyzed the time-distance accessibility in Seoul city which does not reflected in-vehicle crowding. The time-distance of (o, d) is the minimum travel time, and the penalty for a transfer is 5 minutes. We analyzed about 120 million all-to-all public transport route.

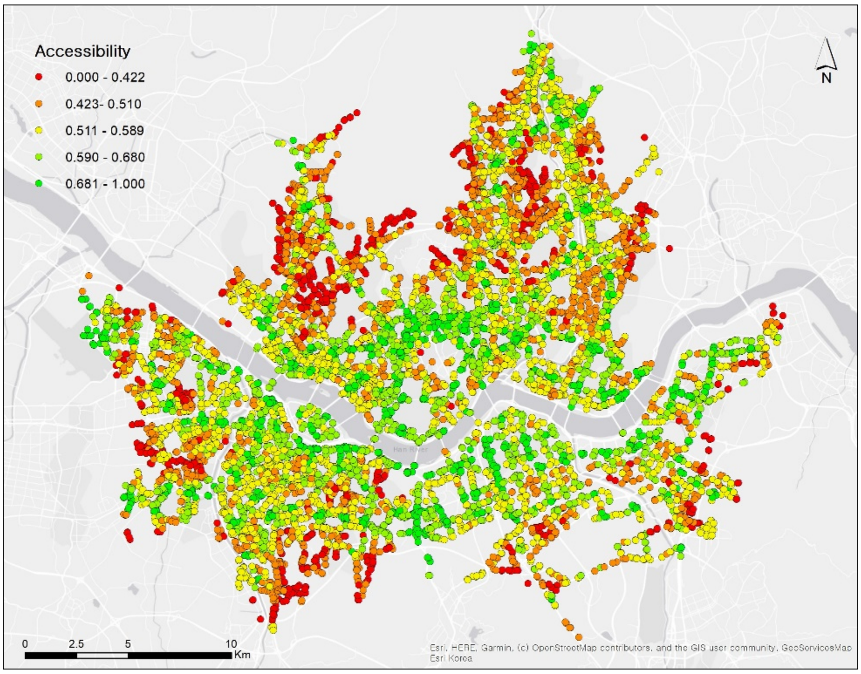

Figure 2. The time-distance accessibility of each transit stops in Seoul city.

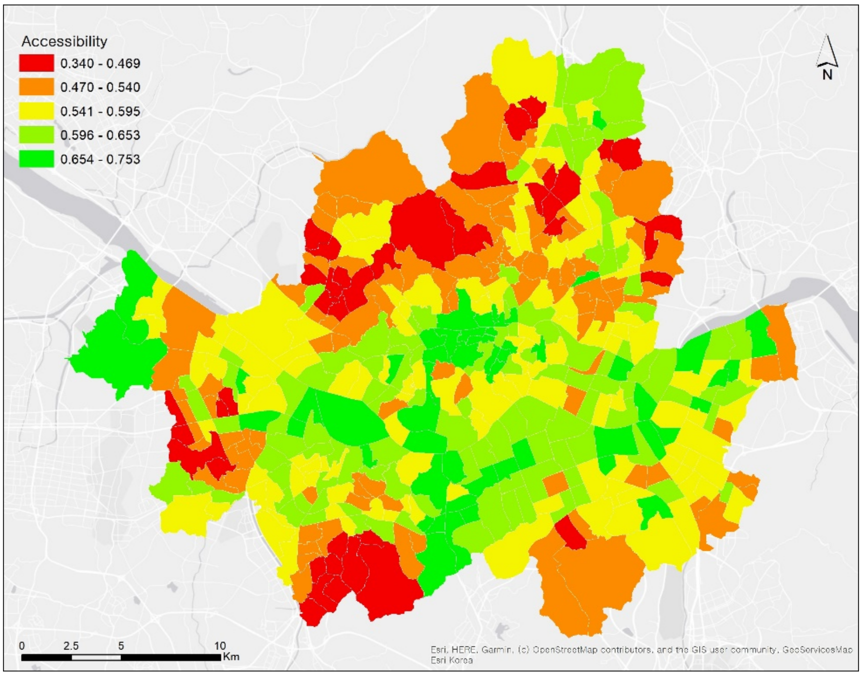

Figure 3. The time-distance accessibility of each administrative areas in Seoul city.

The *figure 2* shows the accessibility of each transit stops. The accessibility was normalized between 0 and 1. Thus, a stop that can be quickly moved to all other stops has accessibility close to 1. High accessibility appeared in the major urban centers and subway influential areas. Highly accessible stops were formed along the subway lines. Low accessibility was mostly analyed in the northern areas rather than the southern areas. In particular, accessibility was poor in areas with low land prices. The *figure 3* shows the accessibility of public transport by administrative district.

4. Conclusions

In this study, we proposed the concept of time-distance accessibility index that contains the in-vehicle crowding based on the smart card data. It is possible to analyze the accessibility based on the travel time experienced by the passengers. In future work, we plan to estimate the number of passengers in a subway, and consider GIS data such as population and land use.

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A Simulation Method for Adjustment of Public Transportation Routes using Geotagged Smart Card Data

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Abstract. In most studies on adjusting public transportation routes, passengers' behavior is identified through surveys, and travel demand is forecast by traffic zone. In recent years, passenger's travel information such as stops, routes, and boarding times have been stored through automated fare collection(AFC) systems, and studies are being conducted to utilize them. So, we proposed a simulation method of public transportation routes adjustment using smart card data. And then we used an actual bus adjustment case to verify the proposed simulation method.

Keywords. Geotagged smart card, Public transportation, Route adjustment

1. Introduction

An adjustment of public transportation routes is carried out in consideration of various interests, including users, operators and administrators (Yun 2018). Related studies on route adjustment have been analyzing passengers' behavior based on survey and forecasted travel demand by units of traffic zone such as administrative areas (Tsekeris & Tsekeris 2011, Briem et al. 2017). Since the use of smart cards has become more common, it has become easier to obtain travel information for individual passengers (Djavadian & Chow 2017, Liu et al. 2019). Therefore, recent studies have been trying to adjust public transportation route at a more microscopic level. In this study, we proposed a method of simulating public transportation routes adjustment. It can analyze changes before and after the route adjustment with quantitative indicators using personal travel information recorded on the smart card.

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The simulations are conducted in the order of GUI-based network editing, transit assignment and effect analysis. To verify the proposed simulation method, we used the actual bus adjustment case in Seoul city

2. Methodology

2.1. Smart card data

Smart card data are generated when passengers tag their cards to terminals while riding and alighting the vehicle. *Table 1* shows an example of smart card data. Since smart card data store passenger's travel information such as stops, routes and boarding time, it is possible to know which route passengers were at a certain time and which stop they were waiting at. In addition, if we analyze passenger's travel on a daily basis, we can predict the travel patterns and trajectories of passengers

Table 1. An example of travel information in smart card data

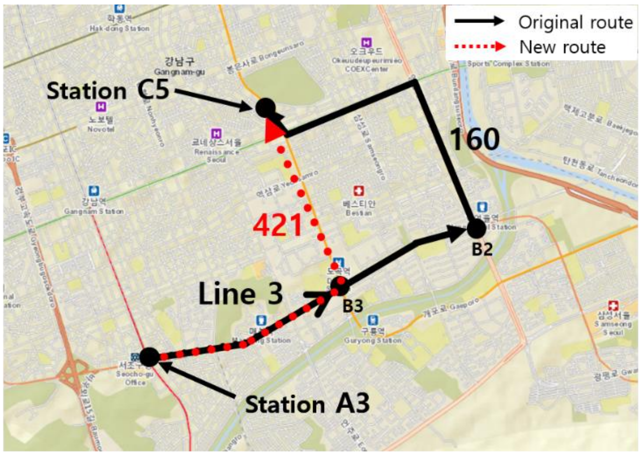
Passenger ID	Passenger Type	Ride Station	Ride Time	Alight Station	Alight Time	Routename
1	Adult	A3	08:07	B2	09:03	Line 3
1	Adult	B2	9:06	C5	09:15	160
2	Student	A4	15:33	C2	16:09	8863

2.2. Simulation method for public transportation routes adjustment

The purpose of the public transportation route adjustment simulation is to predict how passenger's travel time and operation cost change according to route adjustment plan. We assumed that the travel demand recorded in the smart card data is current demand and calculated how this demand will change after adjustment. For this purpose, we carry out three steps. The first step is to change the transit network such as stops, routes, timetables according to the route adjustment plan. At this stage, the route adjustment planner creates a new public transit network through the GUI, changing the order of stops on the route, the headway of bus, and so on. The second step is traffic assignment to new created network. In short, it is to estimate which stops and routes will use by the passengers on the smart card after the new networks are created. The detailed description will be further explained in Section 2.3. The final step is to calculate the change in demand by route, the reduction in travel time and the change in operating costs before and after the adjustment of the routes. We developed a simulator that can do all of this, and then used it to simulate.

2.3. Transit assignment based on smart card data

Smartcard data includes travel information that has been moved through current public transportation network. However, since we do not know how passengers will move in the newly created network, we need to estimate the route to use based on smart card data. First, only the passenger's departure stop, arrival stop and departure time are extracted from the smart card data, and all other information is deleted. Then, we input into the path finding algorithm the O-D(Origin-Destination) and departure time of passengers extracted from the smart card data to estimate passengers' path. The algorithm searches for the minimum travel time path from the origin to the destination according to the departure time based on the timetable, and we use it to calculate the minimum travel time path for all passengers. Figure 1 shows a simple example of estimating a passenger's path in new transit network. Figure 1 (a) shows the travel information recorded on the smart card and travel trajectory is represented by a solid line on the map. If bus No. 421 was newly



(a)

Passenger ID	Departure Station	Transfer Station	Arrival Station	Departure Time	1st Routename	2nd Routename
1	A3	B2	C5	08:07	Line 3	160

(b)

Passenger ID	Departure Station	Transfer Station	Arrival Station	Departure Time	1st Routename	2nd Routename

Figure 1. An example of transit assignment after routes adjustment

established, we input the passenger's departure stop(A3), arrival stop(C5) and departure time(08:07) into the algorithm. Then, as shown in Figure 1 (b), it is estimated that different transfer stop(B3) is used and the route using bus 421 instead of bus 160 is used. passengers choose No. 160 bus, which is by-passed because there is no alternative route, but after route adjustment, they will probably choose a path that took No. 421 directly to the arrival stop.

3. Simulation results

To verify the methodology of this study, simulation was conducted based on the case of the established new bus line. The target of the case is the new bus line No.1167, which was established August 2018. About 1 million people who stored on smartcard data on October 12, 2017 were simulated, and the simulation results were compared to the average daily usage of the No.1167 bus in May 2019. Figure 2 shows a comparison of the number of passengers by stops in simulation and No.1167 bus. The solid line is the actual number of passengers, the dotted line is the number of passengers in the simulation results, and the horizontal axis means the order of stops along the bus line. As a result, we confirmed that the actual demands and the simulation results were very similar. Also, comparing the daily average number of passengers on the new bus line with simulation results, the simulation was forecast at 1,724 and the actual number of passengers was 1,696. As a result, the number of passengers per stops on the new route came out similar to the actual demand, and other routes also were derived very similar to the actual demand.

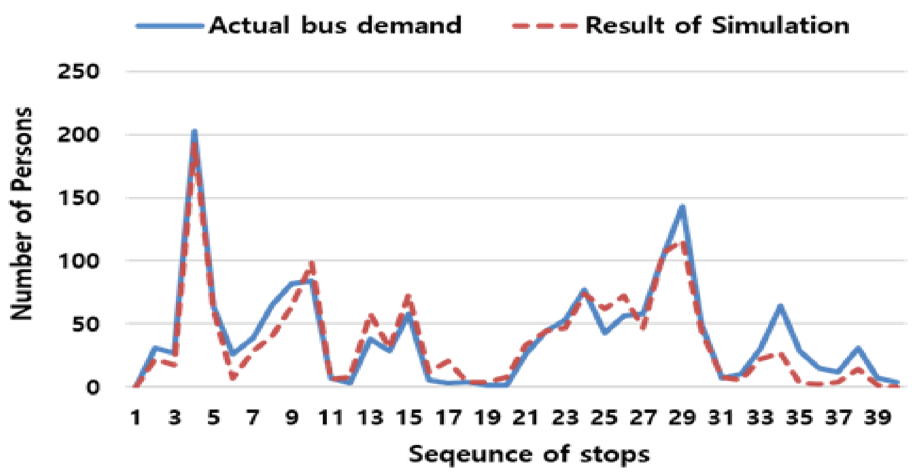


Figure 2. Comparison of the number of passengers by stops in simulation and No.1167 bus

4. Conclusion

In this study, we proposed a simulation methodology that analyzed the effects before and after routes adjustment using the smart card data which recorded the travel information of public transportation passengers. The simulation results applied to actual route adjustment case were very similar to the number of passengers in actual bus line by stops. In later studies, we plan to verify the simulations in more diverse scenarios.

Acknowledgement

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Spatial interpolation of mobile positioning data for population statistics

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Abstract. Mobile positioning data has been mentioned in many agendas as a new input for official statistics. In current paper, we compared four different spatial interpolation methods of mobile positioning data. Best results to describe the population distribution appeared with adaptive Morton grid model where the R^2 was 0.95. Widely used point-in-polygon and areal-weighted interpolation gave much weaker results ($R^2 = 0.42$; $R^2 = 0.35$).

Keywords. Mobile positioning, Population statistics, Spatial interpolation

1. Introduction

Many agendas and strategic plans are mentioning mobile positioning data (MPD) as a potential new smart data source to produce official statistics and enhance data-driven governance. MPD are used more and more to study the placement and mobility of population (e.g. Ahas et al., 2010, Deville et al., 2014). However, MPD also introduce problems, uncertainties and representativeness issues related to sample and spatiotemporal accuracy.

Current paper is focusing on the spatial interpolation of MPD, specifically, how to convert data from discrete antennae locations to meaningful spatial units (i.e. administrative units) or grid. We compare four spatial interpolation methods and extrapolate the data to the general population, which allows to evaluate the goodness of different methods by comparing the results with census data.

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2. Theoretical Overview

Mobile phone data have been applied to study human mobility behavior since the early 2000s. In the last decade, the number of studies using MPD has increased significantly. Despite the rapid increase in studies using MPD, there are only few papers that focus on the problems associated using MPD in population research (Williams et al., 2015) and how to minimize them.

Main problems and uncertainties of MPD are related with sample, time, space, differences in data types, and spatial interpolation. In current study, we focus on the spatial aspects of interpolation of MPD. Most common location information of MPD are the discrete locations of antennae which radio coverage areas are presented through Thiessen tessellation. This assumes that signal strengths of the antennae are uniform and do not overlap. However, in real life the situation is much more complicated and the statistics produced with Thiessen polygons or other simplistic interpolation methods (i.e. point-in-polygon) tend to create areas where population count is strongly over- or underestimated.

There are several studies that have tried to overcome the bottlenecks of spatial accuracy of MPD and uneven spatial distribution of network using more complex models or including additional contextual data (e.g. Ricciato et al. 2015, Järv et al. 2017). But they focus on densely populated areas. In addition, extrapolation of results from the level of subscribers of MNOs to the whole population is missing in many cases, and researchers only bring out correlations, trends and/or coefficients, but no real numbers (e.g. Järv et al. 2017). In the following chapters we describe the essence of different spatial interpolation techniques and compare the outputs with census data.

3. Methodological Framework

3.1. Data

Mobile positioning data covers a wide range of different datasets. In the current study, CDR (call detail records) data have been used. It is a set of log-files collected by mobile network operators to collect information about billable calling services used by their clients. CDR data covers the year 2011 and is collected by one of the biggest mobile operators in Estonia. Monthly average number of unique ID-s is approximately 405 000 (ca ⅓ of Estonian population). For interpolation we use the meaningful locations (place of residence, daytime location, etc.) detected from anchor point model developed by Ahas et al., (2010). In addition to MPD, census data from the same year is used to compare the population size in municipalities (n=226).

3.2. Spatial Interpolation Methods

Point-In-Polygon (PIP)

Point-in-polygon method has been used surprisingly often for spatial interpolation. The reason for this is obviously the simplicity of the method: statistics calculated for mobile antennae are assigned to the spatial units (e.g. municipalities) within which specific antenna is located. This method can work only for cases where the density of mobile antennae and the size of spatial units are at the same scale (or spatial units are bigger than theoretical coverage areas of antennae), otherwise, the output contains a lot of units where the value is zero because there are no antennae present in the borders of specific unit.

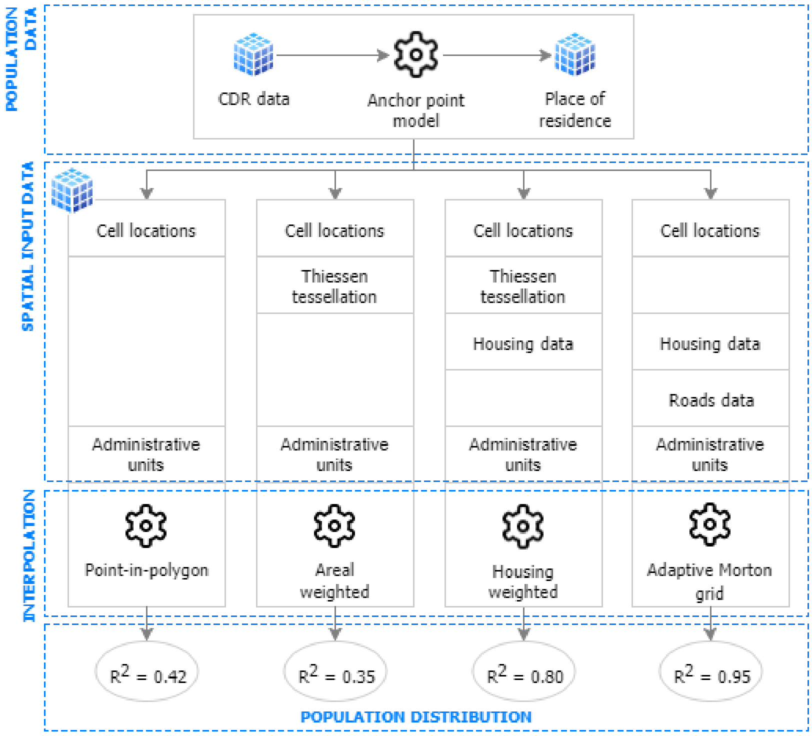

Figure 1. Workflow of spatial interpolation of mobile positioning data.

Areal weighted interpolation (AWI)

Areal weighted interpolation tries to take into account also the radio coverage areas of antennae. Statistics calculated for antennae are assigned to the Thiessen polygons of mobile antennae and those polygons are reaggregated to the level of desired spatial units (e.g. municipalities). The aggregation is based on areal share of theoretical area covering the polygon of municipality (e.g. if 50% of the area of Thiessen polygon covers the polygon of municipality then also 50% of the calculated value is assigned to the specific municipality). Compared with PIP the main advantage of this method is the fact that it avoids white spots and every polygon has a value. At the same time the problem is that in reality the population is not evenly distributed in space.

Housing weighted interpolation

This method works in principle the same as the AWI. The only difference is that the geospatial layers of municipalities and Thiessen polygons are overlaid with the housing layer. The assignment of values is not based on the area, but the number of buildings in specific part of Thiessen polygon.

Adaptive Morton grid interpolation

One possibility to achieve greater accuracy is to use probability surfaces like land use. People are mostly in houses or on roads and much less likely in the forests. In order to use the land use probability surface, it is better to use reference grid by dividing the territory into smaller units. One possibility to achieve a homogeneous layer is to divide the space into grids in the designated coordinate system (Morton, 1966). We are using customized Morton grid system that we call adaptive Morton grid and it is adaptive in a way that the size and the level of the grid is dependent on how many people are probably using it. Probabilities calculations are based on housing and roads densities. In cities, the grid cell size is smaller and in natural areas larger. After we have generated a grid for a country then we will assign all call activities into the grid cells based on indices, and the proportion of coverage area intersecting the specific grid. To estimate the goodness of described interpolation methods (Figure 1), we compared our results with the census data using linear regression models.

4. Results

The results from analysis confirmed initial expectations, explanatory power of point-in-polygon model is rather low ($R^2 = 0.42$). Biggest problems are in municipalities without any mobile antennae. Areal-weighted model is even worse than point-in-polygon model ($R^2 = 0.35$). Although the model is able to avoid white spots, the variance of predicted values is even greater than for the PIP method. The results of the housing-weighted model are much better ($R^2 = 0.80$). Predicted values are considerably closer to the model line and only for a few municipalities, the difference between census and predicted population is strongly biased. In case of adaptive Morton grid, that also takes into account the values of population probability, the results improve even more (Figure 2). In this case, the R^2 is 0.95.

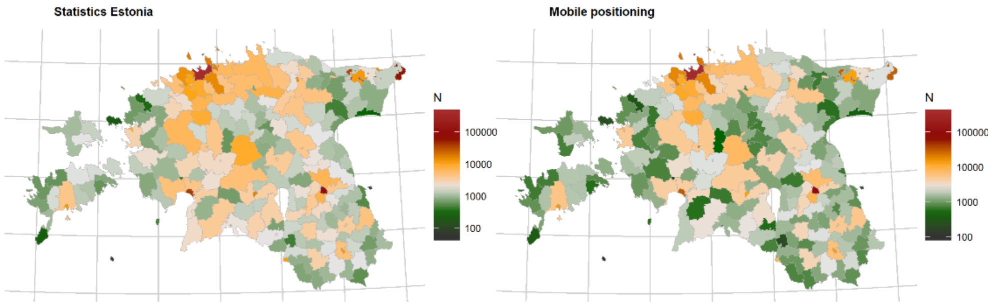

Figure 2. Population distribution according to the Census (left) and mobile positioning data based on adaptive Morton grid method (right).

5. Conclusion

Current analysis demonstrates the weakness of frequently used methods like point-in-polygon and areal-weighted spatial interpolation. We show that using the housing layer improves the output remarkably. Another qualitative leap forward comes with adaptive Morton grid.

6. Acknowledgements

The data used in this study was provided by the Estonian Research Infrastructures Roadmap object „Infotechnological Mobility Observatory" (IMO). Study is funded by Estonian Research Council project PUT PRG306.

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Areal interpolation of spatial interaction data

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Abstract. Spatial interaction data, such as commuting flows, are important for many purposes but they often come expressed for a different set of spatial units than required. This happens when comparing data from multiple censuses but especially when cell phone positioning data are involved. This study aims to develop a more accurate method to areally interpolate spatial interaction data to a different set of spatial units and test it on cell phone data-derived commuting flows for Estonia.

Keywords. areal interpolation, interactions, flows

1. Introduction

Data about spatial interactions, such as counts of people commuting between given pairs of places, are important for almost any area of spatially related decision making – they are used to assess demand for social events (Calabrese et al., 2010), model transport network utilization (Bolla et al., 2000), improve disaster response (Bengtsson et al., 2011), study social networks and segregation (Silm & Ahas, 2014) or delimit functional regions to inform administrative divisions (Martínez-Bernabeu et al., 2012).

However, the most fruitful source of spatial interaction data today, cell phone networks, where real mobility behavior of their users is recorded through collection of network traffic data, do not yield data in a readily usable form – they are defined on an unsuitable support, namely that of mobile phone network coverage cells. These usually map poorly to the real settlement network, sometimes with multiple cells covering parts of the same central place as well as outlying rural settlements (see *Figure 1*). To make use of the data, we need to solve the *change of support problem* (COSP)

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and transfer to a different set of spatial units depending on the use case – e.g. administrative units of a chosen level or regular grids.

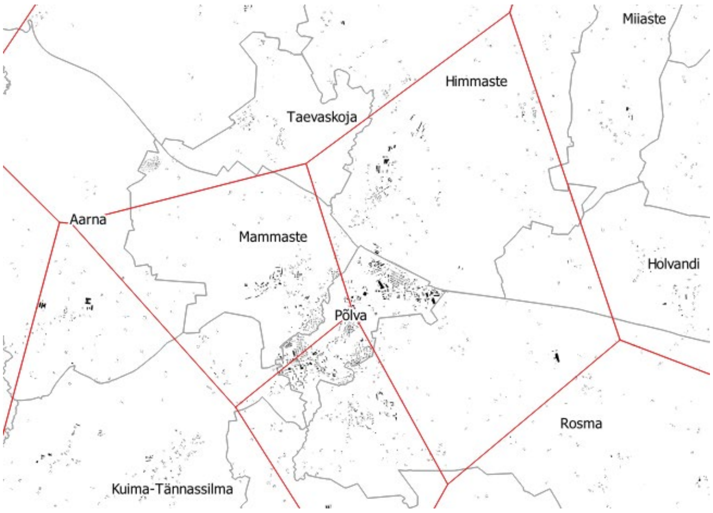

Figure 1. Support mismatch between mobile network cells (red) and territorial communities (kandid; gray) around the Estonian town of Põlva.

COSP is most often encountered for static (non-interaction) data (Gaughan et al., 2015) and solved by *areal interpolation* (Goodchild & Lam, 1980); an example for cell phone stay data was presented by Järv et al. (2017). For interaction data, some limited attempts were made for the purpose of temporal comparison of commuting data across censuses (Boyle & Feng, 2002; Jang & Yao, 2011) due to administrative division changes; however, these methods were primarily suited to small area adjustments, whereas cell phone networks, completely different in both scale and extent of its units, have to the best of our knowledge not been studied in this regard yet.

This article proposes to extend the method from the above studies to account for these differences and presents an example on the Estonian cell phone network.

2. Methodology

2.1. Static areal interpolation

Areal interpolation is a method more widely applied for static quantities such as population densities or various demographic indices. They usually work by computing a *transfer matrix* $T_{i\alpha}$ which determines which fraction of the value for a given *source* area i (in our case, a mobile phone network cell) is to be transferred to a given *target* area α (in our case, an administrative unit). The matrix is usually zero except for intersecting pairs of units, where the entry is given by a measure of their overlap. The values must be nonnegative and $\sum_\alpha T_{i\alpha} = 1 \; \forall i$ (the *pycnophylactic property* that ensures the sum of all interpolated values remains the same).

In the elementary case (so-called *areal weighting*), the entries of the transfer matrix are given by the fraction of area of the source unit covered by the given target unit. However, the method described below works with any valid transfer matrix, such as one generated by more sophisticated *dasymetric mapping* techniques, which weigh areas differently according to their properties, such as land cover (Gallego et al., 2011) or (more appropriately for our purpose) population density (Monteiro et al., 2018).

The values for the target units v_α are computed using the transfer matrix $T_{i\alpha}$ from the source values v_i:

$$v_\alpha = \sum_i T_{i\alpha} v_i$$

2.2. Spatial interpolation of interactions

For interaction values r_{ij} (which represent e.g. the number of people commuting between source areas i and j), the situation is a bit more complicated. The easiest solution would be to apply the transfer matrix twice, once for the *origins* i and once for the *destinations* j of the interactions:

$$r_{\alpha\beta} = \sum_i \sum_j T_{i\alpha} T_{j\beta} r_{ij}$$

This is the form used by Boyle and Feng (2002). Although Jang and Yao (2011) also investigated more sophisticated approaches such as gravity modeling, they found them less accurate than this one, supposedly because additional complexity brought by those models is already embedded in the data itself.

The method is simple and seems to produce good results overall (provided the transfer matrix is accurate) except for the case of self-interactions (where $i = j$ or $\alpha = \beta$). In the case of commuting, self-interactions represent non-commuters, people that live and work in the same spatial unit. Self-interactions tend to be generally underestimated when a source area is split into more target areas because the weighing equation assigns too much of the originally static activity (self-interactions) to interactions between the target areas, generating artificially high interactions between units covered by the same cell (see *Figure 2*).

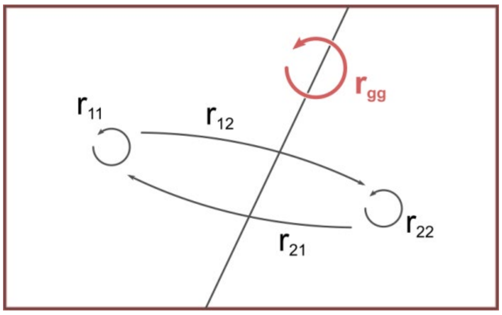

Figure 2. A self-interaction of a source unit r_{gg} is to be redistributed to two target units, both to their self-interactions r_{11}, r_{22} and to interactions between them r_{12}, r_{21}.

2.3. Modification for self-interactions

A slight modification to the above formula can cause it to have more source self-interactions redistributed into target self-interactions. This would be done using a *self-interaction parameter* $\eta \in [0;1]$ that signifies the fraction of source self-interactions to be a-priori allocated only to target self-interactions:

$$r_{\alpha\beta} = \sum_i \sum_{j\neq i} T_{i\alpha} T_{j\beta} r_{ij} + \sum_i T_{i\alpha} \left[\delta_{\alpha\beta}\eta + (1-\eta)\, T_{i\beta} \right] r_{ii}$$

where $\delta_{\alpha\beta} = 1 \Leftrightarrow \alpha = \beta$ (self-interaction) and 0 otherwise.

The larger the value of the η parameter, the more the target units will be isolated (more self-interactions of source units will be redistributed to self-interactions of the target units and less to interactions between them). Setting $\eta = 0$ reduces the equation to the simple form from *2.2*, $\eta = 1$ means self-interactions will only be redistributed to self-interactions (not mutual interactions). To satisfy the pycnophylactic property, η has to be constant across any given source area i.

2.4. Estimating the self-interaction parameter

The question is how to get to the value of η that is appropriate for a given settlement system or its individual units (because its value can be varied across different source units according to their characteristics).

A way to get to the value of η using only the data to be interpolated is through simulated aggregation – we merge a few adjacent source units a (two or three as that is generally the amount of units significantly overlapping one source unit) into one (g) and measure what η should be for that breakdown. For this, we use their actual interactions r_{ab} compared to the total aggregated self-interaction $r_{gg} = \sum_{(a)} \sum_{(b)} r_{ab}$, using the relative marginal sums in place of transfer weights from ($T_{ag} = r_{ag}/r_{gg}$). The η_g for the grouping is then computed as a mean of values generated by the internal interaction matrix, weighted by the absolute interaction values:

$$\eta_g = \sum\nolimits_{(a)} \sum\nolimits_{(b)} \frac{r_{ab}}{r_{ag} r_{gg}} \frac{r_{ab} r_{gg} - r_{gb} r_{ag}}{\delta_{ab} r_{gg} - r_{gb}}$$

Then, the question is how to compute η for any set of source areas for which the areal interpolation is attempted. The simple approach undertaken here is to use a single value for η across the whole system. We can obtain its value by a weighted global mean:

$$\eta = \frac{\sum_{(g)} \eta_g r_{gg}}{\sum_{(g)} r_{gg}}$$

A more advanced approach would take into account distinctions across source areas.

3. Validation

3.1. Data

We tested the proposed approach on areal interpolation of commuting interaction data generated from the Estonian cell phone network, which provides information about the home and work anchor points (Ahas et al., 2010) of each mobile network user; commuting interactions were then derived by summing users having home and work anchors respectively in the given pair of mobile network cells.

The interpolation was performed from the level of mobile network cells to that of Estonian municipalities and the results were compared to the census-derived dataset for the comparable period, 2011, which were considered ground truth. For comparison, the interpolated commuting interactions were multiplied by a coefficient to match their overall sums to the census figures; this is necessitated by the fact that the mobile network data only capture a segment of the population according to the network operator's market share.

3.2. Estimating the self-interaction parameter

Using the approach in *2.4*, we computed the η_g values for all pairs of neighboring cells. There seem to be significant differences between the η_g in different areas as depicted in *Figure 3*.

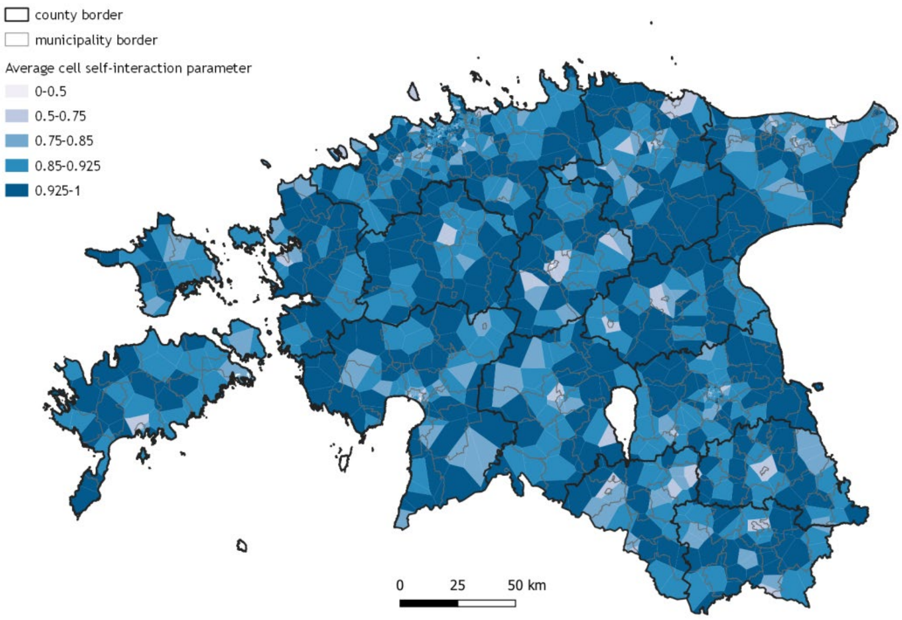

Figure 3. Self-interaction parameter η_g values across Estonian mobile network cells. The value for a given cell is a weighted mean of all its neighbor pairs.

η_g is usually significantly larger in rural Estonian areas than in urban ones, hinting at a lower degree of interaction there. Lower η_g can be found in cells with non-compact shapes that share long borders with neighboring cells whose centroids are close by. Also, lower η_g is observed around mid-sized settlements. Using the global mean estimation method yielded $\eta = 0.865$ with a mean absolute error (MAE) of 0.102.

3.3. Areal interpolation

We examined the effect of different values of η on the interpolated municipal interactions, performing the interpolation with values varying across the $[0; 1]$ range and comparing the result with the census-derived interactions. The share of self-interaction volume in the result increased linearly from 70.2% at $\eta = 0$ to 75.1% at $\eta = 1$. *Figure 4* shows the effect on the correspondence of the interpolated interactions with the census-derived interactions as measured by relative total absolute error (RTAE):

$$RTAE = \frac{\sum_{(\alpha,\beta)} |r_{\alpha\beta} - c_{\alpha\beta}|}{\sum_{(\alpha,\beta)} c_{\alpha\beta}}$$

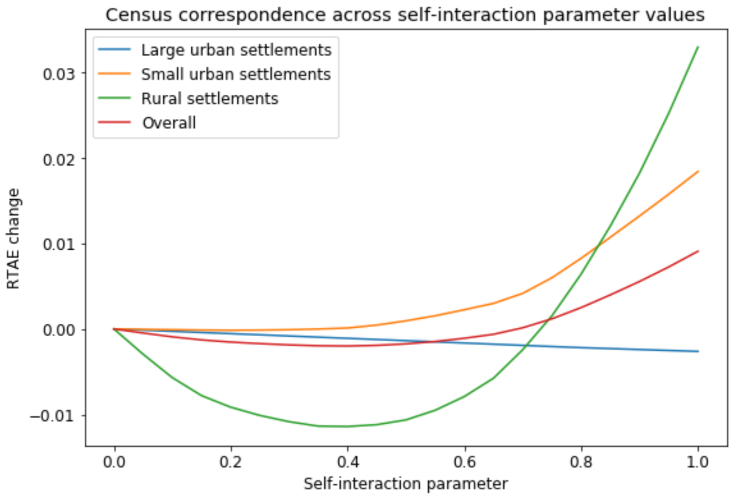

Figure 4. Correspondence of interactions interpolated from source self-interactions with census data, across different settlement classes and self-interaction parameter values.

It seems that overall, greater correspondence with census interactions is achieved at a lower but non-zero value of η in this case, although the differences are rather low. However, within different categories of settlements (rural settlements below 1 000 census commuters, large urban settlements over 20 000 and small urban between these bounds), very different values of η might be appropriate. Therefore, the development of a model that would be able to estimate η for each source area independently could increase the interpolation accuracy further. The global mean value shows itself not to be a suitable estimator in this case, perhaps because it is computed on a higher level (source area aggregations) and therefore tends to minimize the error for larger areas.

4. Conclusion

We suggested an improvement to a commonly used method for areal interpolation of interaction data by Boyle and Feng (2002) with respect to self-interactions that normally tend to produce interpolation artifacts. The method does not require additional data. Using a globally calibrated self-interaction preference parameter η to control self-interaction assignment, a small improvement in accuracy is achieved. An option to increase accuracy further by calibrating the parameter locally is proposed as a further research direction. The method presented here works for spatially extensive variables such as counts of commuters, but it can be easily adapted to spatially intensive variables such as modal split fractions by switching from sums to weighted means.

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Automatic Floor Matching for 3D Indoor Spatial Modeling

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Abstract. With the advent of a variety of indoor location-based services, the necessity of 3D indoor model construction has become a significant issue worth noting and following. The aim of this study is to propose an algorithm of floor matching to construct a multi-floor building model. In this case, the characteristics of shape and position of lift features are used to search matched pairs in the algorithm. In addition, the vertical connectivity information also can be generated through the process. The proposed algorithm was applied to the Seoul National University Library to verify its suitability. In the case of a high-rise building, it is expected that a multi-floor building model can be constructed efficiently by automatically aligning the data generated per each floor through the method developed in this study.

Keywords. Floor Matching, Floor Alignment, Vertical Connectivity, 3D Indoor Spatial Model

1. Introduction

As various location-based services of indoor are being provided, demand for three-dimensional indoor spatial information is steadily increasing. In fact, various studies have been carried out to generate a 3D indoor model such as with the use of geometric models or networks by utilizing CAD, scanned floorplans, or sensor data such as laser and LiDAR. Prior research related to the 3D indoor spatial information can be categorized into two categories: first, limited information is generated for single floor, and second, multi-floor buildings are reproduced by overlapping after data is built by layer (Dosch et al. 2000, Karas et al. 2006, Boguslawski & Gold 2016).

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Broadly speaking, the floorplans in various formats are drawn separately by floor, and sensor data can be collected per floor. Therefore, for the establishment of a 3D indoor model for multi-floor buildings, the data generated by each floor must be aligned vertically, and two or more inter-floor matched points and areas are required. Previous studies of multi-floor building modeling have been targeted at buildings with nearly the same floor shapes (Jamali et al. 2016, Zhu et al. 2013, Dosch & Masini 1999). In actual cases, the floor shapes of multi-story buildings can be identical, the upper floor may occupy only a portion of the lower floor, or floors may have completely irregular shapes. In such cases, the alignment of data by the floor is a complex problem, and even the use of manual alignment may also be limited without a basic knowledge of the building. Dosch & Masini (1999) developed the algorithms for matching floors using features of corners, staircases, pipes, and bearing walls as nodes. They configured the compatibility graph using nodes on the condition that the confidence rate is smaller than the fixed threshold. However, there is a limitation in that it is applicable only when the size of the building is small and the shape of the building is similar. In addition, Zhu et al. (2013) aligned data, built by floor based on a 2D vector floorplan, through the type classification of the axis and text. But this approach is applicable only to specific floorplans, because the axis and text used in the study are not in the general form. For the multi-floor model with different floor shapes, Dao & Thill (2017) dealt with a model with 3D indoor network based on floorplans. However, the study focused on accessibility evaluation rather than the process of creating 3D models.

In this study, we introduce a floor matching algorithm to set up a multi-floor building model, by aligning the individual pieces of data using the restricted information that is available in scanned floorplans. Also, in order to utilize the multi-floor building data constructed through floor matching, we generate connectivity information for inter-floor movement rest on matching between building installations such as the lifts and stairs.

2. Methodology

Since features that can be extracted and vectorized from scanned floorplans are not sufficient, miscellaneous feature information in the previous study of Dosch & Masini (1999) cannot be employed. The 3D spatial data is the combination of the horizontal and vertical connectivity relations, and the vertical connectivity relations among the floors can be defined by stairs and lifts (Lee 2004). The corresponding data for lifts and stairs are easy to extract, since they are expressed with a manifest symbol in the floorplan.

2.1. Lift Matching

The lift matching algorithm is described in table 1. The similarity index (*Sim*) can be calculated by combining the shape similarity (Kim & Yu 2015) and the door positional similarity. The shape similarity is calculated by standing on the shape index (Burghardt & Steiniger 2005) representing the shape characteristics of the two polygon objects. The door positional similarity is derived from the distance between measuring the lift-entrance and centroid. If the *Sim* is evaluated as less than the threshold, the two lifts can be regarded as a matched candidate pair. The weights and thresholds are empirically determined. The pair with the largest sum of overlapping areas per each lift feature can be detected as an actual-matched pair. The centroid of lift and lift-entrance centroid of the matched pair can be respectively extracted and stored as a matched point pair.

Input : lift polygon layer L_A, L_B
For each lift j on floor i do
A_{ij} = area of Lift j on Floor i
${C^X}_{ij}, {C^Y}_{ij}$ = centroid (X, Y) of Lift j on Floor
P_{ij} = perimeter of Lift j on Floor i
${E^X}_{ij}, {E^Y}_{ij}$ = entrance centroid (X, Y) of Lift j on Floor i
$S_{ij} = 1 - (P_{ij}/2\sqrt{\pi \times A_{ij}})/\max(P_{ij}/2\sqrt{\pi \times A_{ij}})$
$D_{ij} = 1 - (\sqrt{({C^X}_{ij} - {E^X}_{ij})^2 + ({C^Y}_{ij} - {E^Y}_{ij})^2})/\max(\sqrt{({C^X}_{ij} - {E^X}_{ij})^2 + ({C^Y}_{ij} - {E^Y}_{ij})^2})$
End
For each lift j on layer A and lift k on layer B do
$Sim = w_1\lvert S_{Aj} - S_{Bk}\rvert + w_2\lvert D_{Aj} - D_{Bk}\rvert$
if $Sim < threshold$
Transform using $C_{Aj}, C_{Bk}, E_{Aj}, E_{Bk}$ as standard point
$A_{ov}(L_A, L_B) = A_{L_A \cap L_B}$
candidates.append(j , k, $A_{ov}(L_A, L_B)$)
End
If candidates[2] = $\min(\sum A_{ov}(L_A, L_B))$
pointA = [centroid of lift(candidates[0]), lift entrance centroid of lift(candidates[0])]
pointB = [centroid of lift(candidates[1]), lift entrance centroid of lift(candidates[1])]
output: Point layer including pointA, pointB

Table 1. Pseudo code of lift matching algorithm

2.2. Cross-floor Information

Since the scale of the floorplan for one building is the equivalent, the data by floor can be aligned through the rigid transformation which is composed of rotation and translation on the basis of the matched point. That is when the scales are identical, the coordinates of the upper point can be transformed according to the ones of the lower point as follows:

$$x' = cos\theta x - sin\theta y + T_x$$
$$y' = sin\theta x + cos\theta y + T_y$$

When the matched point pair is fixed through the algorithm illustrated in Section 2.1, the angle of rotation θ and the translation T_x, T_y can be calculated using the corresponding point as a reference point. After transforming, all matched pairs of lifts and stairs can be obtained by applying the position criteria and the overlap area criteria for the polygon matching (Kim & Yu 2015). Once matched pairs of all objects are identified, the alignment error can be reduced by re-transforming of the data using a number of centroid of all building installation features as reference points.

3. Results

The developed algorithm was implemented to the Seoul National University Library. The lower floor contains 2 lifts, and the upper floor contains 4 lifts. A total of 3 matched candidates were found, and one matched pair was determined through a comparison of the sum of the area of the overlaid parts. A reference point pair (matched point pair) was acquired for layout alignment. The results are shown in figure 1, and the ceiling of each layer was not expressed to show the suitability of aligning floors visually. After aligning, the connectivity information for the vertical movement in the building was retrieved through the matched pair searching between building installations among floors (table 2).

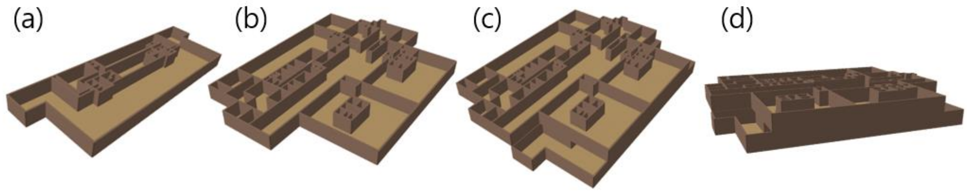

Figure 1. Floor alignment with SNU data; (a) B1 floor (b) 1st floor (c), (d) aligned floors

ID	type	up_connect_id	low_connect_id	floor
1	Lift	3	1	1
2	Lift	4	2	1
3	Lift	1	-	1
4	Lift	2	-	1

Table 2. The attribute of building installation layer with connectivity information

4. Conclusion

This paper presents a floor matching algorithm to establish a multi-floor building model from the scanned floorplan. Through the algorithm, it is noted that data by the floor can be automatically aligned using reference points, which is obtained from matching information between building installation such as lifts and stairs. Also, inter-floor connectivity information for vertical movement can be gained considering matched pairs.

In order to verify the appropriateness of the algorithm, indoor spatial data by the floor of Seoul National University Library were generated and the proposed floor matching algorithm was applied. As a result, the floors were appropriately aligned by the building installations, and the vertical connectivity information between the upper and lower lifts and stairs were obtained. The inter-floor connectivity information is stored in the form of an attribute table, and a vertical network with nodes and links can be formed reliably on the basis of the information. Since the current method can degrade performance when feature detecting and vectorizing results are inaccurate, it is necessary to improve the accuracy of those results. Moreover, it is expected that a vertical network will be formed from the application of connectivity information, thus utilizing in an effective indoor navigation system for the further study.

Acknowledgement

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Topology and Semantic based Automatic Indoor Space Subdivision from 2D Floor Plan

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Abstract. As indoor space becomes wider and more complicated, the need for indoor space information is increasing. In Korea, since 2013, indoor spatial data are being constructed based on IndoorGML, an international standard for indoor navigation in Open Geospatial Consortium (OGC). When building an indoor spatial data based on IndoorGML, it is necessary to divide space appropriately in order to construct more sophisticated indoor network. In this paper, we proposed the indoor space subdivision algorithm to consider the most important connectivity when building indoor spatial data in IndoorGML standard.
Keywords. Indoor, Space Syntax, Subdivision, IndoorGML

1. Introduction

As indoor space becomes wider and more complicated, demand for indoor spatial information is increasing. In Korea, since 2013, indoor spatial data have been constructed based on IndoorGML, an international standard for indoor navigation OGC. IndoorGML assigns one node to one room (physically closed space), but it is not enough to construct an Indoor network by this alone. This is because it is difficult for user to accurately search for a destination when several semantics such as a dining room, a front door, and a kitchen are mixed in a space. Also, if there is only one semantic (ex., corridor) in a large space, a network created with only one node is inefficient because it does not correspond to the shortest network (Khan A 2013). So it is necessary to divide space appropriately in order to construct more sophisticated indoor network. (Diakité A A 2017). In this paper, we proposed a new indoor space subdivision algorithm using topology and semantics from architectural floor plans to consider connectivity when building indoor spatial data in IndoorGML standard.

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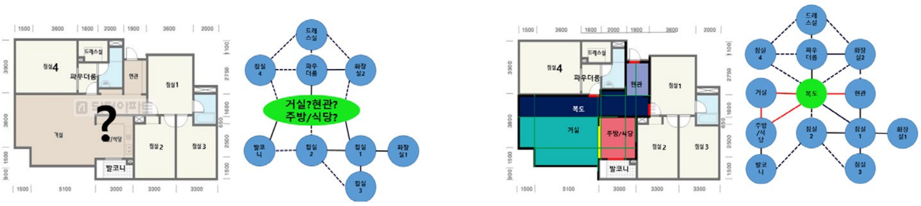
2. Related work

Previous, indoor space for indoor navigating has been divided into physical and conceptual units. However, recent studies (Kang 2015, Zlatanova S 2013, Lee 2012) have divided space by semantics (function) of the space for navigating efficiency. Enactment Provisions on Building Space Information in Korea have stated that space should be divided when characteristics of space are clearly distinguished (ex., in the case of a train station, the gate, etc.) We could derive semantics from the text of architectural floor plans, and extract topologies from the geometry of them through space syntax analysis.

2.1. Indoor space subdivision

Ahmed S (2012) and Lewis R (1998) have shown the possibility of space subdivision considering semantic elements by using the text of floor plans. Lewis R (1998) has divided space into vertical lines of the equidistant axis of the text if there is more than one text in the closed space. Ahmed S (2012) has divided space and merged it with the surrounding area until there is only one piece of text in the space, however, spatial information other than text was not used. Diakité A A (2017) and Lin Z (2017) have suggested the criteria and priority -including geometry, topology, and semantic information of space - of indoor subdivision for IndoorGML data. However, in their criteria, the definition of connectivity was not verified and text was not used.

The text extracted from the architectural drawing reveals the semantics of space, the meaning and function of space. Therefore, if several semantics such as dining room, entrance, kitchen, etc. are mixed in one detected space, it should be distinguished in the process of indoorGML-based data. Figure 1 shows the possible results of dividing an interior space by text.



(a) (b)

Figure 1. Dividing Indoor Space by Text: (a) An original floor plan and IndoorGML diagram; (b) The divided floor plan and IndoorGML diagram

2.2. Space syntax

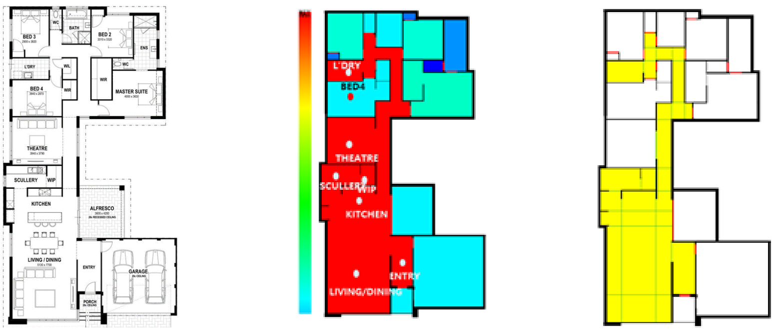
Choi (1996) has argued that the space syntax analysis which Bill Hillier (1984) proposed, space has already shown its validity and reliability based on several previous studies. He (2007) has also argued that if the space syntax is used from the preliminary stage of the building plan, it would be possible to predict traffics and the space utilization from floor plans. Hiller, Hanson, and Graham (1987) were able to extract functions of farmhouses by analyzing their floor plans without room name. Choi (1996) found that the relative spatial depth tended to be low in the living room and corridor of the house. We are trying to find a space with potential connectivity based on variables of space syntax, the integration value of which is the inverse of relative spatial depth.

3. Methodology

In this chapter, we propose an indoor space subdivision algorithm based on geometrical information, topological information, and semantical information.

3.1. Geometric and semantic feature extraction

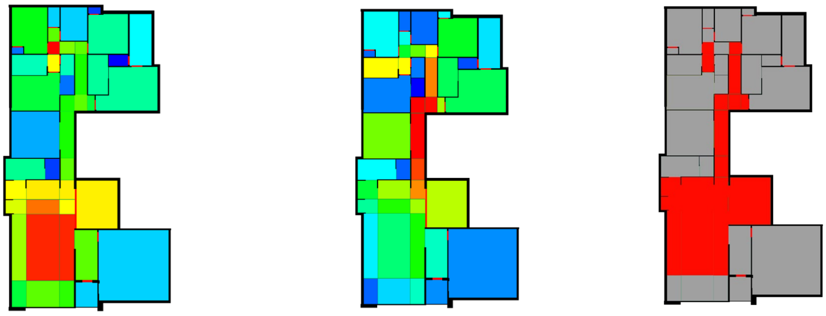
From floor plan image (Fig. 2-a), we can extract polygon features enclosed by wall opening through floor plan analysis (Jang et al. 2018). Text its relative position can be extracted by OCR.



(a) (b) (c)

Figure 2. Space syntax analysis and S-partitioning (a) A raster floor plan.; (b) a visual representation of the Integration(3) value.; (c)Subspaced Floor Plan

After extracting geometric features, space syntax analysis is performed to obtain Integration values of spaces (Fig.2-b). Especially, Integration (3) is a variable considering pedestrian zone (Choi 2005). The red polygon which has a high degree of Integration (3) could be a candidate of a connectivity nodal space. There are also several text points, meaning mixed semantics in a space. It should be divided into several polygons topologically and semantically while maintaining the existing geometry. Thus,we performed S-partitioning (Peponis 1997, Lee 2006). We defined the borderline of the partition as an imaginary line extending from the wall line until it met another wall line. We added some rules to this by making only convex polygon while avoiding making too small subspace helps to minimize exceptions when interpreting results(Fig.2-c).



(a) (b) (c)

Figure 3. The Result of Space syntax analysis (a) Integration(3) of Subspaced Floor Plan; (b) Integration of Subspaced Floor Plan (c) Sum of Top 25% Integration(3) value and Top 25% Integration value.;

The fact that some subspaces have topological or semantical connectivity is an important information that can be used to place connection node of the IndoorGML data. To look more closely at the candidate of connectivity nodal space and extract the right subspace where the connected node would be made, we performed space syntax analysis again on the whole floor plan (Figs.3-a,b).

3.2. Finding final nodal subspaces by semantically difining the space

Finally, from results obtained from space syntax analysis, we selected the subspace with Integration (3) and integration value of upper 25% Generally, if the degree of integration is 1.7 or more, the space is considered to be highly integrated. If it is 1.0 or less, the space is considered to be isolated space (Hiller B 1984).

We adjusted this threshold to the top 25% range to fit the subspaced floor plans. It can be changed depending the floor plans. Sum of the two results is obtained and considered be the candidate of connection nodal spaces (Fig. 3-c). In this process, subspaces are merged or segmented while existing geometric information is maintained. In the next step, the previously obtained semantic information (text) is spatially joined to each subspace (Fig. 4-a). This means it is labeled. This semantic information also informs the connectivity information of the space (ex. porch, entry, lobby, corridor, staircase, etc.). We gave a new attribute 'corridor' to the unlabelled connection spaceAdding nodes for a network.

(a) (b)

Figure 4. Topologically and semantically defined space (a) semantically defined subspaces.; (b) divided connection space

Finally, the space is divided geometrically, topologically, and semantically. However, we still do not have enough IndoorGML data since there is only one node in the connection space. Khan(2013) has insisted that expressing the long corridor as one node is too abstract. Therefore, it is necessary to divide it to achieve better navigating performance. We basically followed the door semantic based partitioning algorithm for corridor (Li 2016) but modified and added some steps to include geometrical and semantical information (Fig. 4-b).

4. Conclusion

In this paper, we proposed an indoor space subdivision algorithm to consider the most important connectivity when building indoor spatial data in IndoorGML standard which is oriented for indoor navigation. We tried to divide the space more practically and suitable for indoor navigation using all information we could draw on the floor plan's geometric information, topology information from spatial analysis, and semantic information from text. Based on the topology information found through space syntax analysis, it is possible to improve indoor navigating efficiency by appropriately dividing the indoor space and designating essential nodes for the IndoorGML data.

In the space syntax analysis, the threshold used to extract the subspace with high connectivity can vary depending on the floor plan. This means that topology information is dependent on geometric information. The subspaces generated by s-partitioning are subjected to spatial analysis. When interpreting the results, the problem of how to set the R value of the Integration can be solved by considering the actual physical size and the number of sub-spaces. We were able to get semantic information of the space from the text only. We analyzed semantic information to classify space with connectivity and used it to construct the network. Future studies are needed to obtain semantic information by symbol detecting.

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Dynamic Wi-Fi Reference Point Recognition along Public Transport Routes

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Abstract. The ubiquity of Wireless Fidelity (Wi-Fi) signals in urban environments has the high potential to employ them for numerous applications for localization and guidance in urban environments. The reach of Wi-Fi localization is extended in this study for urban wide applications and therefore user localization is employed for outdoor and combined in-/outdoor environments. The chosen application is the localization and routing of public transport smartphone users. For the conducted investigations, Received Signal Strength Indicator (RSSI) values are collected for users who are travelling from home in a residential neighborhood to work in downtown and return along the same route. Special tram trains are selected which provide two on-board Wi-Fi Access Points (APs). Firstly, the availability, visibility and RSSI stability of the Wi-Fi signal behavior of these APs and the APs in the surrounding environment along the routes is analyzed. Then the trajectories are estimated based on location fingerprinting. A first analyses reveals that significant differences exists between the four employed smartphones as well as times of the day, e.g. in the morning at peak hours or at off-peak hours.

Keywords. Wi-Fi positioning, User localization, Public transport, RSSI measurements, Performance analysis

1. Introduction

Wi-Fi location fingerprinting is a method of finding a mobile device/person's location based on the RSSI of Wi-Fi networks (see e.g. Chen et al., 2012; Honkavirta et al., 2009; Liu et al., 2007; Xia et al., 2017). In an age of growing Wi-Fi coverage this method is becoming increasingly useful in areas where a GNSS signal does not reach, such as underground or within the built-up city area. In the case of this study, the operability and performance of Wi-Fi fingerprinting is investigated at a set number of

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reference points, referred to as Intelligent Check Points (iCPs), along a tram route. Here the major aim is to facilitate localization and optimum routing considering travel times and user preferences in multi-modal transport situations. In the presented tests, a route from a residential neighborhood to an University building in downtown is selected and analyzed. For that purpose, a short system training was performed in the beginning along the selected trajectory at benchmarks and public transport stops where only a few samples of RSSI were collected. Furthermore, long-term repeatedly observations of the Wi-Fi RSSI along the tram route are used for continuous system updating and training. The most significant novelty of this study is the use of the RSSI observations of the mobile Access Points (APs) installed on the trams (Retscher and Bekenova, 2019). In a first step, the RSSIs were analyzed concerning their availability, visibility and RSSI stability of the Wi-Fi signal behavior. Experiments conducted along the selected tram route leading through combined out-/indoor environments are described in the following.

2. Characteristics of the Selected Tram Route

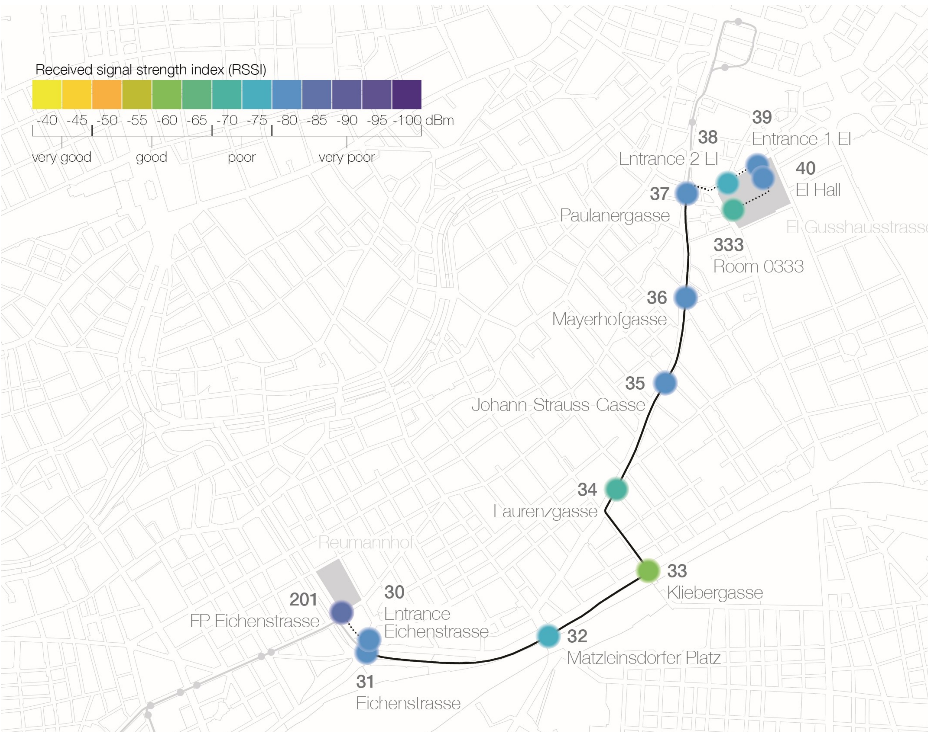

Figure 1. Tram route showing the average RSSI values recorded at each iCP

The particular feature of the tram route is that it runs on different levels partially underground and then above ground in the middle of a road (see *Figure 1*). Checkpoints are employed which are either benchmarks at the start or from a University campus wide network as well as station buildings and stops. The route starts at checkpoint 201 (which is a benchmark) and ends at the office 0333 on the third floor in the multi-story office building leading over the checkpoints 30 to 40. Checkpoint 30 is at the entrance of the first underground public transport stop and checkpoint 31 at the platform. Checkpoint 34 is located at the last station in the tunnel and then the tram travels above ground from the stops 35 to 37 in the middle of a road. At checkpoint 37 the user exits the tram and walks then to the University building along checkpoints 38 to 39 whereby the second checkpoint is front of the main entrance of the building. Checkpoint 40 is located inside the building on the ground floor and checkpoint 0333 in front the respective office in the corridor on the third floor. The total one way travelling time is around 15 to 20 minutes depending on the waiting time for the tram. In the presented tests, the trains with on-board Wi-Fi networks are selected.

3. Availability, Visibility and RSSI Stability of the Wi-Fi APs

Figures *2* and *3* show two different ways of presenting the changing RSSI values, *Figure 2* for the Samsung 1 (S1) smartphone in 2D and *Figure 3* in 3D for all four phones employed in this study.

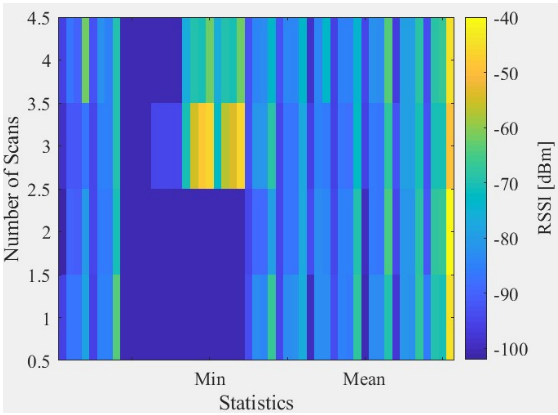

Figure 2. 2D plot for the Samsung 1 smartphone showing the RSSI values along the route

Figure 3 shows more similarities than differences between the graphs as all four smartphones follow a similar trend. The tunnel is very pronounced with a clear channel of -100 RSSI values. Before and after the tunnel values fluctuate around -80 dBm before sharply increasing to exceptional signal (around -45 dBm) inside the office building. These graphs indicate that the environment had the dominating influence on the RSSI values rather than the phones specifications, for example being underground leads to worsened RSSI values.

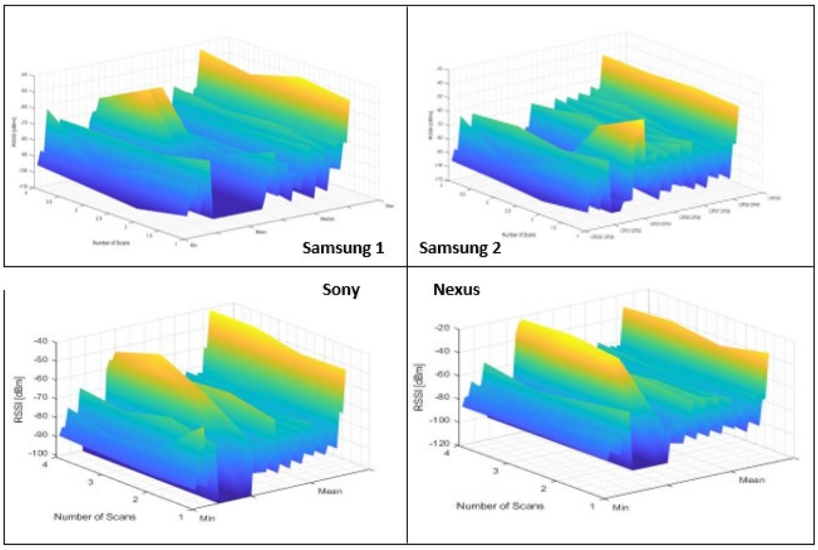

Figure 3. 3D line plots for each smartphone

The 3D bar graph presented in *Figure 4* clearly shows how the number of APs changes along the tram route. The visualization shows a clear drop in the number of APs received by the phones between reference points 31 to 34 where the tram passes underground through a tunnel. This can be explained as a case of the underground segment of the public transport network simply having less Wi-Fi coverage than the areas above ground. The walls of the tunnel are blocking any APs situated on the surface and therefore only Wi-Fi APs within the tunnel (e.g. hotspots from people's phones and the two on-board Wi-Fi APs) will be registered by the mobile devices. The graph also allows for the comparison of each mobile device. It can be clearly seen that the Nexus smartphone picks up the largest number of APs out of all of the smartphones. Despite Samsung 1 and 2 being the same smartphone model, Samsung 2 received notably more APs than Samsung 1. This may result from a number of reasons such as battery life, type of case on the phone and/or where the individual taking the measurements was standing. As for the LG Nexus, due to the high number of APs received, compared to the other phone models it must be assumed that this device has a much better receiver for picking up Wi-Fi networks. This phone can be considered the best device for Wi-Fi fingerprinting as it will give the highest number of APs and in turn RSS values therefore providing the most accurate tool for measuring Wi-Fi coverage, operation and performance.

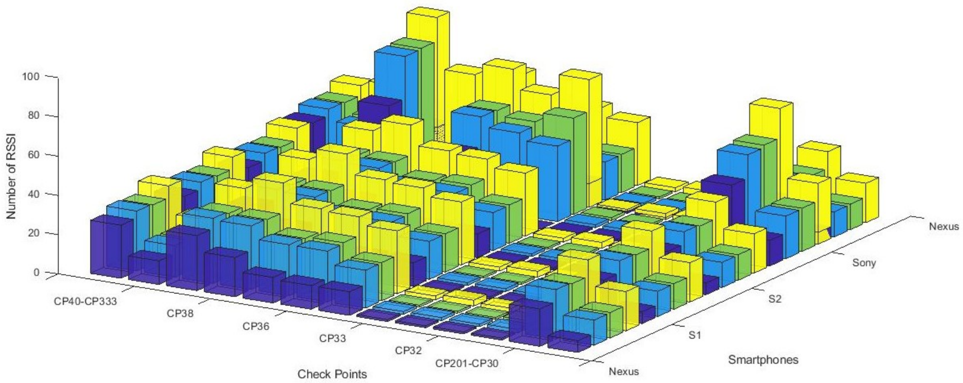

Figure 4. 3D bar graph of RSSI for all mobile devices at each iCP

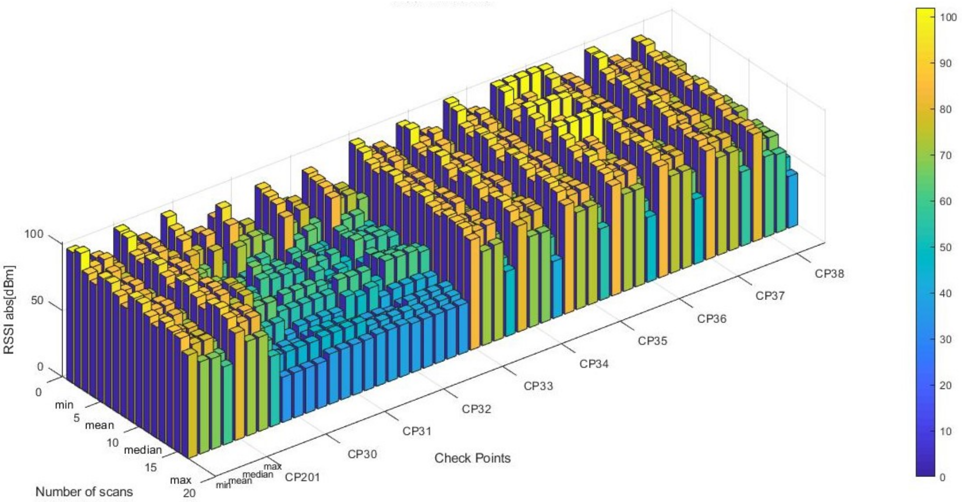

Figure 5. 3D visualization of RSSI variations for all mobile devices at each iCP

The 3D bar graph shown *Figure 5* visualizes the RSSI variations of all the mobile devices at each iCP. At each reference point (Z-axis) the minimum, mean, median and maximum RSSI values are represented against the number of scans at each location (20 for each mobile device) shown along the X-axis. The colour scale signifies the RSSI with blue characterizing a poor signal and yellow a strong signal. At reference point 37 the signal is strongest with values well into the 90s range. This could be due to the number of people with hotspots in the vicinity or a particularly large number of APs in the neighbouring buildings which are subsequently received by the mobile devices. As expected and seen previously the worst signal is in the tunnel where the least number of access points exist and signals from the surface cannot penetrate.

4. RSSI and AP Count Comparison

Figure 1 is a map output showing the average RSSI recorded across all phones at each iCP. These calculations presented a different picture to all other analysis undertaken in this study. Most notably the underground stations (Eichenstrasse, Matzleinsdorfer Platz, Kliebergasse and Laurenzgasse) have the highest RSSI values and inside a technical university has some of the lowest recorded. To try and understand the reasons for this trend the analysis shifted focus to the count of APs for each phone at every stop. *Figure 6* presents the AP count for each phone at each iCP. Here it is clear that there are considerably less APs collected inside the tram tunnel. This indicates that RSSI values are not positively correlated with the AP count (the higher the RSSI doesn't necessarily mean more AP signals being received). *Figure 6* also shows the Samsung phones have received considerably less AP signals than the LG Nexus and Sony Xperia. Despite *Figure 4* this shows that LG Nexus has similar RSSI values despite receiving more AP signals at the majority of the iCPs. This further supports the inference that the higher RSSI doesn't always result in more AP signals being received. The chart in *Figure 7* compares the average number of APs, received across all four phones at each tram stop, with the respective average RSSI. Both, the number of APs and the RSSI follow a similar pattern in that they both change visibly when the iCPs are at street level and in the tunnel. However, the results came partly as a surprise when analyzing the data captured by the phones. Whilst the number of APs received in the tunnel are low, presumably because of the few APs available (such as nearby fellow passengers), the RSSI was at its highest in the tunnel, at iCP 33 (Kliebergasse) even as high as -62 dBm which is considered as a good RSSI value. The possible reasons for this unexpected result are further investigated by looking into the whole dataset. It was seen that the LG Nexus at iCP 31 (Eichenstrasse) did not receive many APs at this location but the ones it did were received very well with an RSSI of up to -34 dBm which is considered as very good. The AP that shows up most often in this and similar environments, such as iCPs 32 to 34, come from the network called "ArberFazliu" which was owned by team member Arbër carrying out the survey. As we worked in a team taking measurements close together and always facing in the same direction at the same time, it is believed that this spatial constellation led to the very good RSSI results.

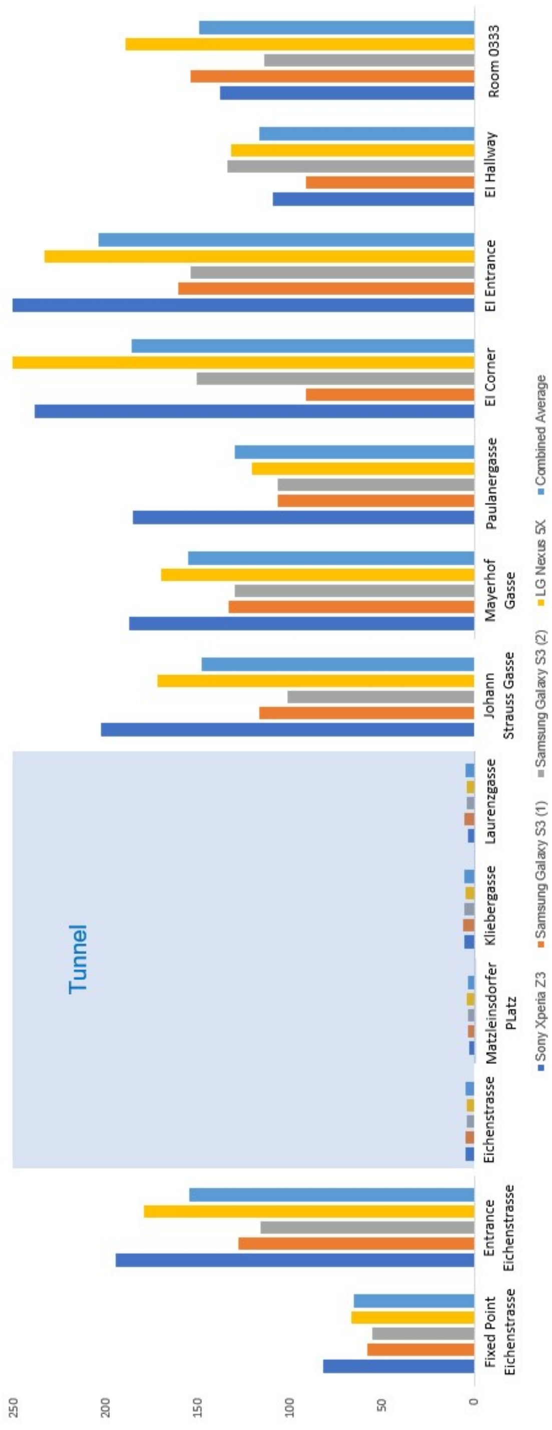

Figure 6. Comparison of the number of AP received per phone and iCP

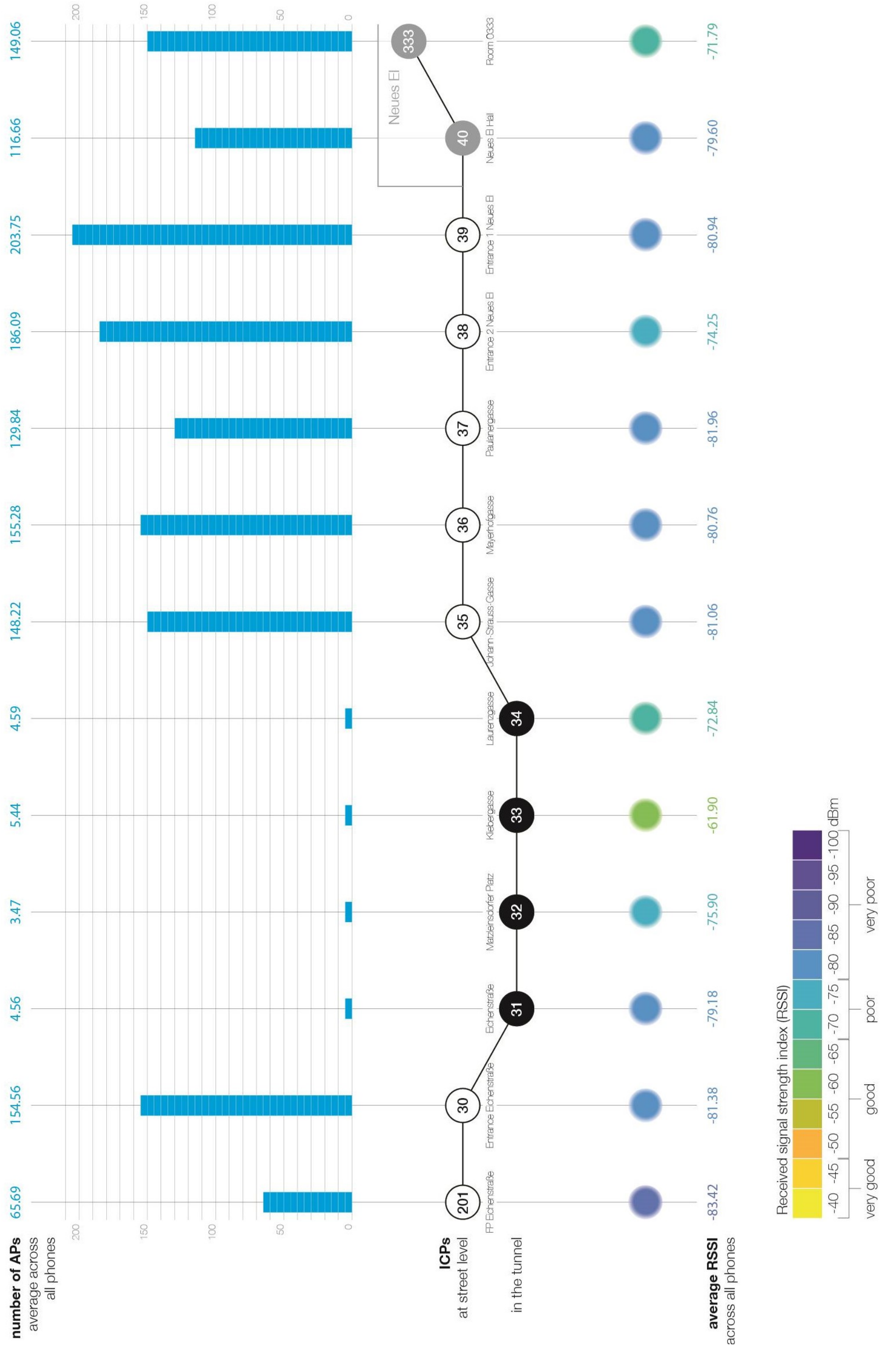

Figure 7. Direct comparison of average number of APs and average RSSI at each iCP

5. Conclusion

In conclusion, there is high variability in the RSSI values found along the tram route and this study has shown that there are many factors that influence this. The RSSI is heavily influenced by the position of buildings or other infrastructure, the most notable example in this study being the underground section of the route. Orientation of the device also played a role, particularly in the underground iCPs due to the presence of physical barriers that can block or impede the signals. If there is an AP originating from an underground environment this typically leads to very high RSSI values being received due to the close proximity of the hotspot APs to the devices. Different phones yielded different results for both RSSI values and number of APs received. This is suspected to be down to the phone specifications with the LG Nexus having the most sensitive receiver and therefore picking up the highest number of APs at each iCP. However this cannot account for the differences between the two Samsung devices which were the same model and therefore had the same specifications. Their difference can be justified by comparing the phone's battery life, type of phone case and the position that the user holding the phone was standing in. These can be considered possible future avenues for research which would require further measurements with phones of the same model.

Overall, the Wi-Fi fingerprints at each iCP were distinguishable from one another and would therefore allow for the accurate positioning of a user at these points. To improve these databases the number of measurements taken at each point could be increased to improve the accuracy and therefore the reliability of the iCP recognition. Measurements at different time periods and at different times of year could also help improve the checkpoint recognition as this study was focused on only two days of the year in May. These improvements are required to improve the overall accuracy because the RSSI values change throughout the year and, in general, are affected by the number of people present at that particular time (mobile hotspots, blocking of the signal, etc.). Finally the use of a greater range of smartphone devices would further increase the accuracy of the database as the majority of people are not limited to owning a Samsung Galaxy S3, LG Nexus 5X and Sony Xperia Z3.

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A Low-cost Public Transport Tracking and Information System for Commuters in Sri Lanka

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Abstract. Public transportation in developing countries, such as in Sri Lanka, can be generally quite chaotic; these ranges from poor management of the vehicles, traffic congestion, reckless driving and unreliable service provision. The main objective of this study is to develop a customized location-based service catering for the needs of public transport users. For that purpose a free prototype solution for management of public transport is developed providing GPS and GPRS technologies for real-time transmission of locations from the tracking devices (i.e., ticketing machines and/or Android phones) to the central database server and finally rendering to an Android application. The development process of the system involves the analysis of existing systems used in Sri Lanka, system design and development, evaluation and implementation. Thus, a cheaper solution can be provided for passenger information saving users waiting times for public buses and effective transport management by preventing vehicle misuse. The chosen solution comprises an Android application providing real-time graphical visualization on Google maps for prediction of the arrival time of the vehicles.

Keywords. Low-cost vehicle tracking, GPS, GPRS, Android application, Public Transport

1. Introduction

In Sri Lanka most people use trains and busses as mean of public transportation. According to the 2018 statics 6,152 busses are in operation

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under the Sri Lanka Transport Board. By managing travel disruptions caused by heavy traffic it is possible to improve traffic flow and living quality. Especially with the Android devices, development of web GIS technologies and mobile GIS, a good solution for management of public transport can be realized. The project uses an application for Android mobile devices to present a solution to improve the management of public transport. The nature of the internet in the country through the cell phone network and mobile GIS provides a great platform for management. Recent developments in geospatial technology have led to the emergence of GPS-enabled cell phones and mobile devices which have promoted the growth of location-based services (Damani et al., 2015).

2. Development of a Public Transport Tracking System

In a first stage of the development the current existing bus tracking systems were studied while visiting several companies (Dialog Axiata PLC, Sri Lanka Transport Board-Sahasara project). From this investigation fundamental requirements for the project were clearly identified and common problems of the existing systems verified. The main expectation of the system user is to graphically represent the location of the bus on the map on their portable device. Users want to know the location of the bus, estimated arrival time and occupancy of the bus to see how many seats are still available in real-time on a map. By interviewing commuters who are waiting for the bus it was seen that they may get impatient waiting for the bus and they are not trusting the official time tables. *Figure 1* shows the result of the survey of the commuters. The Figure on the left depicts how the public transport users currently get information about bus arrival times. It is either from time tables, asking someone, by experience, through internet or other means. Most remarkable thereby is that the arrival times are guessed nearly by half of the commuters by experience, i.e., 42 %. Then the end user acceptance of a new public transport tracking and bus arrival time system was queried in the survey. It could be seen that 62 % of the users would agree to share their location information to the system. Only 26 % said no and 12 % maybe. Furthermore, it was seen that 97 % of the commuters have already Android smartphones. Thus, the implemented system is currently based on the Android platform.

The overall system architecture is depicted in *Figure 2*. Using the Android device either from a commuter or the bus driver the location of the bus is determined with GPS. In the following, this information is sent to the online database through the GSM network. Finally, this information can be distributed through the internet. The data transmission part as shown in

Figure 3 has five stages, i.e., (1) reading and displaying the current location of the device, (2) creation of the database for saving the location information, (3) implementation of the application to transfer the location to the database, (4) implementation of periodically performing this procedure and (5) combining and integrating everything together. *Figure 4* shows the location data receiving system at the users' side. In this system part, the locations are displayed on Google map in the Activity window. A code was written in a JSON (JavaScript Object Notation) format to provide the location data on the map from the database. Because of the users' intent he can switch between the main to the map activity. Finally, the arrival time of the public transport vehicle is estimated following the procedure illustrated in *Figure 5*. In this arrival time analyzing system, the users' location coordinates and vehicle location are sent to the API (Application Programming Interface). Then the API provides a JSON output with which the arrival time of the vehicle can be estimated.

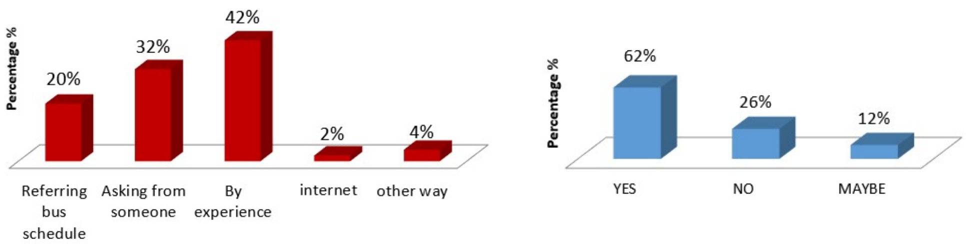

Figure 1. Results of a survey of commuters concerning the information collection (left) and end user acceptance of a new public transport tracking and bus arrival time system (right)

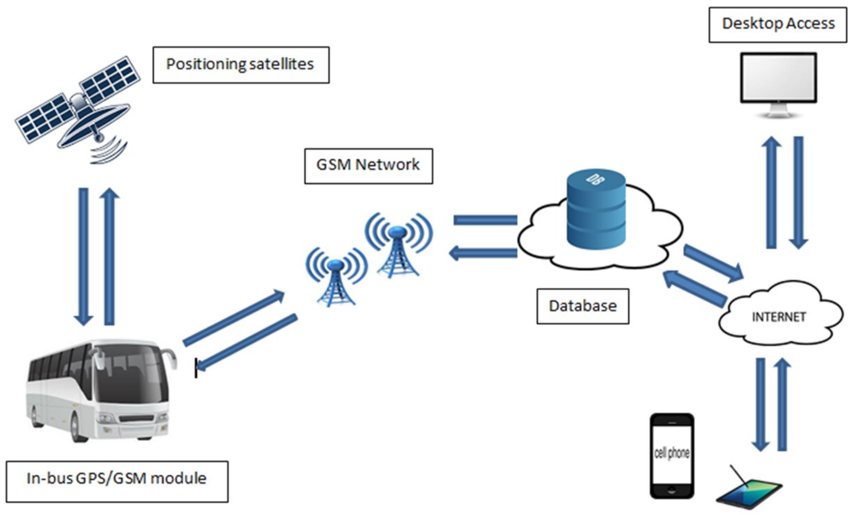

Figure 2. Overview of the public transport tracking system

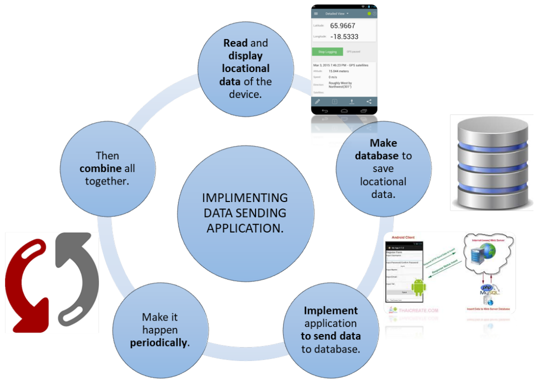

Figure 3. Location data transmission system

Figure 4. Location data receiving system

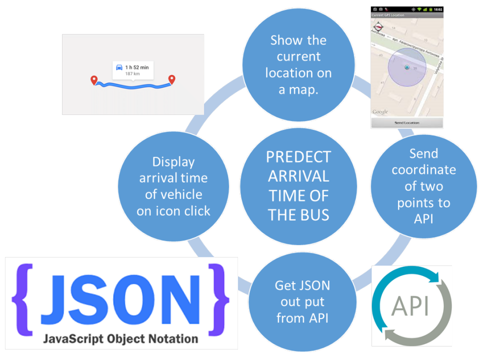

Figure 5. Arrival time analyzing system

3. Exemplary Results and Discussion

An application to track and send location data on the relevant bus to the server was implemented and tested on several Android phones. It is demonstrated that the developed real-time graphical representation method for national transport in Sri Lanka is very reliable and inexpensive. *Figure 6* shows the resulting App interface and three examples for providing information to the system users. As can be seen the trajectory of the bus is estimated and visualized and the estimated arrival times are presented to the App users. The gap in the trajectory shown in *Figure 6* (left) is due to lacking of GPRS coverage and connectivity to the server. Therefore it was not possible to transfer the bus location in this road section. *Figure 6* middle and right show two examples of responses to the user providing information about the current bus location and estimated arrival time. Thereby the blue pin depicts the current location of the commuter. The text box at the bottom in the App interface contains the respective information for the user, i.e., the distance to the current location of the user and the estimated waiting time until the bus is arriving.

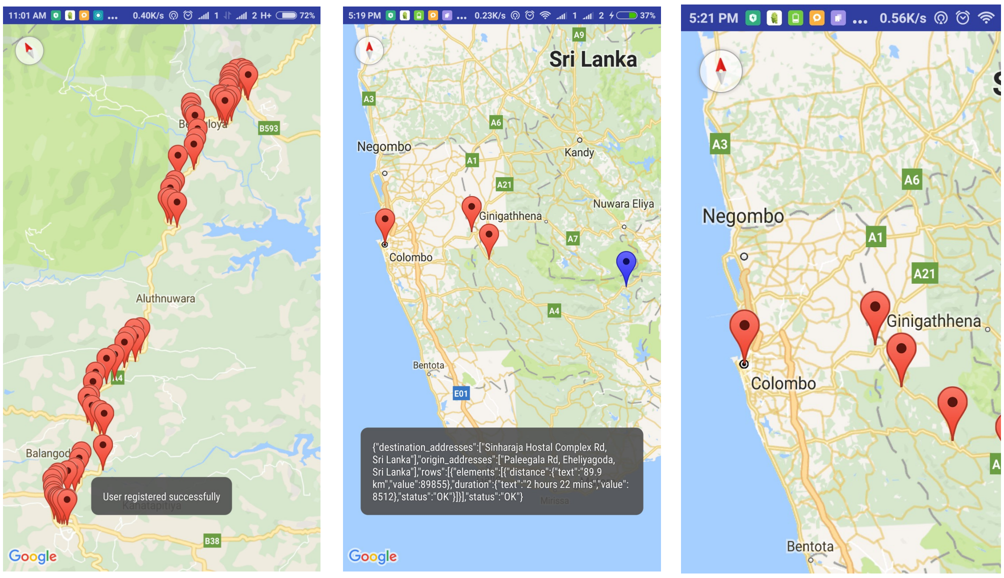

Figure 6. Example of an estimated bus trajectory (left) and two responses to the user providing information about the current bus location and estimated arrival time (middle and right)

4. Conclusion

Because of long waiting times for public vehicles people may feel impatient and anxious if they do not know when a vehicle arrives. Although timetables are provided, most probably bus drivers are unable to drive according to them. If passengers can see the location of the bus in real-time it will be beneficial for both sides. Thus, such kind of platform was developed in this study applied for the public transport network in Sri Lanka. In order to increase the performance of the public transport service, a real-time bus tracking system is needed. This system provides the ability to the passenger to know the exact location of the desired vehicle on the fingertips on his Android device. Further enhancement is on the way do to make it more efficient and user friendly. This will further increase the user acceptance.

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Consistency Across Geosocial Media Platforms

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Abstract. The increasing use of geosocial media in research to draw quantitative and qualitative conclusions about urban environments bears questions about the consistency of the data across the different platforms. This paper therefore presents an initial comparative analysis of data from six different geosocial media platforms (Facebook, Twitter, Google, Foursquare, Flickr, and Instagram) for Washington, D.C., using population and zoning data for reference. We find that there is little consistency between the different platforms at small spatial units and even semantically rich datasets have severe limitations when predicting functional zones in a city. The results show that researchers need to carefully evaluate which platform they can use for a particular study, and that more work is needed to better understand the differences between the different platforms.

Keywords. Geosocial Media, Location-Based Social Networks

1. Introduction

The abundance of data from a large number of users, easily accessible through APIs, has led to numerous studies based on geosocial media. Researchers have used geosocial check-ins or geotagged tweets and photos to study online communities (Yin et al., 2016), event detection (Sakaki et al., 2010), urban structure (Hollenstein and Purves, 2010) and its dynamics (McKenzie et al., 2015), gazetteers (Keßler et al., 2009), and functional regions (Gao et al., 2017), to name but a few examples. Population mapping (Patel et al., 2017; Aubrecht et al., 2011) and population mobility (Noulas et al., 2011) have drawn particular interest, following the assumption that users of geosocial media can be used as a representative sample of the overall population in a city. Some of this work has produced interesting, meaningful,

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and broadly cited results. Systematic comparisons across different sources of geosocial media are still scarce in the literature, though, with the few examples focusing on the complementarity of different geosocial data sources (Lee et al., 2004) or differences in the ability to track individual users (Silva et al., 2013; Wang et al., 2013].

The goal of this research is therefore a systematic quantitative and semantic cross-comparison of data from six widely used (geo-)social networks. This paper presents initial results for Washington, D.C., comparing the datasets to each other and to population and zoning in the city as reference data.

2. Data

The data used in this paper consists of 8 different datasets for the area of Washington, D.C., and is summarized in Table 1.

Source	**Data points**	**Acquisition period**
Facebook[a]	2,409 places	December 2018
Twitter[a]	118 places	April 2016
Google[a]	6,978 places	April 2016
Foursquare[a]	24,428 venues	September 2017
Flickr[a]	6,945 geotagged photos	December 2018
Instagram[a]	3,130 geotagged photos	April 2016
Population[b]	179 census tracts; 6,507 census blocks	July 2019
DC Zoning[c]	885 zones with 149 classes	July 2019

Table 1. Overview of datasets used, obtained from the respective API (*a*), from the 2010 census (*b*), and from https://opendata.dc.gov/datasets/zoning-regulations-of-2016 (*c*).

3. Consistency analysis

A visual comparison of density across the datasets (see Figure 1) shows little consistency, particularly when compared to the distribution of population across the city. While this may be a result of Washington, D.C. being a major tourist destination – the National Mall and government districts in the center of D.C.'s diamond shape are bare of any population, but show the highest densities for photo-based platforms and Foursquare POIs –, this raises serious concerns about the use of geosocial media to enhance population mapping.

In order to quantify the degree of consistency across these datasets, each of them has been aggregated to the containing census tract and block, respectively. The corresponding numbers for the 179 tracts and 6507 blocks were then tested for correlation; results are summarized in the pair plot shown in

Figure 2. There are still reasonable correlations for the fairly large census tracts, with the maximum values R = 0.85 between number of Foursquare venues and population, and R = 0.81 between number of Foursquare venues and number of Instagram places (see upper right half of Figure 2). When going to the block level, however, the maximum correlation values obtained are much lower, with R = 0.46 between the number of Foursquare venues and the number of Foursquare checkins, and R = 0.4 between number of Foursquare venues and number of Instagram places (see lower left half of Figure 2). Again, these findings do not support the use of geosocial media data for fine-grained population mapping.

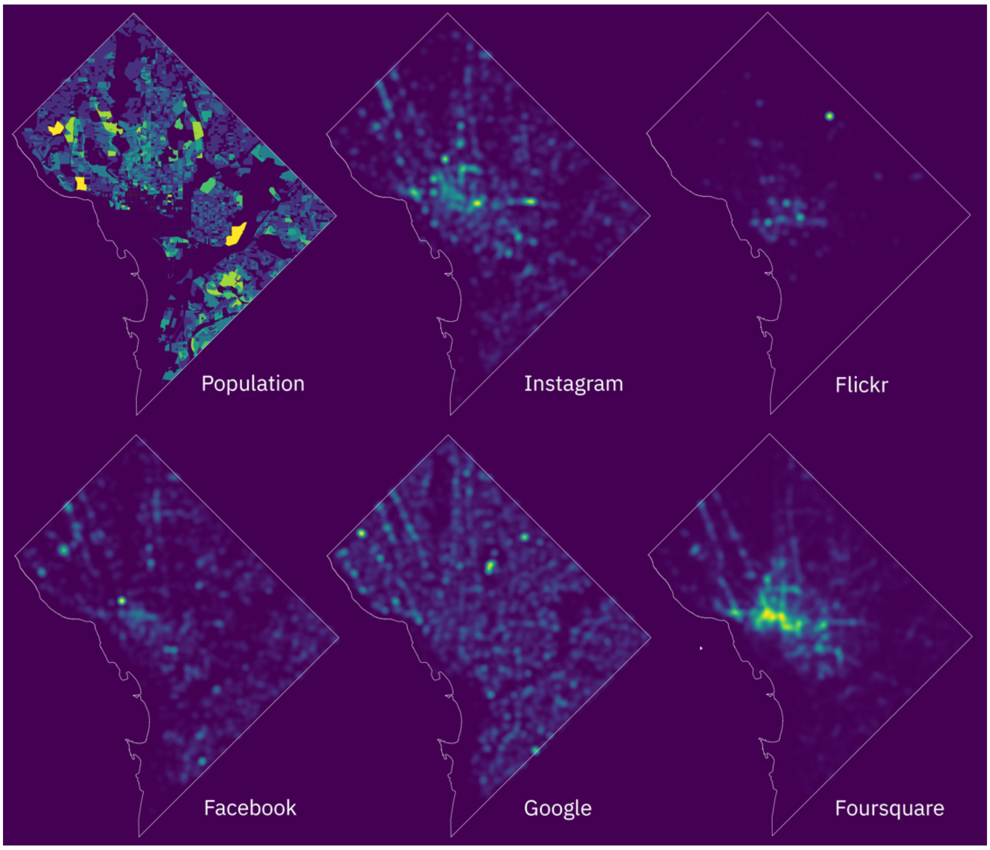

Figure 1. Density maps of data from the different platforms, with population per census block as reference; Twitter places are not shown due to the small number places in the dataset.

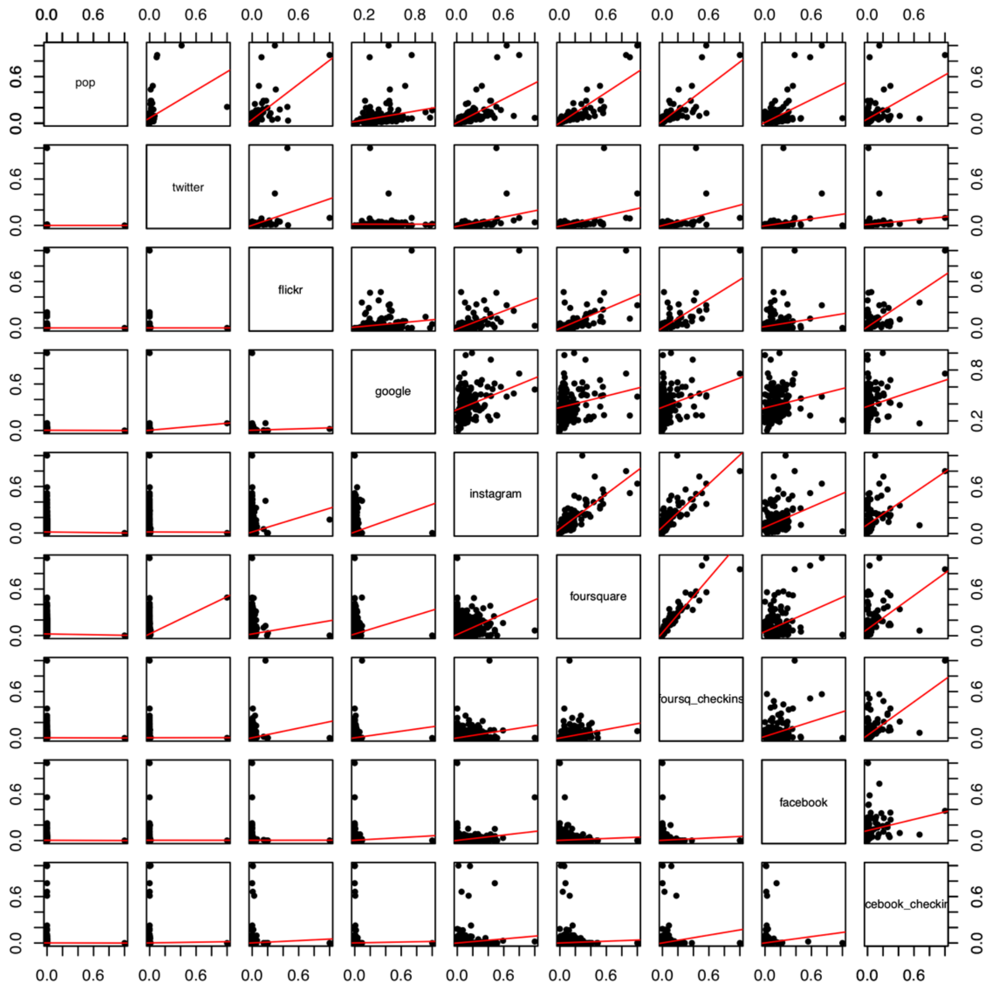

Figure 2. Pair plot showing the relationships between all combinations of data sources per census tract (upper right) and per census block (lower left).

After this quantitative analysis, we wanted to see whether the semantic information in geosocial media can reveal any insights about functional areas of a city. We used the Foursquare dataset for this purpose, as it contains both the largest number of data points (24,428 venues) and is also semantically the richest, with a total of 10 top-level categories (e.g., *Food*, *Outdoors/Recreation*) and 449 second-level categories (e.g., *Latin American Restaurant*, *Athletics/Sports*). The 885 zones defined in Washington, D.C.'s zoning regulations were used as functional areas in this analysis. Each zone belongs to one of 149 classes, grouped into six zoning groups (*Downtown*; *Mixed Use*; *Production, Distribution, and Repair*; *Residential*; and *Special Purpose Zones*). Since the distribution of different kinds of POIs across zones should be indicative of the zones' functions, we aggregated each first-level and second-level category of Foursquare POIs to the 885 zones and used the corresponding vector to train a random forest model to classify each zone into the correct zoning group. When training on the top-level Foursquare categories, the random forest classifier obtains an out-of-bag estimate of error rate of 39.8%; using the much richer second-level categories only lowers the out-of-bag estimate of error rate to 35.2%. This indicates that even an extensive and semantically rich dataset such as the one used here is not sufficient to reflect functional zones in urban environments.

4. Conclusions and Future Work

Our analysis of Washington, D.C. geosocial media data has shown that there is little consistency across the different platforms at small spatial units. At a semantic level, an initial analysis has shown that the use of the data to predict functional zones in the city was limited, even when using rich semantic annotations. Our results indicate that more care needs to be taken when using such data to draw conclusions about urban areas both at a quantitative and at a qualitative level. Researchers need to be much more aware of the kind of platform they choose for their research. Further research is needed to gain a better understanding of the nature of the differences between the datasets. These may be related to the socio-economic groups that use the different platforms, but also to data collection practices (active check-ins and posts vs. passive observation of user presence, as in the case of Google places, for example), as well as the classification systems that produce the semantic information on the platforms. Future work will therefore focus on an assessment of the semantic consistency between the platforms, and a replication in further major cities.

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Using Geotagged Photos to Study Visitors Mobility in Urban Parks during Shadow

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Abstract. The share of urban parks in a metropolitan is mostly small, nevertheless, they are one of the main attractions affecting the experience of mobility in urban cities. Since shaded areas influence active traveling, e.g., walking and cycling, the effect of shaded areas in cities is currently being investigated, specifically as temperatures continue to rise. In this study, we analyze mobility patterns of photographers by mining spatio-temporal descriptors associated with crowdsourced geotagged photos from Flickr integrated with the computation of the 3D line of sight to the sun position for shadow computation. Mining photographers' trajectories with unsupervised location clustering are used to recover knowledge about the main attractions visited in urban parks while considering shadow analysis. Such an approach can contribute to diverse city management aspects, including urban design and planning, tourism and more. Preliminary results for Central Park in Manhattan are presented, showing an original approach for the retrieval of relevant valuable information on visitors mobility patterns and hot spots identification while considering building shadows.

Keywords. Geo-tagged User Generated Content, Shadow Analysis, Unsupervised Data Clustering, Mobility Patterns

1. Introduction

Traveling in public urban parks is a different travel experience than traveling in densely built-up urban areas. Visitors travel urban parks for various reasons, e.g., tourism, scenery, sports, and recreation (Vu et al., 2016). Moreover, urban parks have a specific direct psychological effect on senior visitors. Takano et al. (2002) studied the positive psychological value effect

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parks have on senior citizens. In addition, Ciange & Popescu (2013) showed that urban parks have attractive attributes that are sufficiently valuable for travel planning.

As temperatures continue to rise, the shadow has an effect also in parks in terms of their attractiveness to visitors. Skyscrapers are becoming more popular and common in urban environments, being developed around urban parks, such that their shadow is directly affecting the park. Investigating the effect of urban park shadow on the visitors mobility can provide insights on urban planning. User-generated geotagged data sources are increasing dramatically, and are nowadays more commonly used to share travel, tourism, as well as daily experience (Mor & Dalyot, 2018). Although only a small part of tourists is presumed to share their travel experience, which in case of mobility analysis can bias the results, current research suggests that active participation in social media is constantly expanding (Antelmi et al., 2019). Using these active trail data together with shadow analysis can provide information on main routes and attractive locations in parks during the day, which can serve as an aware solution to explore and analyze the shadow impact on visitors in urban parks, and how the existence of shadow can contribute to better urban planning.

In this research, we analyze geotagged photos from Flickr to retrieve photographers' travel trajectories and identify main clusters around attractive park locations by using an unsupervised DBSCAN clustering (Vu et al., 2016, Ester et al., 1996). This information is integrated with a shadow analysis according to the visit time (i.e., geotagged photos' captured timestamp). Accordingly, we recover knowledge regarding the correlation of mobility patterns and shadow. An experiment presents preliminary promising results in understating the visitors mobility pattern and the main attraction locations in urban parks together with understating the impact of shadow. This showcase of using updated crowdsource geotagged data shows its potential for retrieving valuable and immediate information that is otherwise hard to retrieve, which can benefit visitors to urban parks.

2. Methodology

2.1. Geo-Spatial Data

For the analysis area of Central Park in Manhattan, an accurate and detailed DSM (Digital Surface Model) of the area was used, composed of gridded raster produced by LiDAR technology in a resolution of 1 foot (approximately

0.3 meters)[1] and with 3D buildings model[2]. Geotagged photos from Flickr database were retrieved for the same area. Flickr stores geo-located and temporal metadata information about the uploaded photos and the photographers who took it. the photographers' mobility patterns are analyzed by spatio-temporal descriptors associated with their geotagged photos (Mor & Dalyot, 2018).

2.2. Shadow Analysis by Line of Sight Analytics

Shadow computation is based on two main angels that define the sun position: azimuth and elevation. The angles are computed based on spherical trigonometry using the geographic location and the timestamp of the geotagged photos. The geographic coordinates of the sun are computed artificially based on the creation of a 3D vector from the origin point of the geotagged photo to a distant point using the parameters: azimuth, elevation and slant distance (defined as 5 km). 3D vector of the line of sight (LOS) analytics is used for visibility analysis using the generated DSM (Morello & Ratti, 2008), as presented in Figure 1. The result of the relational analysis between the artificial sun position and the location of the geotagged photos provides the inference between light (visible) and shadow (invisible) points to the sun. 3D LOS computation (shadow analysis) can be time-consuming, especially for the analysis of aggregated shadow over a continuous time period (Miranda et al, 2018); accordingly, our development is a discrete solution for shadow analysis that is computed efficiently for specific time stamps of visitors mobility, considering the 3D buildings' obstruction.

2.3. Unsupervised Data Clustering: DBSCAN

Unsupervised DBSCAN data clustering is implemented to obtain main visited attractions in urban parks (Vu et al., 2016); it is used to acquire knowledge about the current state of shadow at the clusters' locations. In our approach, we use the K-nearest neighbors (KNN) (Ester et al., 1996) for predicting the optimal values for the DBSCAN. An Euclidean distance was computed for all pairs of points for a different K value, and for each cluster, we compute the 90th percentile of the average distance. We extract the geotagged photos that fall inside each cluster and retrieve the photographers' information. For each cluster, we compute the percentage of photos that were

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[1] https://opendata.cityofnewyork.us/

[2]https://www1.nyc.gov/site/planning/data-maps/open-data/dwn-nyc-3d-model-download.page

taken while that location was in a shadow. For each cluster, we calculate the statistics of shadow, and carry out a temporal seasonal analysis.

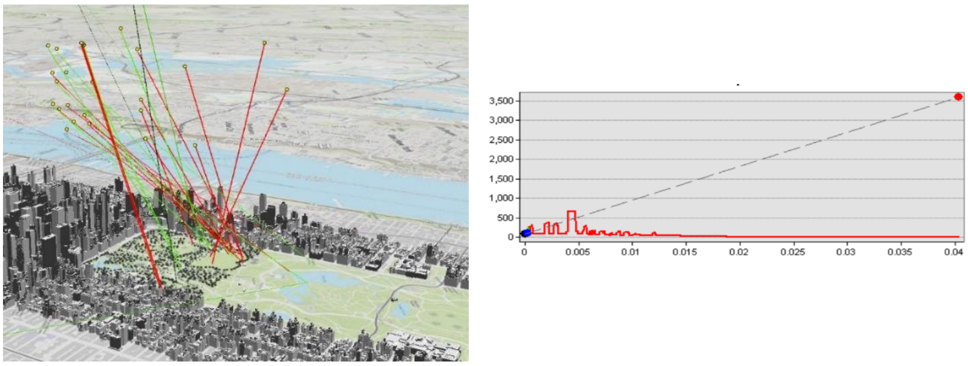


Figure 1. Left: 3D LOS analytics between geotagged photos and artificial points representing the sun (red: shadow, green: light). Right: profile visibility analysis.

3. Preliminary Results

Central Park, Manhattan, New-York, is considered as one of the most famous and visited attractions in the heart of Manhattan. This urban park is visited by residents and tourists alike and is the most visited urban park in the United States. A total number of 33,000 geotagged photos taken by 4,900 unique photographers were extracted for the region. We used photographers that took more than three photos (1,370 photographers) to allow the construction of valid visit mobility. Shadow analysis is computed for each geotagged photo independently and an aggregation process is achieved for gathering information for each photographer. Shadow analysis results are divided into two main subgroups: One main group consisting of approximately 200 visitors who are completely in the shadow, mostly at night-time, and the second main group consists of over 600 visitors that are in the sun.

150 clusters are found by using the unsupervised DBSCAN, depicted in Figure 2 (left). Exploring the DBSCAN parameters was conducted using the KNN approach and using the elbow method, as depicted in Figure 2 (right), evaluated according to the 90th percentile, indicating that the optimal values are 30 points (photos) within 30 meters. We analyzed the most popular places in Central Park that are extracted by our algorithm and are recommended on tourism websites[3]. The common visit time that people are not in shadow at different attractions in Central Park is between 12 pm to 2 pm, while the common visit time in shadow is between 4 pm to 5 pm (photos

[3] www.planetware.com/

that were captured at night-time are excluded). Analyzing over seasonally, the summer period of June to August is the less-visited season in Central Park by photographers. Usually, most people visit the main attractions during the spring season (March-June). Analyzing the shadows (%) at different clusters, depicted in Figure 3, we can see that the main attractions are usually visited not during shadow; however, when they are visited during shadow, they are likely to be at the southern attractions who are shadowed by the skyscrapers that are located south to Central Park; for example, the Pond area is 15% visited while in the shadow.

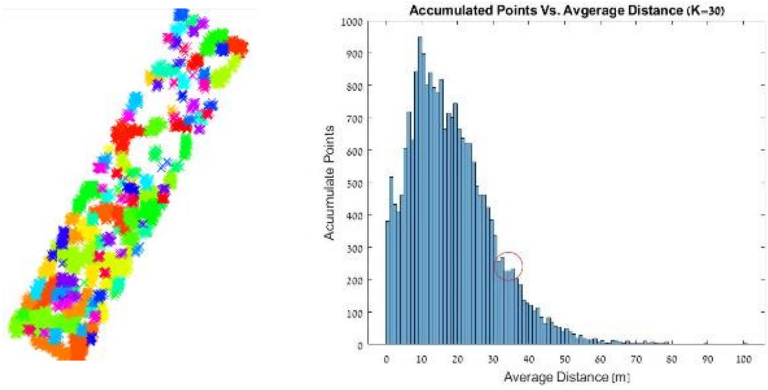
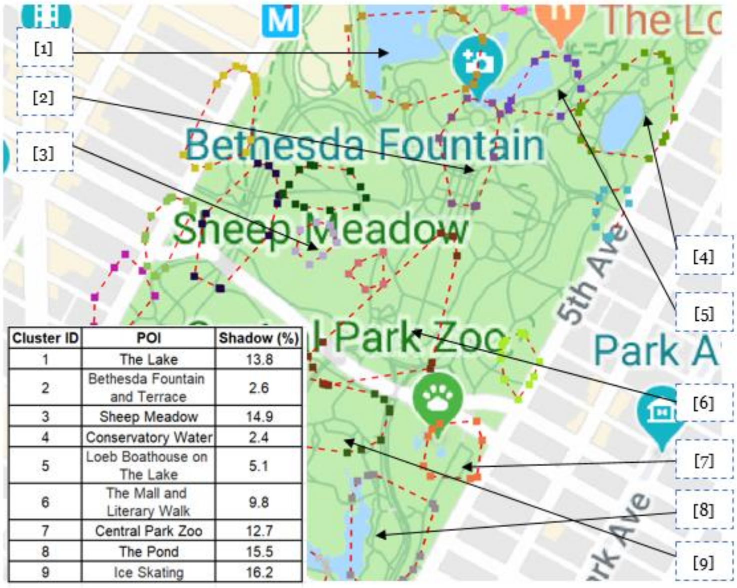


Figure 2. Left: DBSCAN clustering (each color represents a cluster). Right: KNN statistics analysis of the average distance for amount of points (red circle represents the optimal value using the elbow method).

4. Conclusions and Future Work

Experiments show very promising results in exploring and recovering visitors mobility in urban parks while considering existing building shadows by integrating user-generated crowdsourced data for analysis. We have managed to study the temporal behaviour of visitors in Central Parks' main attractions during shadow at different seasons. Integrating a more detailed and high-resolution DSM infrastructure that includes canopy would improve the visibility computation analytics, while improving our clustering implementation to retrieve better results. Future work will include deeper understanding of the visitors routing considering shadow, and to develop a recommendation system that will use shadow and additional environmental and temporal parameters to recommend route planning. We believe that development of urban parks is an important key role of development in various disciplines; urban designers and planners, city municipalities and tourism facilities could better plan the effect of urban structures on urban parks regarding the visitors mobility in attraction areas by using updated and dynamic geotagged crowdsourced data.



Cluster ID	POI	Shadow (%)
1	The Lake	13.8
2	Bethesda Fountain and Terrace	2.6
3	Sheep Meadow	14.9
4	Conservatory Water	2.4
5	Loeb Boathouse on The Lake	5.1
6	The Mall and Literary Walk	9.8
7	Central Park Zoo	12.7
8	The Pond	15.5
9	Ice Skating	16.2

Figure 3. Shadow analysis at the southern Central Park area according to different attractions (background layer: Google Maps).

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L'd Up: Examining the Effects of a New York City Metro Shutdown on Public Discourse Using Twitter Data

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Abstract. In 2016, announcements of a major renovation plan of the L train Metro line in New York City sparked intense discussion among commuters. In this study, we use Twitter data from 01/2016 – 04/2019, geolocated in New York City, to investigate the sentiment in the population towards topics related to different aspects of the shutdown. The results indicate the strongest sentiments towards alternative travel modes and the effects caused by the shutdown. We further show how the sentiments differ in their spatial clustering characteristics. Tweets conveying a negative sentiment toward the L train tend to cluster in lower Manhattan whereas positive and neutral hot spots are slightly less intense and spread out more evenly.

Keywords. transportation, sentiment analysis, twitter, urban planning, traffic disruption, planned events

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1. Introduction

The New York City Subway serves as a means of transport for almost 5.48 million daily passengers, up to 420,000 of which use the L train on BMT Canarsie Line[1], which connects the boroughs of Manhattan and Brooklyn with a tunnel crossing the East River. After being flooded and damaged in 2012, the tunnel was only partially renovated. In 2016, the operating agency proposed two scenarios for a full renovation, starting in April 2019: either a three-year partial closure affecting one of the two tubes at a time, or an 18-month full shutdown. The plans sparked intense discussion among those affected by the shutdown, as it would interfere with their commuting routines by causing side effects like longer travel times or higher costs. For context, table 1 provides an overview over the timeline of events. In this paper, we use geolocated Twitter data from 01/2016 – 04/2019 (n = 29,556,272) from New York City and use natural language processing and spatial hot spot detection methods to assess how the shutdown reflects in the public discourse and sentiment of Twitter users and what the spatial characteristics of these effects are. Due to the Twitter data being obtained from different sources, the total number of tweets varies over time, which explains the overall increase of data counts from late 2018 onward. The insights gained from this study can help decision makers understand the impact of traffic disruptions on the affected population's subjective feelings on a highly granular level. This is not only important for the planning process, but also for information announcement strategies that acknowledge and respect sensitive topics.

Table 1: Timeline of selected events and public announcements regarding the L Train

25.07.2016	MTA decides on full shutdown for 18 months beginning in 2019
24.01.2018 - 14.02.2018	MTA holds open houses to raise awareness of the official L train shutdown mitigation plan
17.03.2017	MTA announces the closure will only last 15 months beginning in 2019
03.01.2019	Gov. Cuomo announces there will be no shutdown
13.02.2019	MTA releases a draft plan for evening and weekend repairs starting 27.04.2019

[1]http://web.mta.info/nyct/facts/ridership/ridership_sub.htm

2. Methods

Text preprocessing: To make the text matching used for the subsequent sentiment analysis consistent and performant, we developed a tailored preprocessing workflow using the built-in text search functionality of the PostgreSQL database management system. In our custom text search configuration, the preprocessed texts do not include stopwords or non-words like numbers or URLs. To further improve the text-matching quality, we applied stemming to eliminate ambiguous word endings of synonymous words. We also manually defined a number of n-grams, so groups of multiple words that are treated as one semantic term, e.g. *real estate* or *New York*.

Message Categorization: Because we aim to understand public discourse, we categorized all message texts based on manually defined semantic groups, each related to an aspect of the shutdown. Each group is made up of several keywords, which we initially chose manually and then refined based on the most frequently used words in each group. The groups are policy, effects, alternatives, actors, destination/purpose of travel, location, and L train. If a message text contains a keyword from a given group, a link between the message and the group is established. This check is performed for all groups, thus allowing $n{:}m$ relationships. Categorizing the data allows us to observe whether public discourse of the shutdown changes over time and what topics are most prevalent. It further allows us to focus parts of the analysis specifically on messages including the L train. All results shown below are derived from tweets belonging to the L train topic (n = 3,348).

Sentiment Analysis: We performed sentiment analysis of the tweets' texts to determine whether a tweet contained a positive, neutral or negative emotion. We matched every word or n-gram in the message texts to the corresponding sentiment value in a sentiment lexicon (Hu and Liu, 2004) and summed up the values of the whole message text. The resulting sentiment score s was interpreted as negative, if $s < -1$, neutral if $|s| \leq 1$ and positive if $s > 1$ (Kovacs-Gyori *et al.*, 2018).

Hot Spot Analysis: We performed a hot spot analysis based on the Getis-Ord G_i^* statistic (Ord and Getis, 1995) for the point coordinates of tweets associated with the L train topic, grouped by sentiment. We chose a p value of 0.05, so only hot spots with $|G_i^*| > 1.96$ were considered in the results. The grid size of the statistical units is based on a heuristic used for square cells (Wong and Lee, 2005) and adapted to yield hexagonal grid cells of equal area with an in-circle radius $r_i = \sqrt{A/(n \cdot \sqrt{3})}$ with A being the area of the study region and n the total number of tweets. This setup allowed us to detect whether there are statistically significant spatial clusters of the sentiment groups in the area of interest and if so, compare them.

3. Results

Different discussion topics vary not only in size, but also in composition of sentiments over time. The groups of highest relative sentiment are *Alternatives* and *Effects* (see figure 1). This means that messages concerning these topics tend to be composed of a more emotion-laden vocabulary than others and gives an indication of a strong opinion towards the topic. The value of this knowledge lies in understanding the topic-sentiment links and acting accordingly. In this case, the responsible agency could respond by showing to the public their efforts to minimize negative effects on commuters and creating or promoting viable alternatives. The result maps of the spatial analysis shown in figure 2 indicate that, as expected, L train related tweets tend to cluster around the L train Metro line. The strongest clustering effect for all three sentiments is in the vicinity of the 14th Street station and negative hot spots are more concentrated in Manhattan. Like the results shown above, the spatial distribution of sentiments is also essential for understanding and acting upon the public opinion towards a topic. The strong clustering of tweets with negative sentiment in lower Manhattan may indicate that a disproportionate amount of commuters are experiencing difficulties in that area, although this conclusion may be skewed by the high tweet frequency in the area.

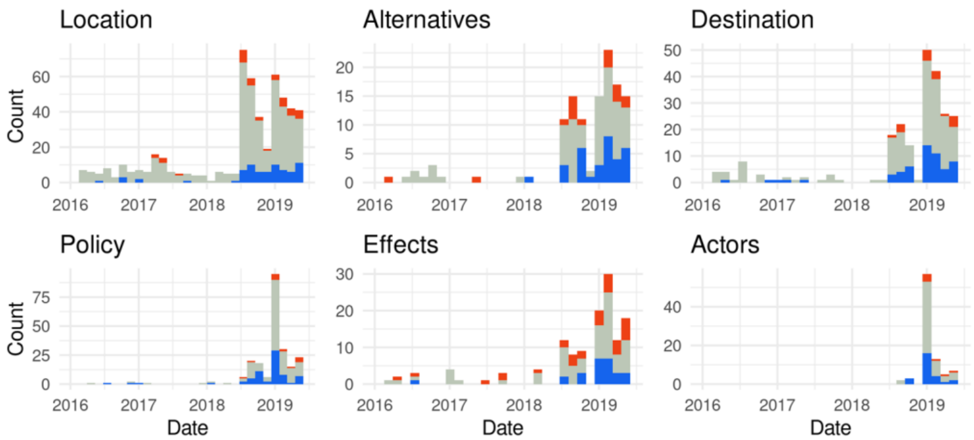

Figure 1: Sentiments in different groups over time within the L train topic (red=negative, gray=neutral, blue=positive). For readability, the graphs use different scales on the y-axis.

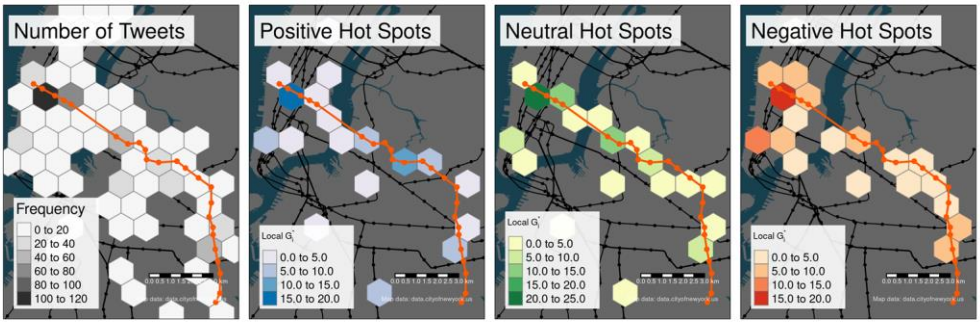

Figure 2: Number of L Train related tweets and distribution of L train topic tweets with positive, neutral, and negative sentiment.

4. Discussion and Conclusion

There are several promising strands of analysis that could be completed in the future. Because, beginning in April 2019, L train service was curtailed on evenings and weekends analysing the content of tweets by time of day will reveal the degree to which the slowdown affects the sentiments of those tweeting. Pairing these data with a spatial analysis would identify particular service pinch points. These could be contrasted with similar data collected on evenings and weekends in July and August 2019, where service is slated to be shut down completely during certain hours. Again, this will help us understand what areas of the city were most affected by the service changes and when allowing us to better model who is using the subway and for what purposes. Contrasting both with construction shutdown dates prior to the slowdown will enable us to gauge how sentiment reacts to (relatively) planned and publicized service changes (such as the current L train slowdown) versus unanticipated closures. Finally, analyzing the content of the tweets may enable researchers to pinpoint what types of adaptation people may have taken in response to the service changes.

However, some caution should be taken in interpreting this data. The segments of the population that take to Twitter to vent their transit-related frustrations (or successes) publicly may not be an accurate sample of L train ridership. Similarly, limiting the analysis to English-language tweets excludes the large Spanish- and other foreign-language speaking population resident along this transit line. Further, the sentiment analysis results still leave room for interpretation. For example, all topics show a bias towards positive emotions, which might seem surprising given the context of traffic disruptions. This might be attributable to the universal language positivity bias shown by (Dodds *et al.*, 2015). Other effects like the relative decrease of responses in the *Alternatives* category can be observed but not causally explained, which is a limitation from working with only one data source. Future work would therefore benefit from integrating additional data sources like questionaries or news articles in the analysis.

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WordCrowd – A Location-Based Application to Explore the City based on Geo-Social Media and Semantics

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Abstract. WordCrowd is a dynamic location-based service that visualizes and analyzes geolocated social media data. By spatially clustering the data, areas of interest and their descriptions can be extracted and compared on different geographical scales. When walking through the city, the application visualizes the nearest areas of interest and presents these in a word cloud. By aggregating the data based on the country of origin of the original poster, we discover differences and similarities in tourist interest between different countries. This work is part of the project Eureca: European Region Enrichment in City Archives and Collections of Ghent University (IDLab, CartoGIS), the Technical University of Vienna (Research Group Cartography) and several city and state archives from Ghent and Vienna.

Keywords. Geo-social Media, Location-based Service, Spatial Clustering, Word Clouds

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1. Extraction and Visualization of Areas of Interest

A post on social media reflects the thoughts and feelings of the poster about a certain topic as a data point in space and time. By focusing on the location of the post instead of on the content, areas of interest (AOIs) can be extracted as areas with a higher post density. By spatially clustering these points, these AOIs are automatically extracted and most of the noise is filtered out. The dataset (Verstockt et al. 2019) used for this research consists of geolocated Flickr pictures and their associated tags. It covers continental Europe with metadata of all the images uploaded from 2004 to 2018. Nevertheless, our approach and application can work with any type of geolocated textual data.

The clustering technique is an essential part of this analysis and modifying it will impact the number of AOIs, their size, shape, and contents. In this research, HDBSCAN (Campello et al. 2013) is used as the main clustering algorithm. HDBSCAN is an extension of the popular density-based DBSCAN algorithm and performs better on datasets with varying densities. By changing the parameters of the algorithm, the clustering can be performed on different scales. This multi-scale clustering is necessary for an interactive LBS application, as the user might be overwhelmed with a large number of smaller clusters when he zooms out on the map. To ensure the application works in real time with a dynamic interface, we have preprocessed the data into multi-scale clusters and visualize only the nearby clusters instead of all the nearby points.

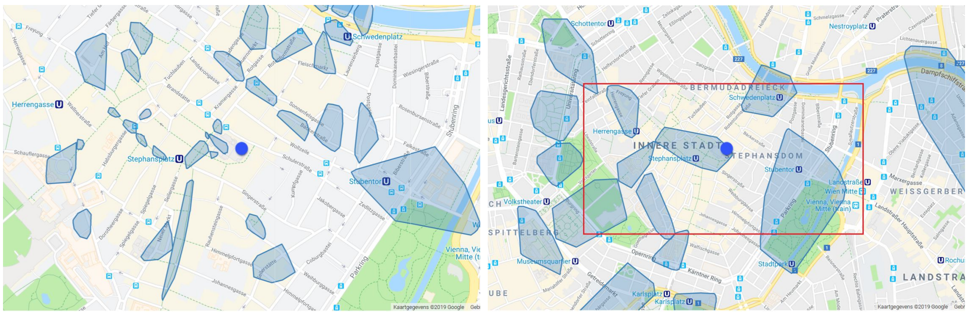

Figure 1. Visualization of the smallest clusters for a part of Vienna (left) and the larger clusters when the user zooms out (right). The user's current position is marked with a blue dot.

When the user zooms out, the application will fetch and visualize the larger nearby clusters from the database to reduce the network and memory load. *Figure 1* shows this functionality. Clicking an AOI displays its aggregated tags in a word cloud. This provides an intuitive visualization of the tags contained in each AOI.

Initially, the points located in Austria (370,000 points) were clustered on three scales, resulting in 845, 79, and 8 clusters. For each cluster, we aggregate and preprocess all the related tags. The top 100 most frequently occurring tags and their frequency are then saved in our database. This gives us geolocated AOIs and their descriptions generated from the Flickr picture tags. Afterward, this process was repeated for all the points located in Belgium (430,000 points).

Because we are dealing with very noisy and multilingual picture tags, these need to be preprocessed to improve the generated word clouds. First, all the tags were translated into English to provide a common language for the following preprocessing steps. Next, irrelevant tags like brand names and stop words were removed. Afterward, NLP techniques (close/sequence matching and stemming/lemmatization) were used to group very similar words together. Finally, redundant multilingual place name tags were removed. Most pictures include a tag with the current place name, making that tag the most important one for that area. However, its inclusion in the word cloud is redundant, as the user already knows where he is or which area he is looking at on the map. These multilingual place names were filtered out with the use of Wikipedia and Wikidata.

These techniques made the resulting word clouds much clearer, but they still contain some errors. The most common errors are due to a bad translation or due to joined tags that are normally written with a space in between (e.g. *domkircheststephan)*. This is a common problem with social media tags. The emergence of tags relating to the name or company of the photographer is another problem that occurs within the word clouds of smaller clusters.

This spatial clustering of data shows us the AOIs for each region and its general description through the eyes of the crowd. The AOIs often coincide with landmarks and popular areas of each city. As a next step, we investigated if there is a difference in extracted AOIs when comparing people from different nationalities.

2. Tourism Interest Analysis

Only a fraction (32%) of the Flickr users provided information about their home location in their user profiles, limiting the available data for some countries of origin. To classify the other users, a home determination method was developed based on Bojic et al. (2015). The method considers all the posts created by each user and the country in which he has the most pictures is considered as a potential country of residence. If the time span between the first and the last post is greater than 6 months, the user was classified as a resident of that country. This algorithm was validated on the fraction of users who supplied information about their country of residence. This information was first preprocessed with a gazetteer[1] to determine the English name of the city or country provided by the user. The developed algorithm achieved a precision of 0.87, a recall of 0.76 and an F_1 score of 0.81.

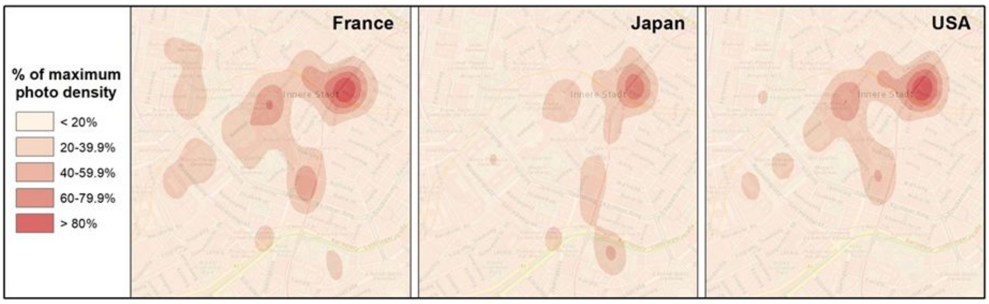

Figure 2. Footprints of visitors from France, Japan, and the USA in Vienna.

Kernel density estimation (KDE) (Grothe & Schaab, 2009) was selected as a visualization tool to generate continuous raster surfaces from the points. These rasters are heat maps representing areas with varying picture densities. KDE was chosen as most users are already familiar with the concept of heat maps and it is immediately clear where the hotspots are located. Each heat map shows the unique footprint of visitors from a certain country of origin. These heat maps can be compared for different countries, to analyze the differences in tourism interest. *Figure 2* shows the footprints of visitors from France, Japan, and the USA in Vienna. We see that the most popular areas of interest (the most popular tourist attractions) are shared and that larger differences occur in the less popular areas.

When looking at the generated tags for different nationalities, many tags are universal and widely used in the same locations. The most common tags are the more generic ones such as architecture, church, and travel. Between some nationalities, there can be major differences in the areas or topics of interest. *Figure 3* shows the word cloud for all points in Belgium from Dutch and English tourists. All of the points were included because the data is rather limited for specific regions of Belgium. It is clear that the interest of Dutch visitors, or at least those who posted on Flickr, is more focused on

[1] https://www.geonames.org/

leisure activities (*tomorrowland, motorsport*) whereas the English tourists are more focused on traditional tourism. Tags related to the First World War (*passchendaele, thegreatwar, memorial*) show up in the data for English tourists, as Belgium (especially Ypres) is often visited to commemorate the Great War and its casualties.

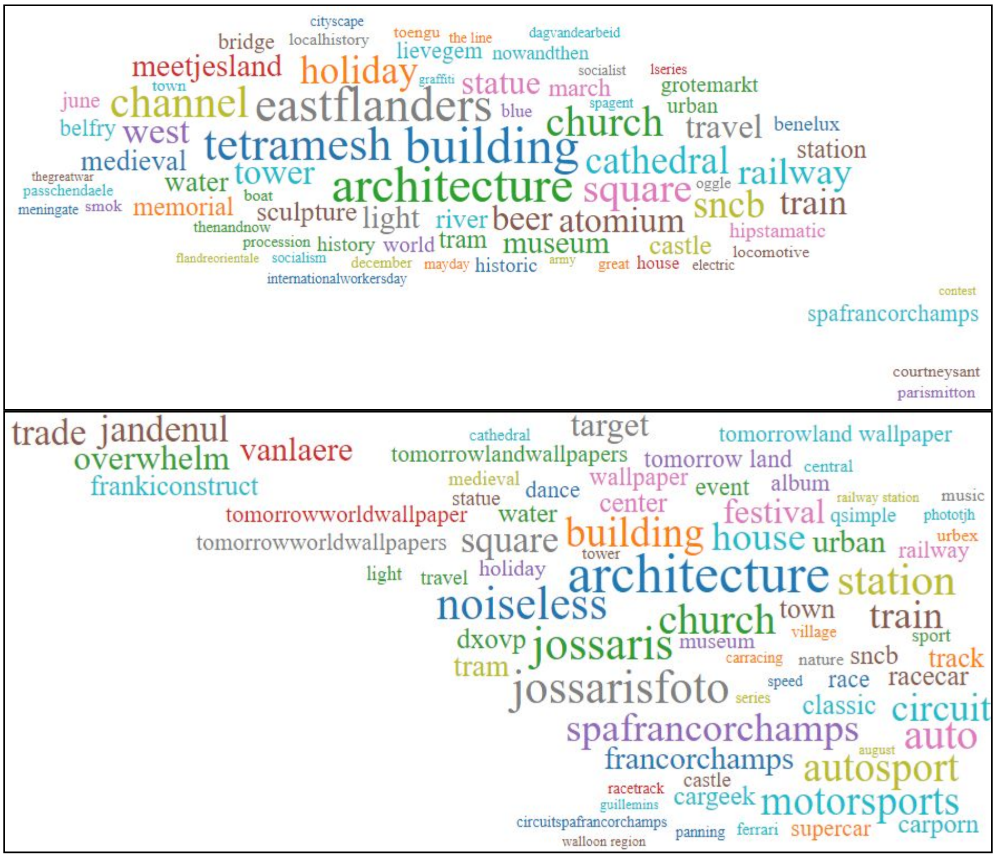

Figure 3. Word cloud of all points located in Belgium for English (top) and Dutch (bottom) tourists. Words are positioned relative to the user's location, which is Brussels for both word clouds.

3. Current State and Future Work

Currently, the AOIs situated in Belgium and Austria are extracted at three different scales and their tags have been preprocessed and clustered. These clusters are visualized in an interactive map, where the word cloud of each cluster is shown when it is clicked. The current prototype[2] is live and we

[2] https://tw06v072.ugent.be/wordcrowd/map/

have made the dataset[3] publicly available. As suggested by Tessem et al. (2015), the word cloud algorithm was adjusted based on the location of each tag. The positions of the words on the word cloud correspond to the location from where they were extracted, relative to the current user position. Both word clouds in *Figure 3* were constructed with Brussels as the user's location. The tag *Passchendaele* is located on the left side (west) and *Francorchamps* is grouped with motorsport-related tags on the bottom-right (southeast). This visualization offers the benefit that it often groups related tags from the same place together, at the cost of introducing additional whitespace.

As a next step, data aggregation and semantic clustering are the focus of this research. We aim to collect additional data sources, aggregate these based on mentioned place names via geoparsing and summarize the information with meaningful tags. Incorporating more advanced NLP techniques to hierarchically cluster semantically similar tags (e.g. replace *cathedral* with *church*) can also help reduce the noise in the generated word clouds. When a user shows interest in a specific tag of an AOI, he will be redirected to the original content. WordCrowd would then serve as an easy-to-use LBS tool to aggregate and explore the vast collection of public data available when visiting Europe.

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[3] http://bit.ly/wordcrowd-dataset

Snap4city Platform: Semantic to Improve Location Based Services

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Abstract. Location-based Services are becoming crucial in the most recent smart city scenarios, when, according to scholars and urban planners, one of the main objectives is to improve the living conditions of citizens who act and move within an urban or regional area. This work-in-progress paper aims to present the Snap4city platform, an infrastructure capable of collecting large geographical and statistical data from different sources, to integrate them into a semantic and is compliant with the Km4City multi-ontology and finally provide LBSs for multiple users. The Snap4City platform is currently running in many geographical contexts (such as Antwerp, Helsinki, Santiago de Compostela, etc. Italian cities such as Florence, Cagliari, Pisa, Livorno, Modena, Bologna, etc. and entire geophysical zones: Finland, Belgium, Tuscany, Sardinia, Garda Lake, etc.). This allows the authors to present preliminary results for system validation.

Keywords. Smart City, Big Data; Geospatial Ontology, Geospatial APIs

1. Introduction

The amount of information available today is such that issues relating to the quality and significance of it must be addressed already in the designing of an architecture supporting the smart city. Reference scenarios must be well defined to analyse the specific needs of citizens and their behaviour and the actions that contribute to achieving them. Within these scenarios the geo-referenced information is crucial in order to get context-sensitive description and analysis of emergent local practices. Add to this that each city is to solve their specific problems, due to its geographical position, its geomorphology or history and culture that make it a *unicum*. For these reasons,

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even though digital and technology-driven approaches are often considered in literature as a universal solution, when it is intended to replicate a model in different cities, individual specificities must be taken into account and therefore develop strategies that may get inspiration from other contexts but are as unique and specific as the city itself. In this logic, the experimentation conducted in different urban and regional areas through Snap4City architecture highlights the paradigm shift, since it does not adopt a simply technology-driven but more specifically data-driven approach. Big Data, open data, sensors, IoT/IoE for monitoring, controlling and managing urban developments, resources, urban infrastructures, energy consumption, traffic congestion, waste, pollution, risks and people, are the tools for a governance inspired by a data-driven urbanism, according to which the expected changes are a consequence of a decision-making process. (Acuto et al., 2019). The nowadays availability of geospatial knowledge and the worldwide generation of geospatial data allow to design services that can support decision making and help to find solutions to daily life problems. However, "the lack of explicit semantics inhibits the dynamic selection of those data, services, and geoprocessing workflows needed for processing geospatial information and discovering knowledge in a data-rich distributed environment" (Yue et al. 2011). An ontology-based approach allows the representation and semantic interoperability of geospatial data and related processes. The integration of semantic information makes LBSs intelligent and able to enhance a smart city. In order to cover all these aspects and manage the large amount of data coming from different sources, from the Smart Cities Open Data Portals to the IoT/IoE connected devices (sensors, actuators and various agents rapidly increasing in number in a smart city context), a Big Data approach is necessary. One of the most innovative tools, is to flank to a Big Data Platform, the possibility of aggregating data at a semantic level allowing data to communicate among themselves. Thus, the aggregated data, can be used to extract new knowledge and develop services for citizens increasingly performing and focused on their needs. In such a context a Big Data Platform must be compliant with: i) Data Precision in terms of Geospatial representation and timing; ii) Semantic Data Aggregation; ii) Scalability in terms of data stored/managed and services provided; iv) Guarantee of different Privacy Levels.

2. Snap4city Architecture

The Snap4City infrastructure respects all the requirements above described. Snap4City is a Big Data Platform compliant with the KM4City multi-ontology, managing and aggregating data from EU cities and regions.

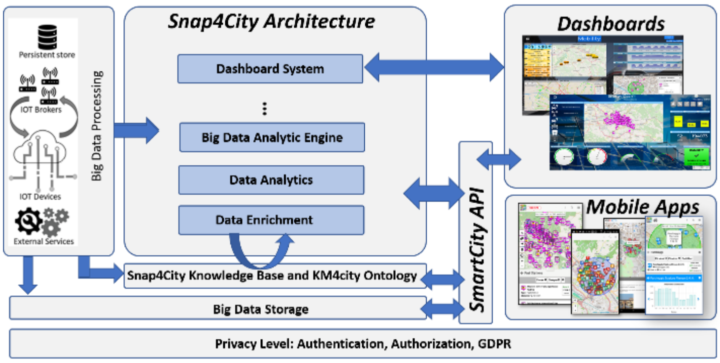

Figure 1. Snap4City Architecture.

In Fig. 1, the Snap4City Architecture is depicted. The starting point is the Big Data Processing (harvesting, formalization, geo-localization enrichment, storage, etc.), all the ingested data are aggregated and collected in the Snap4City Knowledge Base, in compliance with the Km4City multi-ontology (Bellini et al., 2014), and indexed in order to speed up and facilitate data retrieval. A such semantic aggregation of data poses the basis to provide LBSs to the final users, always at the forefront both in terms of functionalities offered and of performance achieved. These activities are included in many European (Snap4City, TRAFAIR, Replicate, etc.) and national (Sii-Mobility, Ghost, MOSAIC, etc.) research projects. Thus, the aggregated data can be Analysed and used to produce Smart LBSs by generating predictions and suggestions for final users. The Snap4City solution allows to ingest and manage Big Data coming from different providers, External Services, OD Portals, ArcGIS Enterprise Servers, IoT/IoE devices, applications and services, and finally provides LBSs, available to the final users thanks to the set of visual tools developed. A Dashboard System allows all registered users to easily create a set of different thematic dashboards (weather, mobility, energy, etc.), respecting user authorizations and privacy level on the data (Snap4City is GDPR compliant). These interactive dashboards support decision-making processes for: Public Administrations, tourists, citizens, developers, etc. Moreover, Snap4City allows the creation of data-driven applications: based on Microservices, exploiting mobile and web apps, flows of processing data and IoT data (Bellini et al., 2018; 2019).

3. Km4City Multi-Ontology

The need to standardize and aggregate data becomes increasingly necessary in a Big Data context, for this reason the Snap4City solution is based on the Km4City multi-ontology. The development of Km4City started in 2013 to interconnect the data provided by the Tuscany Region, the Open Data of the City of Florence (Static and Real Time). Some notable works included are:

(i) the Ontology of Transportation Networks (Lorenz et al., 2005); (ii) the Semantic Sensors Network Ontology (Compton et al., 2012); (iii) the IoT Lite Ontology (Bermudez-Edo et al., 2016); (iv) the Schema.org Ontology (Hernich et al., 2015), that now also includes the GoodRelations project. Km4City enables interconnection, storage and the retrieval of heterogeneous data from many different sources. Its main sections are: (i) *administration*; (ii) *road infrastructure*; (iii) *POIs*; (iv) *public transport*; (v) *Internet of Things (IOT)*. Predictions and early warnings, mobility planning, multimodal routing, resiliency, are just a few of the challenges that can be faced to improve city governance and people behaviours, and therefore citizens' quality of life, tourists' satisfaction, environmental sustainability. On the other hand, IoTApps are required to: (i) collect huge amounts of heterogeneous data at real-time; (ii) be resilient and ensure safety, security and privacy of distributed data and communications; (iii) enable machine learning and data analysis; (iv) enable effective data displaying (Badii et al., 2019). The Km4City Ontology also includes a set of concepts for modelling real-time status and predictions and a flexible modelling of IoT/IoE entities has been achieved, introducing *IoTSensor* and *IoTActuator,* and *IoTBroker* with its specializations *NGSIBroker*, *MQTTBroker*, etc. Types of measurements and managed input signals are modelled as *DeviceAttribute* instances*,* each having a *value_type* property filled by an SSN *Property* (Compton et al., 2012) that allows to distinguish devices that measure temperatures from those that measure traffic flows and so on.

4. Snap4city Location-Based Services

LBS are largely dependent on the data coming from IoT/IoE and from the mobile user's location: understand where the user is and what are his/her needs, is one of the primary objectives of a service provider system.

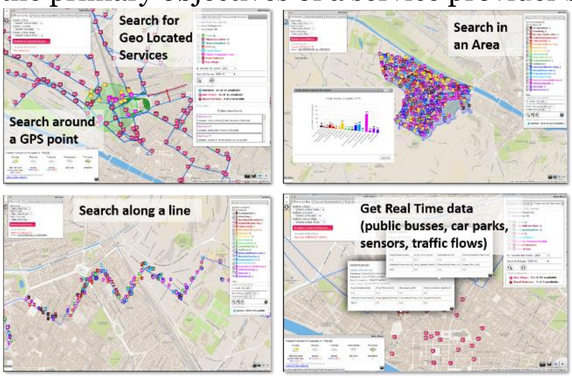

Figure 2. Snap4City Geographical searches.

Some of the most common LBS applications include: POI, local events, multimodal routes, emergency, asset tracking, weather forecast, statistics, previsions, etc. All the services can be requested by the users (pull) or sent to them in form of recommendations (push). The Snap4City most common LBS requested by the users could be services: i) around a user (GPS point); ii) in a specific geographical area described (e.g. a polygon in Well-known text format); ii) among a line; iii) related to the Public transport lines, routes, timetables, etc. (Fig. 2). The Snap4City Recommendation System is capable to establish what are the user needs and sending them suggestions basing on their position in the city (via Mobile Apps, totem, etc.).

5. Conclusion. Snap4city Validation Scenarios in Smart Cities

The Snap4city platform is currently used in many cities and regions. The Snap4city APIs allow accessing all this information from different applications. Some mobile applications have been developed (e.g. Helsinki in a Snap, Antwerp in a Snap and Tuscany in a Snap) to leverage all these geographically annotated information and provide useful services to the citizens or tourists on the move from their mobile phones (find services nearby, time tables, heatmaps of pollution or weather conditions, etc.).

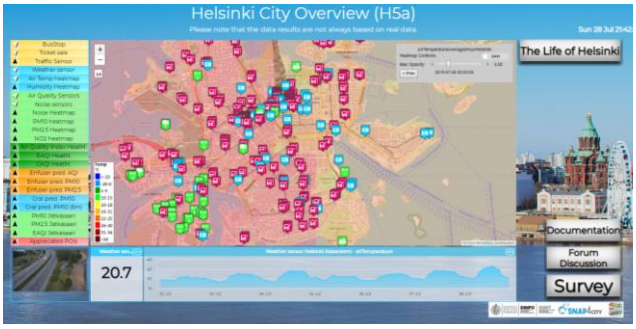

Figure 3. City of Helsinki dashboard

The platform allows building custom dashboards using the data coming from the city. The dashboards can use maps allowing users to locate services and access to data associated to them, such as that developed for the city of Helsinki, Fig. 3. The experimentation of the platform in the context of the Select4Cities project is currently in progress (July-October 2019) testing the Snap4City tools in Helsinki and Antwerp cities. Table 1 reports the Snap4city geographical search APIs use, in different cities in the month of July 2019. Most of the APIs used are related to geographical searches (93%) and performed in a circular shape; while searches in a rectangular area reach the 6.5% of total. The advanced searches inside a complex polygonal area or along a path cover the 0.13% of the requests.

Geo search Type	N. requests	
Coord & radius	445,608	93.32%
Rectangle	31,248	6,54%
Polygonal area/path	655	0,13%
Total	**477,511**	

Table 1. Snap4city geographical search API.

6. Acknowledgement

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Drone Imagery for OpenStreetMap Sidewalk Data Enrichment

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Abstract. Several Location Based Services (LBS) are developed from open sources. The OpenStreetMap (OSM) is most stable and used one and, besides being open data source, has a collaborative characteristic, known as Volunteered Geographic Information (VGI). In this context, some routing services have emerged supported by LBS and VGI, and personalization has become a trendy. However, customization as wheelchair and pedestrian route planning requires specific and detailed information about sidewalk. Currently, most sidewalk in OSM are nearly missing or tags absent. Besides that, there is a lack of standardization for mapping this data. In a first moment, this study was developed aiming to fill this gap by using remote sensing, specifically Drone. The procedure for data enrichment proposed consists of: (i) data completeness search; (ii) data acquirement and processing, and (iii) data availability. The initial results showed that the pilot area has a high degree of incompleteness and, once drone imagery was provided, sidewalk could be mapped based on the resulting orthomosaic. The next step will be a study targeting sidewalk tags and features pattern definition. At the end of this study, besides the exploration of the possibility of high quality imagery sharing, sidewalk standardized mapping may improve location based services data for engines, such as wheelchair and pedestrian routing.

Keywords. Location Based Service, Volunteered Geographic Information, OpenStreetMap, Sidewalk, Drone, Remote Sensing.

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1. Introduction

There has been several innovations and applications for drones – or unmanned aerial vehicles (UAVs) – among location based services (LBS). Technology development has increased its uses in urban areas, mainly approaching buildings and streets mapping tasks in order to provide information for LBSs (Alwateer, Loke, and Zuchowicz 2019).

Despite is unlikely that everyone will have a drone - as happened with the smartphone spread phenomenon - there is a trendy that drones will integrate a range of location based services in different ways. For example, there are already companies offering drone products and services. (Alwateer, Loke, and Zuchowicz 2019).

Open sources engines has also incorporated drone technology, exposing new possibilities for Volunteered Geographic Information (VGI). In this context, OpenStreetMap (OSM), which is the most widespread VGI project, allows high quality aerial imagery - including drone – visualization. The images can be uploaded at OpenAerialMap[2] (OAM) and then used as a layer at OSM editor (online or Java OSM App - JOSM).

Currently, OSM is supported by Bing imagery layer, which provides resolutions up to 15 meters depending on world location. In contrast, drones can reach an average of 10 ~ 15 square centimeters per pixel, depending on different aspects, being flight altitude and camera type the most decisive (Domingo et al. 2019).

This level of resolution would allow users to map details undistinguished at most common satellite images. Sidewalk is an example of limited feature to be outlined utilizing low-resolution image, aspect that could be attenuate by using high quality images.

In the case of sidewalk in OSM, there is a recurring case of completeness related to lack of data. This is a result of sidewalk being mapped as a street tag ("yes", "no" or "both") until 2016, ignoring sidewalk characteristics such as width, surface, incline and accessibility. Just recently sidewalks have started being mapped separately (Neis and Zielstra 2014), mostly due to remote mapping complications. In other words, OSM sidewalk identification task rely on local users, whith site knowledge.

According to Zipf (2016), completeness of data is one of the most relevant aspects towards LBSs. Van Oort (2006) refers to completeness as both missing/defective data and extra/overlapping data, being the first one called incompleteness and the second one overcompleteness.

[2] https://openaerialmap.org/

OSM data incompleteness can be measured in different ways. The tool OS-Matrix[3], which is no longer available, was able to calculate the number of objects of a selected featured. One tool widely used that is still available is OSM Quality Assurance[4] that can identify ways and streets without tags, being able to highlights streets without sidewalk tag.

Nevertheless, none of these tools interacts with sidewalk data mapped as an independent feature. Approaching this issue, an engine available at uMap[5] is able to highlight in screen sidewalks in this way.

Additionally, the knowledge of what must or must not belong to the complete set of data is imperative (van Oort 2006). In simple words, for wheelchair and pedestrian routing proposes, besides knowing if sidewalks were mapped, we need to know if the OSM tags were properly assimilated.

The present study approaches a possibility for sidewalk data mapping using a remote sensing technique based on the unmanned aerial vehicle Drone. The central idea is to evaluate the methodology potential by updating the imagery product to OAM, allowing OSM users to incorporate orthomosaics as a layer during collaborative mapping. We choose a central city area in Brazil, in São Carlos municipality (São Paulo state) as a pilot study.

2. Methodology

In this section, we discuss the method used for OSM sidewalk data enrichment developed in a pilot area located in an inner city of São Paulo state in Brazil, São Carlos urban central area (22°01'S; 47°53'W).

The proposed procedure aimed remote sensing OSM edition and comprised three main steps: (i) data completeness search; (ii) data acquirement and processing, and (iii) data availability.

Completeness search consisted in a real-time OSM data checking process performed in “uMap - Pedestrians Overlay”, focusing on verifying the need for sidewalk features enrichment.

Once confirmed some level of incompleteness, data acquirement started using the unmanned aerial vehicle DJI Phantom 4®. This quad copter Drone was equipped with a camera with the following specifications: sensor 1/2.3” (CMOS), effective pixels:12.4 M, lens FOV 94° 20 mm (35 mm for-

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[3] https://github.com/GIScience/osmatrix-client

[4] http://editor.osmsurround.org/

[5] http://umap.openstreetmap.fr/en/map/pedestrians-overlay_21247#6/51.000/2.000

mat equivalent) f/2.8, focus at ∞, image size 4000x3000, photo format JPEG, DNG (RAW) and approximate focal length 3.61 mm.

Then, data was processed through Maply[6] online platform. The resulting orthomosaic was made available online in OAM. Once available there, sidewalk features and tags could be designed at OSM online editor.

3. Preliminary Results

The initial and the final search regarding completeness are presented in *Figure 1a*, scanned before data enrichment, and *Figure 1b*, scanned after data enrichment.

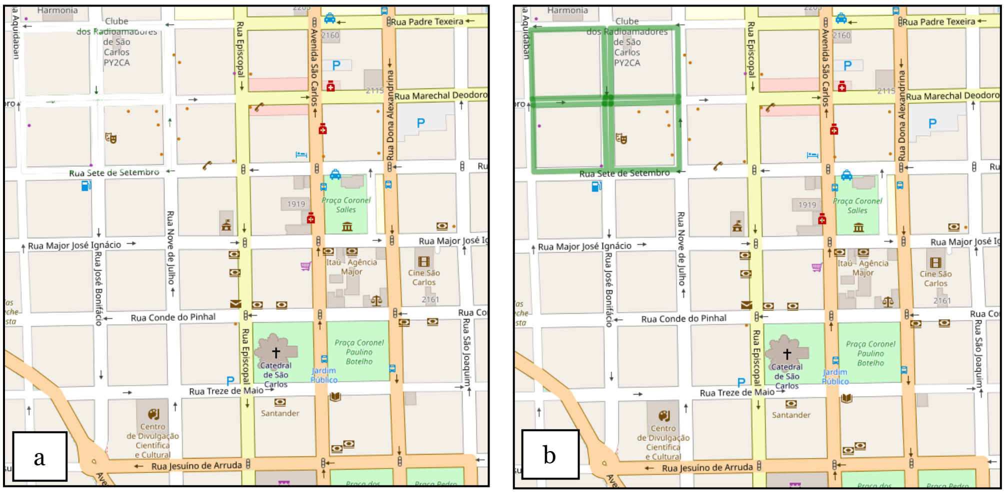

Figure 1. Study area scanned around completeness. Green lines (in b) shows sidewalks mapped separately (uMap, 2019).

In *Figure 1a* none sidewalk mapped separately was identified, meaning a high degree of incompleteness and, therefore, being suitable for data enrichment. *Figure 1b* represents the same measurement after a testing sidewalk mapping at OSM using the resulting drone imagery as a base map layer, exposing the effectiveness of the measurement method.

As proposed, data acquirement was performed imagining approximately 0.4 square kilometers, with 80% of longitudinal and 70% of lateral overlap. The orthomosaic photo obtained resulted in a ground resolution of approximately 0.12cm^2/pixel, a 28137 x 25920-pixel resolution and an 8-bit radiometric resolution (see a fragment of it in *Figure 2b*).

[6] Complete platform for drone data processing: https://www.maply.io/.

Once orthomosaic was produced and made available on OAM platform, and since sidewalk could be visually distinguished and mapped by OSM users, the next steps are working on sidewalk tags and features pattern definition.

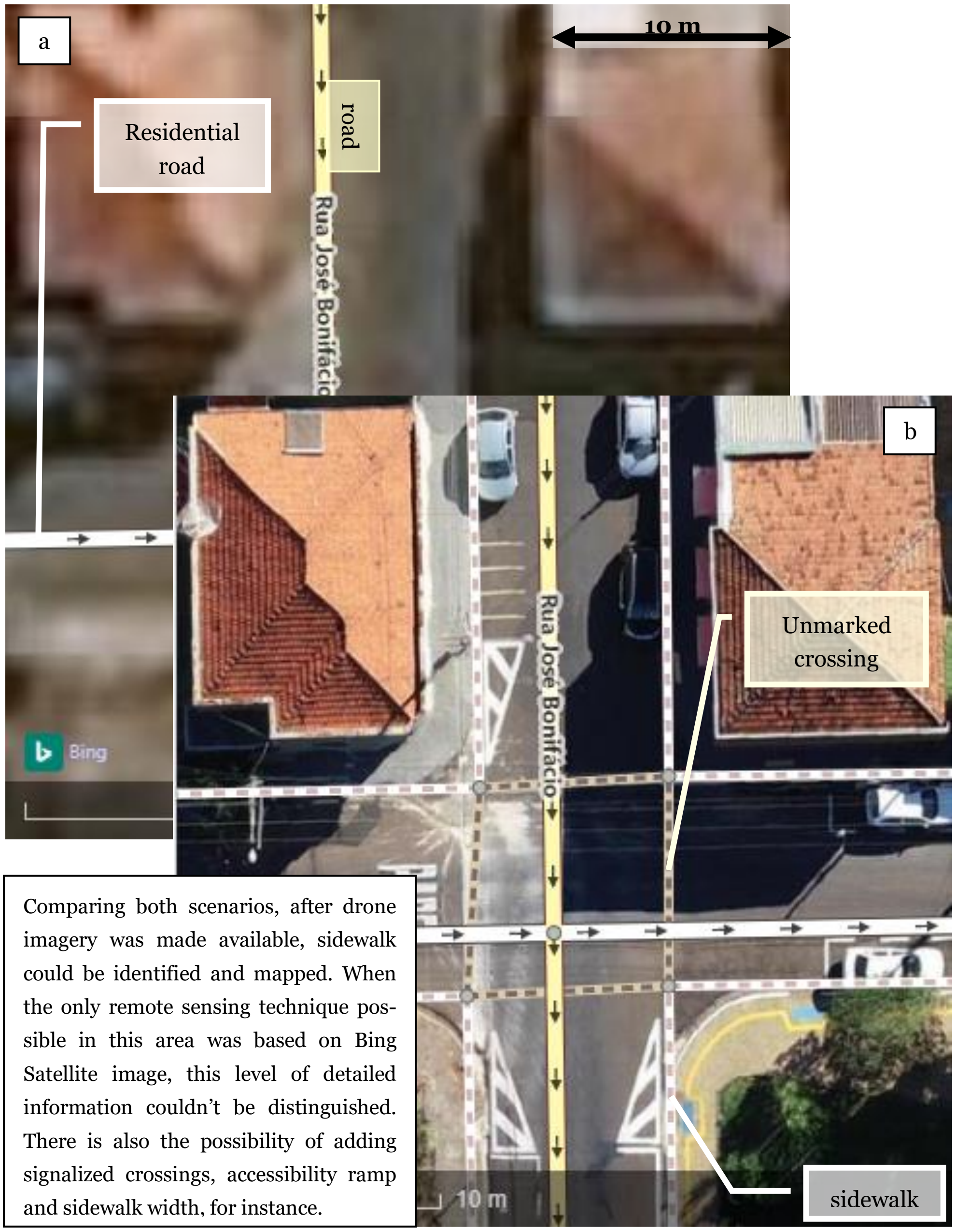

Figure 2. Study area view at OSM. In a: Bing base map. In b: orthomosaic obtained from Drone imagery, available in OAM (search for "São Carlos Brazil").

4. Final Considerations

The main output from these initial steps is the possibility of high quality imagery sharing and the potential of data supplying for LBS through collaborative mapping in open source engines. Specifically regarding sidewalk information, open LBS aiming pedestrians and wheelchair routing, for example, could improve their functionalities.

Among the study area, considering the lack of quality imagery for remote VGI edition on OSM and the absence of sidewalk and crossing features, the proposed methodology went beyond enrichment.

It is important to emphasize that there are other methodologies for sidewalk mapping on OSM, such as GPS tracking and data mining techniques as proposed by Mobasheri et al. (2018). However, both techniques should be supplementary to each other once one is dependent on UAV photography availability and the other one requires on site presence/knowledge.

Another relevant point refers to the next steps of this study: features and tags definition. Among OSM community there are some standard issues regarding sidewalk. There was an agreement, that sidewalk may be mapped separately. Although, there are some discussions about accessibility ramps, which are tagged as kerbs “lowered” or “raised”, and marked crossings, which are featured as ways or nodes depending on user preference.

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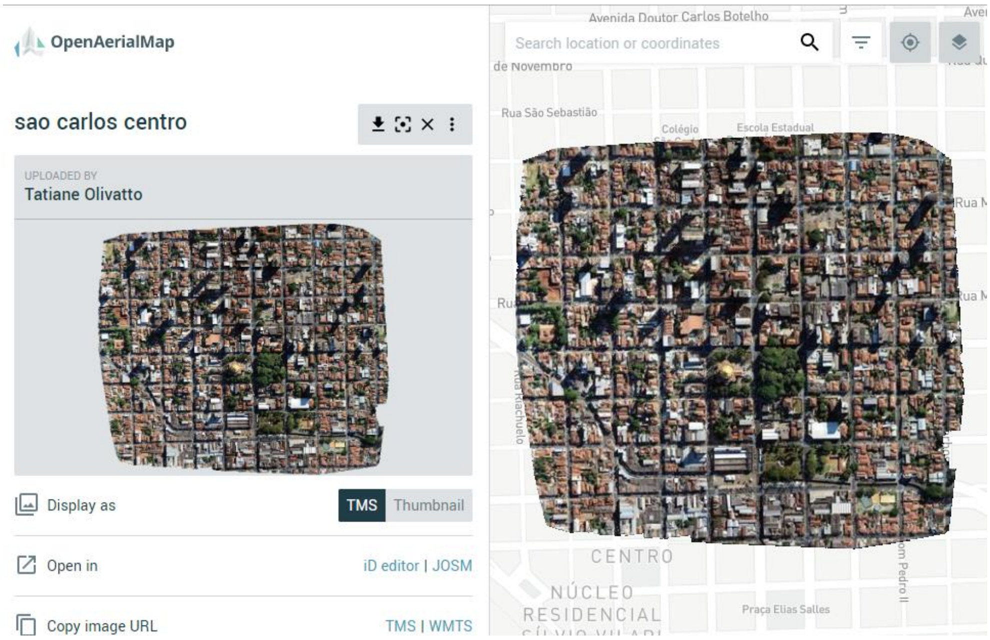
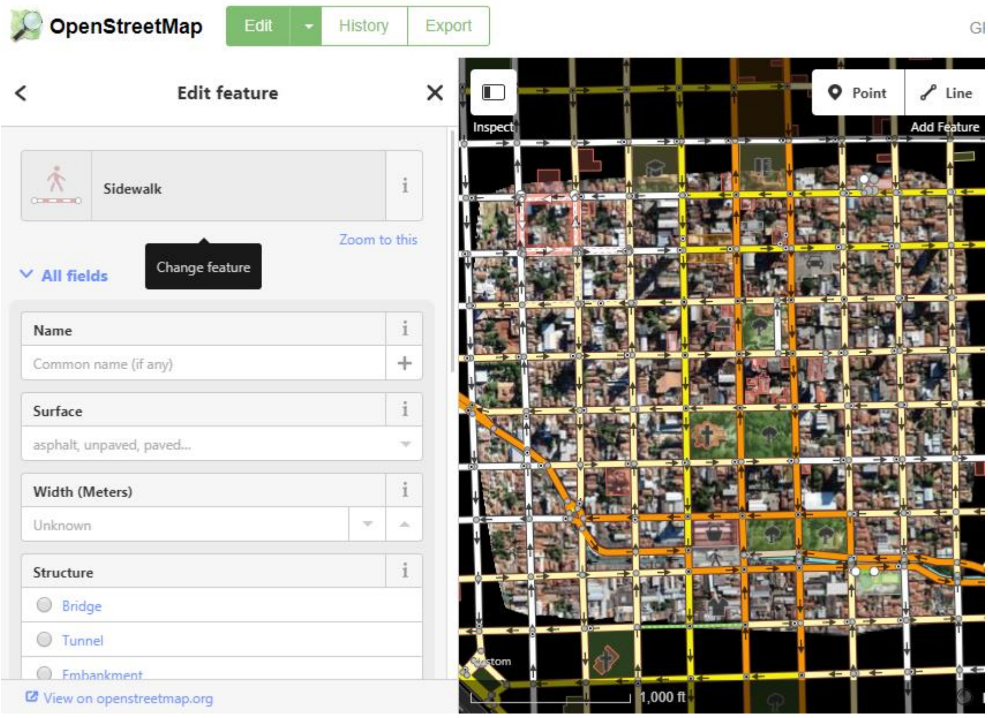
Appendix



Orthomosaic at OpenAerialMap.



Orthomosaic at OpenStreetMap Editor.

Barriers seen by potential local Providers of Applications using Location-Based Services

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Abstract. This contribution focuses on obstacles in the adoption of location-based services (LBS) as a tool for potential providers of localised applications and content. The following key question needs to be answered: *What are the key factors preventing LBS from being accepted in their full potential by potential providers and being used as an element of context marketing?* In order to investigate restrictive factors of application of LBS in the German city of Brunswick (Braunschweig) and the surrounding county, this empirical study follows an inductive approach. Five guided focus group discussions were conducted with representatives of relevant sectors for potential LBS usage. These were identified as the *tourism industry*, the *cultural industry*, *journalism*, the *trade and service sector* and the *sports industry*.

Keywords. location-based services, (hyper-)local media communication, context marketing

1. Introduction

With the possibility of accurately locating and tracking a user, LBS allow for various areas of application like navigation, information, entertainment, data analytics and mobile payment (Jagoe 2003, Lee & Kang 2015, Mallat et al. 2004, Xu 2007). The opportunity of locally addressing customers through their mobile devices is of particular interest for businesses with a fixed address (Möhlenhoff et al. 2011). Especially small and medium-sized businesses are predestined to make profit from the benefits of the applica-

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tion of LBS (Faber & Prestin 2012). Examples of these businesses include restaurants, bars, hotels, retailers, gyms and cultural sites like museums and galleries among others (ibid). Making use of LBS, owners of these businesses and sites are able "to target consumers directly with context-based personalised marketing messages which could have advertising or promotional nature" (Amirkhanpour et al. 2014). Context marketing refers to the targeted and issue-based distribution of automated advertising media through online channels (Ciaramita et al. 2008, Greve et al. 2011). Despite all potentials there are still some barriers restricting the use of LBS in general, like a poor network coverage, insufficient data volume and data security concerns (Heinemann 2018). As pointed out by Huang et al. (2018), it is important to identify these "challenges and [derive] potential opportunities that help to address these challenges". A few studies have already examined factors influencing LBS usage in specific sectors like tourism (Beier & Aebli 2016, Frey et al. 2015, Uphaus et al. 2019), retail (Kang et al. 2015, Kang & Johnson 2015) and cultural institutions like museums (Kang et al. 2017). All of these studies however focused on the users' acceptance of LBS, while the perception of potential providers remains largely unexplored.

2. Methodology

This contribution aims to bridge this identified gap of research by analysing five separately conducted guided focus group discussions with representatives of relevant sectors for potential LBS usage – one focus group discussion for each of the following sectors: the *tourism* sector, the *cultural* sector, the *journalism* sector, the *trade and service* sector and the *sports* sector. These sectors were chosen because of their high potential for the application of LBS in context marketing (cf. Faber & Prestin 2012, Kang et al. 2017, Kramer et al. 2009, Kjærgaard 2012, Weiss 2013). The guidelines for these discussions covered questions concerning the *fields of application*, the *target group*, the *implementation*, the *barriers for the organisation and end users* and a *general look into the future*. This contribution however will focus on the barriers of LBS adoption. The focus group discussions lasted for approximately two hours each and were held in May 2019 with six to ten participants. The discussions were recorded, transcribed and coded with the QDA-software MAXQDA using a qualitative content analysis based on Mayring's approach. After determining the level of abstraction as well as encoding, context and evaluation units, categories were derived from the semantic content (Ramsenthaler 2013) resulting in a system of eight overarching dimensions with various categories and subcategories. A codebook was created to define the authors' understanding of all codes, and intercoder as well as intracoder reliability were ensured before and after the encoding process for all five coders. Validity was ensured by revising the categories during and after the encoding process (Mayring 2000).

3. Preliminary results

So far, the preliminary results hint at the dimension *barriers of LBS adoption* being a relevant dimension with the second highest number of codes (number one being the *fields of application*). This already supports the assumption that the unfolding of LBS's potential is still being held back by a large number of factors. In the focus group discussion, the participants, who were representatives of businesses and organisations, discussed about both barriers they experienced in their own work as well as barriers they perceived from the contact with customers. Therefore, in our study, the barriers were separated into barriers for end users and intraorganisational barriers. Table 1 depicts different topics that were mentioned multiple times in one or more focus group discussion and therefore considered to be of high relevance.
Certain aspects are especially noteworthy: End users have to download and install an app first in order to use the LBS functionality. Therefore, providers face the challenge to somehow communicate the LBS-app's benefits before a user can actually use it. Already in 2003 Kölmel identified the fact that users often cannot estimate the benefit and usage frequency of LBS apps in advance as an obstacle in LBS distribution. Over the years, this seems to have remained an obstacle and may coincide with the also mentioned users' willingness to pay: For smartphone apps it is particularly important that an explicit benefit is communicated to the user (Dogruel et al. 2017). Furthermore, the danger of overloading the user with information he may not want to receive was another topic brought up in many of the discussions. To counteract this risk, several participants suggested an option selecting only relevant content within apps as an important measure.

From the providers' perspective, the following intraorganisational barriers were especially noticeable: Effort, costs and missing personal resources were brought up the most and seem to be affecting all five sectors. Especially small businesses and organisations do not seem to have the resources to develop LBS apps that could be able to stand out among the market leading competitors. This goes hand in hand with the also mentioned clear market leader position by Google (Haucap & Heimeshoff 2014). A major problem seems to be the challenge of offering a service that market leaders like Google are not yet offering in an already well-established form.

Three aspects were mentioned which prove obstacles for both the provider and the end user: The data protection laws are limiting the providers' possibilities of collecting user data and therefore limit the potentials of personalisation, data analytics and a targeted user approach (Fan et al. 2015), while on the other hand professionals are concerned that end users might hesitate to use their services because of privacy concerns (cf. Xu & Gupta 2009, Zhou 2012). Furthermore, a poor internet coverage was mentioned as a barrier of LBS adoption for both sides, as well as an insufficient knowledge about the technology.

Journalists showed the strongest concerns about LBS. They saw particularly strong barriers in the high costs of developing and maintaining an LBS-app.

	tourism	culture	sports	journal-ism	trades / service
barriers for end users					
age-related rejection		[x]			[x]
app must be downloaded/installed				X	X
app must be established			[x]	X	
danger of manipulation				X	
insufficient internet coverage	X				
insufficient knowledge	X		X		
privacy concerns			[x]		[x]
risk of overload	X		X	X	X
willingness to pay				X	
intraorganisational barriers					
costs	X	X	X	X	X
data protection law	X	[x]	X	X	X
effort	X	X	[x]	X	X
Google's market leadership	X			[x]	[x]
heterogeneity of target groups			X		
imitators				[x]	X
insufficient internet coverage	[x]		[x]		
insufficient knowledge	X	[x]	X	X	
low usage expectation	X				
no chance in the free market		[x]		[x]	
no personal resources	[x]	X	X	[x]	

[x] = single mention, X = multiple mentions.

Table 1. Barriers of LBS adoption for end users and businesses

4. Limitations

During the focus group discussions, the aspect of insufficient knowledge about LBS and its functionalities among the potential providers became apparent. Some of the statements could not be evaluated because they did not refer to applications that could be defined as LBS. Examples were the mentioning of QR codes, which however do not require a localisation of the user (Christmann et al. 2012, Rouillard 2008). Further research in the field should try to ensure a uniform and accurate understanding of LBS's definition in advance (Mack & Tampe-Mai 2012). Doing so might reduce distortions in the resulting category system due to a wrong understanding of the term. Moreover, a larger sample size would ensure a broader spectrum of perspectives and opinions of relevant potential providers to be covered. Additionally, focus group discussions with participants of heterogeneous sectors could reveal interesting new insights into the possibilities resulting from cross-sector collaborations – another frequently mentioned issue in all discussions. This study is also suited for replication in other cities that differ in terms of touristic and entrepreneurial potentials.

5. Conclusion

This research was able to provide some first insights into key factors preventing users and providers from using LBS as a tool for potential providers of localised applications and create a good starting point for future investigations in this field. Even though only representatives of relevant sectors participated in the discussion, it became apparent that there are not only intraorganisational barriers – most of which are related to missing resources for the development of LBS, especially considering the competition in form of the market leader Google –, but there are also many barriers on the end users' side, that potential LBS providers are aware of. Getting users interested in using an LBS *before* they go through the process of downloading and installing an app seems to be a major obstacle, as well as keeping that interest alive while using the app by providing services as adjusted to the users' personal needs as possible. Potential privacy concerns on the user side and constraints caused by data protection laws on the provider side further complicate the realisation of LBS-apps being able to directly address the users' needs. From the authors' point of view, further investigation should focus on how an ideal regional or local LBS-app could be realised without being restricted by data protection – for example: What kind of user data can be collected without raising privacy concerns to a large extent in order to adapt to a user's interests in the best possible way? Further research should pay particular attention to the impact of Google's market leadership in many areas (Beel et al. 2010). In this context, it would also be advisable to discuss the possibility of embedding services like Google Maps into other applications (Boulos 2005). The authors are convinced that further research of the aforementioned remaining dimensions discussed with the focus groups will provide valuable additional insights into key factors influencing the users' LBS adoption in the field of context marketing and hyperlocal media communication.

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Usability Analysis of 3D Maps for Pedestrian Navigation for Different Demographic Profiles

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Abstract. 3-Dimensional (3D) maps may provide the users with a more real-world like view in comparison with the 2-Dimensional (2D) maps. 3D maps offer more degree of freedom in movement to the users, a first-person perspective view and other dynamic details such as time of the day, weather could also be incorporated. This paper demonstrates the evaluation of the usability of 3D maps for navigation purposes, in several general aspects including recognizing landmarks and using these visual cues for navigation among different representative user-groups. The 3D model was designed to replicate the High Street, Stratford, London, UK. The participants of the survey were required to explore the model, identify and memorize the landmarks and form a mental map. They were also asked to reproduce the route they took in a 2D paper map and answer a questionnaire on their perception of their own cognitive abilities and their response on the performance of the 3D model. The results confirmed that the usability can vary among users of different demographic profiles – age, gender and language and familiarity with 3D technologies. It also showed that with some improvements in level of details incorporated in the model and design, 3D maps could become a useful tool for navigation purposes.

Keywords. Navigation, Landmark, 3D Maps

1. Introduction

Wayfinding is a complex cognitive task fundamental to all human beings and the level of complexity could be affected many factors, including the level of familiarity with environment (Farr et al., 2012). The process of wayfinding includes interaction with one's surroundings, and landmarks could be used for positioning and orientation (Basiri et al., 2016), since they are easily recognizable. The uniqueness of the landmarks is defined relative to the environment it is present and since pedestrians move at relatively slow-

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er speed, it allows them to notice these unique features/objects (landmarks) in the environment they are navigated through.

3D maps allow for more degree of freedom in movement, more interaction with the surroundings, easier self-positioning and self-orientation through a realistic portrayal of the outside world and first-person perspective view. The rapid improvement in technology and 3D modelling software enabled the creation of interactive and dynamic maps which could be implemented in the user's mobile devices without consuming a lot of data and storage space (Haeberling, 2002; Oulasvirta et al., 2005). The realistic view offered by the 3D maps could be helpful for non-native people such as tourists since they don't have to follow the written and spoken instructions offered by 2D maps. In 3D maps, the viewpoint of the user can be set to the user's current view, so that the use can match the real world with the 3D components of the map (Maehara et al., 2002).

In this study, a model of a 3D urban setting was developed to analyse the usability of 3D maps. Another focus of the study was the influence of language in wayfinding and whether it could become a barrier for people who are non-native English speakers. The analysis of the usability was done with the purpose of examining the general attitude and experience of the representative user group with 3D maps and was studied from the following aspects: (A) interacting with objects around them, and (B) recognizing and memorizing the important features/objects, i.e. landmarks.

This paper structured as follows; next section explains the experiments and section 3 discusses the results of the conducted survey. Finally, there is a conclusion and future work section.

2. Experiment

The study site used to build the 3D model is in High Street, Stratford, London, E15, the UK. Stratford is a part of the London Borough of Newham. The study site is popular among tourists as a cultural and leisure centre. This helped achieve one of the primary objectives of the study which is analysing the usability of the 3D navigations apps among non-English speakers or tourists.

The primary applications used for constructing the model were SketchUp and Unity 3D. The model was created using basic shapes in Unity 3D to ensure minimum file size. Some models (for e.g. bus-stops) were imported from 3D warehouse in SketchUp. The textures for the geometry were obtained from Google street view, Google images and from photographs of the study site. Then the terrain (parts of roads and pavements) was baked to NavMesh to make sure that it is walkable. The classic skybox from Unity asset store were added to the scene and then was exported as WebGL build.

2.1. Survey

The rationale of the survey was to collect the responses of the participants, which in turn would reflect their views on the proposed 3D navigation system. The participants were recruited after making sure that they are unfamiliar with the study area. 35 participants (see Table 1 and figure 2) were asked to explore the 3D model and were presented with a series of representative images. Few of these were images of buildings which were present in the model and others were images of buildings inserted at random. The participants were asked to pick the buildings that they can recognise from the model and on which side of the street it was located. The participants were not required to use the 3D city model as a navigation app and explore the study site. Hence, the time spent on the tasks were not measured. There were required to answer a questionnaire to collect the following details: their demographic profile, familiarity with 2D and 3D navigational applications, their perception of their own cognitive abilities, the level of communication between the participants and the app, the level of details and interaction provided by the app, and the level of user satisfaction.

The 3D model developed in this paper, is a combination of various objects representing different features of the study site – including the terrain, buildings, infrastructure and other street properties. Figure 1 shows two instances of the 3D model of the location created using Unity 3D.

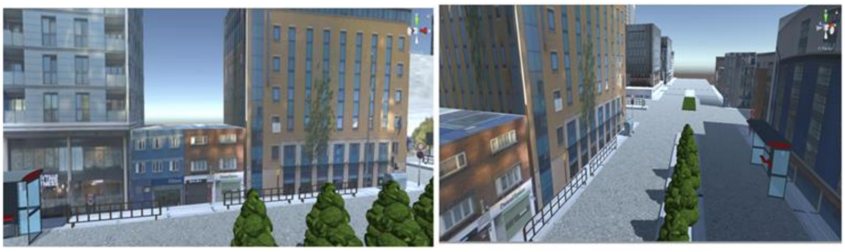

Figure 1. Two instances of the location on the created 3D model

3. Results

The 3D model was built so that the participants can travel from location A (Belvedere Olympic One Eighty, 180 High St, London) to location B (Londis, London E15 2HR). Figure 3 shows the path on Google maps for pedestrians to travel with visible landmarks along with the count of number of times each landmark was identified.

Among the non-English speakers, 74% of the participants were comfortable using the spoken instructions provided by the navigational apps. 26% of the non-English speaking participants were not comfortable following the spoken instructions provided by the navigational aids, and they depend entirely the visual cues. 85.7% of the participants were able to relate the virtual world with the real-world scene and recollect the route they took in the 3D model. Only 5.7% of the participants were not able to relate the virtual world with the real-world scenes and recollect the route they previously took. Compared to the female participants the male participants were able to relate the 3D model with the real-world.

Category		Number	%
Age	18 – 26	5	14.3
	27 – 35	9	25.7
	36 – 49	17	48.6
	Above 50	4	11.4
Gender	Male	16	45.7
	Female	18	51.4
	Prefer Not to say	1	2.9
Native Language	English	18	34.3
	Non-English	17	65.7

Table 1. Demographic Profile of the participants

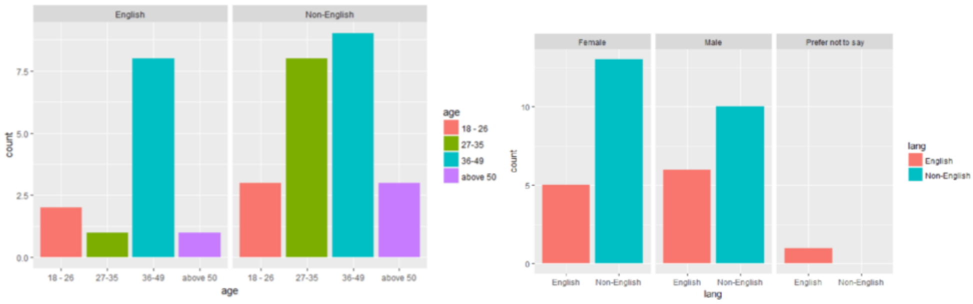

Figure 2. Bar-graph showing the CrossTable between age and language (left), Bar-graph showing the CrossTable between native-language and gender

Landmarks	Number of times	Percentage (%)
A	32	91.43
B	5	14.29
C	3	8.57
D	34	97.14
E	35	100
F	4	11.42
G	12	34.29
H	26	74.29
I	2	5.71

Figure 3. Location of the landmarks on the path traversed by the participants using the 3D marked in Google map (Google maps, 2019; Google street view, 2019)

There was no relationship between language and the ability to form a cognitive map. However, the tourists tend to observe their surroundings more compared to the natives, since they found it easy to remember directions relative to landmarks. 82.86% of the participants thought the 3D model was able to convey the real-world entities and that with some improvements, the model could be useful to them for wayfinding.

4. Conclusion

This paper discussed the usability of 3D maps for pedestrian navigation among users with different demographic profiles. Another focus of the study was to analyse the influence of landmarks in wayfinding in 3D maps. These landmarks could be used for positioning and orientation in a 3D map. Compared to the male participants, the female participants seemed to have notice the surroundings and use the visual cues for wayfinding. Age was another constraint in the performance of the 3D model. The younger generation, due to their familiarity with 3D technologies were comfortable relating the virtual world with the real-world and with the use of controls and interfaces provided. From the field survey, it was observed that the non-English speaking users prefer not to listen to the spoken instructions while travelling in an unfamiliar environment and they depend on the visual display provided by the Google maps throughout their journey. In general, with more research on the end-user requirements along with some improvements in the design, 3D maps could become a useful tool in navigation across all demographic profiles.

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Usability Test of Map-based Interactive Dashboards Using Eye Movement Data

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Abstract Map-based dashboards support users to extract and reveal spatial data into insights. Understanding the cognitive process of users during their interactions with map-based dashboards is important for designing useful dashboards. However, there are little studies about users' sense-making procedures of map-based dashboard usage. This study tries to find out the usability of map-based interactive dashboards in users' insight revealing process. An experiment is designed to collect more than 40 users' eye-tracking data for four predefined tasks. The eye movement data will be quantitatively analyzed using descriptive statistics, and the qualitative questionnaire data will be summarized thematically. The results should support better communication of geoinformation map-based dashboards.

Keywords: map-based dashboard, eye-tracking, geo-data visualization

1 Introduction

With the increasing amount of socio-economical measurements, the difficulties of sense-making and communication of number-rich datasets are rising. Map-based dashboard conveys multi-dimensional spatial information by the intuitive visual interface, which makes the knowledge understandable. Moreover, the interactive map-based dashboard carries in-depth information by enabling the communication between the visualizations and the users (Sarikaya et al., 2019). However, little studies about the users' spatial sense-making procedure of map-based dashboards

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are conducted. Kiefer et al. (2017) inferred that eye movement data externalizes the human cognitive process and thus opens a deep understanding of cartographic perception.

Yalçın et al. (2018) studied the insights winning procedure of the users. The experiment was proceeded as the users freely explore a dashboard with the think-aloud method. They have found that less familiar interactivities are more likely lead to incorrect understanding. Additionally, personal differences result to various insight-finding strategies and insights. Bogucka and Jahnke (2018) compared the usability and feasibility of two different cartographic representations with predefined tasks. Eye-tracking data were collected to analyze users' searching strategy, and post interviews were conducted to compare users' preference. Popelka et al. (2019) evaluated the usability of three map-based dashboards with the eye-tracking experiment, which is designed in a combination of free-viewing and task-solving parts. Moreover, the users' searching strategies were visualized and analyzed with the sequence charts.

However, the tasks of the aforementioned studies focused on object identification of the dashboards. The sense-making procedure of more complex tasks, e.g., spatiotemporal trend summarizing, multi-variable spatial correlating, need to be further studied. Therefore, we plan an experiment to explore the differences in the insight winning procedure of given tasks with different complexities. Eye movement data will be collected to reveal the users' visual searching strategies. The results may support the cognition-based geo-data visualization and guide the dashboard design and application.

2 Methodology

We will examine the usability of interactive map-based dashboards through a case study about socio-economic ecosystem in Yangtze River Delta, China. A dashboard is designed to visualize the industrial-related indexes, e.g. the numbers of company, gross domestic products (GDP), population, to support the local entrepreneurs' decision-making. The tasks of the experiment vary in complexity, with identification and summarization cognitive operations respectively. The users' eye movement data will be collected during the experiment. Finally, the effectiveness, efficiency and the task-solving strategy will be analyzed.

2.1 Apparatus

In this study, we will use Gazepoint[1] GP3 Desktop Eye-Tracker, which is with 0.5 -1 degree of visual angle accuracy and 60 Hz update rate, to keep track of participants' eye movement. The eye tracker works with a 3840 x 2160 resolution monitor. The software Gazepoint Analysis will be used to analyze the eye movement data.

2.2 Participants

We plan to recruit at least 40 participants (twenty females and males each) by leaflets and online advertisements. The participants should have different backgrounds, computer skills and previous experience of web-based dashboard. To get the gaze data with high quality, they should have normal or corrected-to-normal eye vision. Besides, they should not have serious mental illnesses.

2.3 Interfaces

For the purpose of this study, we acquired socio-economic data, i.e., enterprise number, GDP, population and logistic related data, from 2013 to 2015 in Jiangsu China. The data is based on a unit of county and city[2]. We designed and implemented an interactive map-based dashboard for users to explore, correlate and analyze the regional socio-economic variables and acquire knowledge. Specifically, small multiples are implemented in favor of correlating, and as the main interaction tool. The interface is shown as Figure 1.

In addition, users can active a county by clicking on either of the four maps, and active the layers from the layer button in the top right of each map. The content of *Panel B-E* is linked. The visualizations in *Panel B, D* and *E* changes according to the users' interactivities in the *Panel C*. Moreover, the four maps are synchronized. If a user zooms or drags one of the maps, the other maps will follow.

[1] https://www.gazept.com
[2] In China, a city includes several counties.

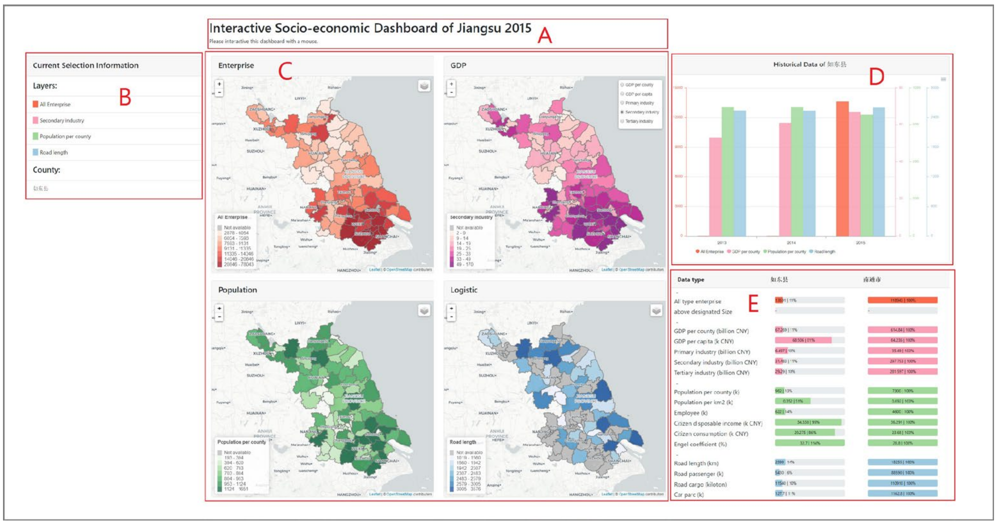

Figure 1: The interface of the map-based dashboard for socio-economic indexes visualization in different perspectives. *Panel A* presents the title and background information. *Panel B* shows the active layers and the name of the active place. *Panel C* is the map view, presenting the spatial distribution of the variables of the same area. *D* displays a histogram of active attributes at a selected place. *E* is a table view, showing all the variables in detail of a selected place and its affiliated city.

2.4 Task setup

Based on the usability design of Popelka et al. (2019), we designed the tasks of using the map-based dashboard at different complexity levels. The following tasks are designed:

- *Task 1*: Please find the county with the largest number of enterprises of the province.
- *Task 2*: Please find the Tertiary industry value of the county *Qidong* in 2015 and the percentage in the affiliated city.
- *Task 3*: Please summarize the spatiotemporal pattern of the GDP index of the whole province.
- *Task 4*: Please find the correlation between Enterprise and Population.

The tasks differ mainly in complexity. T1 and T2 are identifying tasks, which can be solved by objects finding from the dashboards. While T3 and T4 are summarizing tasks, which require users process the information based on their interaction and observation from the dashboards. Moreover, T3 focuses on the trend summarization of only one variable, whereas T4 focuses on correlating two variables. The tasks settings are described in Table 1.

Table 1: The task setting to assess the usability of map-based dashboard.

Task	Cognitive operation	Description
T1	Identify	Find a place according to the spatial trend.
T2	Identify	Find the values of variables at a certain place.
T3	Summarize	Describe the spatiotemporal trend of one type of variable.
T4	Summarize	Compare the spatiotemporal trend between two types of variables.

2.5 Procedure

The experiment will take place at the Eye Tracking Lab at the Technical University of Munich. Before the experiment, the participants will be introduced of the experiment procedure and the data privacy policy. The experiment will be proceeded when the participants agree and sign a written consent. In addition, the participants are allowed to exit the experiment at any point during the experiment.

During the experiment, we will first introduce the background of the dashboard to the participants. Secondly, the participants will be given a dashboard instruction and asked to explore the dashboard freely for three minutes. Thirdly, after calibration of eye position, the participants' eye movement will be recorded while they are asked to complete a set of the predefined tasks by freely interacting with the dashboard. The participants are required to refresh the dashboard after every task is finished.

After the task session, we would give the participants a questionnaire to fill their personal information, i.e. gender, age, education level, profession, computer skills, and their subjective opinions regarding the dashboard usability.

2.6 Analysis

A series of qualitative and quantitative analytical methods will be performed to examine the usability of the dashboard. Firstly, the correctness of each tasks regarding both interfaces will be analyzed respectively. Secondly, we will analyze the task-solving durations respectively. Thirdly, a visual analytical method, will be applied to study the task-solving strategy. More specifically, for each task, 1) a heat map of all the participants' fixation, 2) a scan path map of all the participants' eye movement, 3) a sequence chart of every participant's eye fixation duration across panels will be created and analyzed. Finally, the usability statements of map-based interactive dashboard will be derived from the previous analysis and the questionnaire results.

3 Summary and Outlook

The ongoing study addresses eye movement data with the aim to access the usability of the map-based interactive dashboard for insight revealing in socio-economic data for given tasks.

The tasks are ordered by the relative complexity of winning the insight. At least 40 users will be recruited as subjects of the experiment, and a post-study interview will be used to summarize the usability of dashboards, thus guide the improvement of the dashboard design.

Acknowledgements

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Designing Access Control of a Spatial Decision Support System for Collaborative Maritime Spatial Planning

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Abstract. Successful maritime spatial planning processes require stakeholder engagement and participation, thus requiring tools that support collaboration. Communication-driven spatial decision support systems are designed to facilitate decision making processes of complex spatial problems and are therefore suited for this task, but there are unresolved questions about user access control for these systems. In this study, user access control was designed for a spatial decisions support system for collaborative maritime spatial planning based on observation of two user tests. It was found that there were three distinct groups of users with special access needs to collaborative functionality. The level of access to functionality was organised into three groups: passive *participants*, actively contributing *collaborators* and managing *moderators*.

Keywords. Spatial Decision Support System, Maritime Spatial Planning, User Access Control

1. Introduction

Maritime Spatial Planning (MSP) is a public process of analysing and allocating human activities in marine areas to achieve objectives specified usually by political processes (Pınarbaşı et al. 2017). The MSP processes and dialogue are generally organised and lead by public planners. Stakeholder don't participate in all phases of the MSP processes, but when they do, their roles are clearly defined (Collie et al. 2013). However, the competencies and knowledge of the stakeholders often differ (Morf et al. 2019, Luyet et al. 2012). Successful MSP processes require stakeholder engagement and participation (Pınarbaşı et al. 2017) and thus require tools that support collab-

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oration (Rassweiler et al. 2014; Pert et al. 2013; Center for Ocean Solutions, 2011).

Spatial Decision Support Systems (SDSS) are designed to facilitate decision making processes of complex spatial problems and are therefore suited for the task of MSP. SDSSs provide a framework that integrates database management, geospatial analysis, visualisation, and expert knowledge of decision makers. (Densham, 1991) SDSS can be categorised based on their focus area, such as, data, models, knowledge and communication. Communication-driven SDSS facilitate the communication between different stakeholders to generate some form of results. (Stelzenmüller et al. 2013) To determine how this collaboration works, for example in a SDSS, it is important to know what functionality users have access to in the system. This is determined by the concept of access control or control of user access. In role-based access control (RBAC) permissions assigned to user roles are defined beforehand and users are then assigned to roles based on their responsibilities. The main benefit of RBAC is the low administrative overhead of assigning users permissions, but it also has shortcomings, such as, lack of flexibility and fine-grained control. (Tolone et al. 2005)

This study focuses on designing role-based access control in a communication-driven SDSS for collaborative MSP called Baltic Explorer. The key questions regarding the RBAC are: what user roles are required and what functionality do the user roles have access to? To identify the user roles and their functionality requirements the use of Baltic Explorer was observed in two distinct user tests.

2. Methods

Baltic Explorer is a communication-driven SDSS for collaborative MSP being developed in BONUS BASMATI - Baltic Sea Maritime Spatial Planning for Sustainable Ecosystem Services project. As a web map application, Baltic Explorer is suited for all devices with modern browser support. The user interface is designed for both small and large touchscreens but also for PCs with traditional input devices. In Baltic Explorer users collaborate on a shared workspace where they can share and also edit shared features. Users can also select data to overlay in the shared workspace for other users to see. This collaborative functionality of sharing, editing and overlaying causes many access control challenges, as users of communication-driven SDSS in a collaborative MSP usually have different responsibilities. To gain insight into how groups collaborate using such SDSS for collaborative MSP, Baltic Explorer was used in two distinct user tests. During the tests all participants had access to most of the functionality of Baltic Explorer.

In the first “Workshop test”, Baltic Explorer was tested with users in the Pan Baltic Scope cross-border meeting: “Better maritime planning – towards a shared future, together” organised by FIAXSE in Umea, Sweden. The participators were mainly MSP planners and stakeholders. The test focused on examining which functionality of a collaborative SDSS helps in common MSP tasks. Baltic Explorer was used to support the task. Both groups had two facilitators, one (a planner) acting as the meeting chair and the other managed a shared view of Baltic Explorer on a large screen. The rest of the participators’ utilised personal devices to use Baltic Explorer. In the second “Game test”, Baltic Explorer was tested twice with each three group types: MSP students, GIS experts and non-experts. The test focused on examining how well each device configuration (personal, shared or both devices) supported common MSP tasks. All groups of three were assigned the same task of playing an MSP game. The goal of the game was to collaborate in preparing a plan that takes into account the interests of each participator and the overall interests of the group. The groups used Baltic Explorer either on personal, shared or both devices. For this study, the main research method in both tests was observation of the roles participants took while using Baltic Explorer.

3. Results

During the tests the participators were observed to identify distinct roles. In the “Workshop test” the participators were observed to pay close attention to the shared display managed by a facilitator. The facilitator was observed to be a distinct role as they control the shared display. Some participators also often interacted via the shared display. Participator were observed to physically move to the shared display to contribute into the discussion, even though they had a personal display to work with. This occurred when their personal view of the workspace was in a different state than the shared view, for example, a participator might have been editing a feature not yet ready to be shared on the workspace and wanted to join the conversation. Thus, active participators were observed to be a distinct role. During the “Game test”, in the groups with personal displays and a shared display, one or more participator were observed to performed the same tasks as the “Workshop test” facilitator. They kept the shared display synchronised for the group to have an updated view of the workspace. The shared display was also used to edit features.

Access control for Baltic Explorer, including user roles and access to functionality, has been designed based on the observations from the tests while taking into account the context of MSP and SDSSs. Role-based access control was chosen over only a user-based access for Baltic Explorer since only a few user groups with special access to collaborative functionality were identified. Thus, Baltic Explorer has three user roles: *participant*, *contributor* and *moderator, Figure 1*. Each user can use their own device to access the workspace and manage their personal view. Users can also use their personal device to present their personal view as the shared view visible for all.

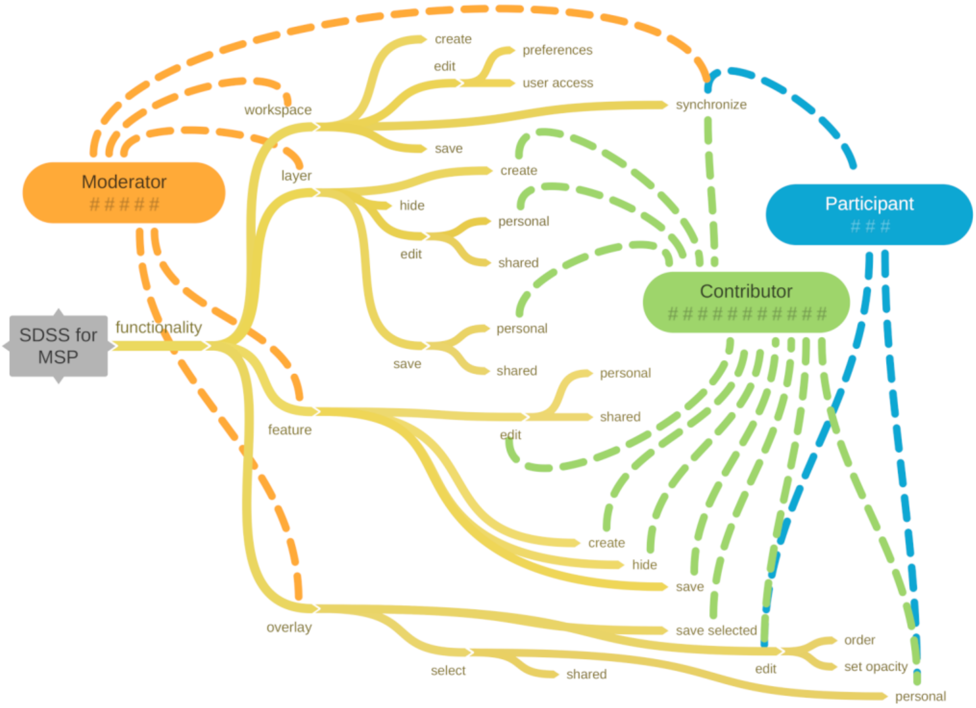

Figure 1. The functionality user roles have access to in a Baltic Explorer workspace.

The *participant* group only has access to basic functionality, such as, viewing features and overlaying data, *Figure 1*. They can select the overlaid data of their personal view, but when they synchronise the overlaid data of the shared view is updated in their view. In an MSP setting, persons who don't actively want to contribute to the task but instead are interested in the process phases and the results of the task, can be assigned as *participants*. The *contributors* group has access to sharing functionality, such as, adding features to the workspace for all to see, *Figure 1*. *Contributors* can select and save the overlaid data of their personal view, share and edit features on the workspace and synchronise the workspace using their personal view. *Contributors* can be, for example, planners or stakeholders who actively want to contribute to the tasks and take part in the decision making. The *moderator* group has access to all functionality regarding the workspace, *Figure 1*. The *moderator* controls the workspace, keeps the shared view synchronised for all viewers and selects the overlaid data visible to the synchronised personal views of *participants*. All layers and features created by the *contributors* can be edited by the *moderator*. It is intended that a *moderator*, who has access to all the workspace functionality, should be the one controlling the shared view. The *moderator* can, for example, be one of the meeting organisers in an MSP setting.

4. Conclusion

In this study, control of user access was designed for a SDSS for MSP based on observing user tests. It was found that there were three distinct groups with special needs of access to collaborative functionality. The level of access to functionality was organised into three groups: passive *participants*, *actively contributing collaborators* and managing *moderators*. The designed access control should be further evaluated in other phases of MSP to further refine the functionality each user group has access rights to. Development of Baltic Explorer will continue based on these findings.

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Evacuation Simulation Considering Fire Spread and Occupants Distribution

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Abstract. A fire simulator and an evacuation simulator are used separately to diagnose the safety of a large building. However, it is hard to diagnose the safety of a building using them, because they don't reflect the movement of pedestrian under fire. This study suggests an evacuation simulation considering the movement of pedestrians and fire spread. it applied the fire spread data of the fire dynamics simulator (FDS) to the floor field model (FFM) and models that a pedestrian recognizes a fire and takes a detour to a safe route. Simulations were performed under various scenarios and it was showed that the number of evacuees at each exit varied by the presence and location of fire as results.

Keywords. Indoor Evacuation, Floor field model, Simulation, FDS

1. Introduction

A fire simulator and an evacuation simulator are generally used independently to diagnose the safety of a large building in the situation of evaluation. An evacuation simulator is used to estimate the required safe egress time (RSET), which is the time required for people in the building to move to a safe location on foot. A fire simulator is used to calculate the available safe egress time (ASET) which is the time before the fire affects pedestrians. The safety of a building is diagnosed by comparing these two indices (Kim & Jeon 2015). However, it is difficult to accurately diagnose the safety of a building using a fire simulator and an evacuation simulator independently, because this method does not reflect on the movement of pedestrian under fire spreading situation.

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This study proposed an evacuation simulation considering fire spread and the movement of pedestrians simultaneously. The proposed evacuation simulation was based on coupling method describing evacuation of occupants while avoiding fire spread by combining the fire spread data of FDS (McGrattan et al. 2013), a fire simulator, with an FFM, a pedestrian model. We used IndoorGML data corresponding to the first floor of the actual campus building as the experimental space and placed occupants in experimental space by using occupants distribution data. Experiments were conducted on general condition and two fire conditions.

2. Methodology

2.1. Floor field model

FFM is a pedestrian model which models the micro-scale movement of pedestrian (Burstedde et al. 2001). FFM is based on a two-dimensional Cellular Automata model. An agent is located upon a cell and determines the movement by interacting with only eight cells around itself. Factors affecting the movement of agent are presented in the form of a floor field which is constructed by cells. Representative floor fields in FFM are static floor field (SFF) which shows the distance to the exit and dynamic floor field (DFF) which shows the influence of other agents. An agent determines the next cell to move by calculating the SFF and DFF values of surrounding cells at each time step.

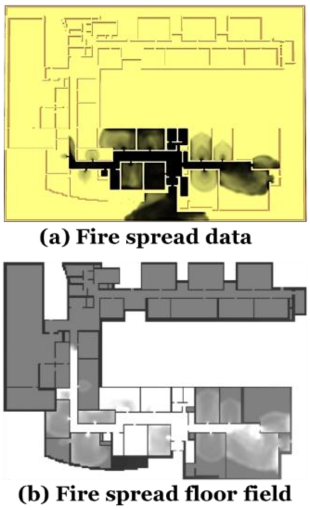


Figure 1. Fire spread in FDS and FFM

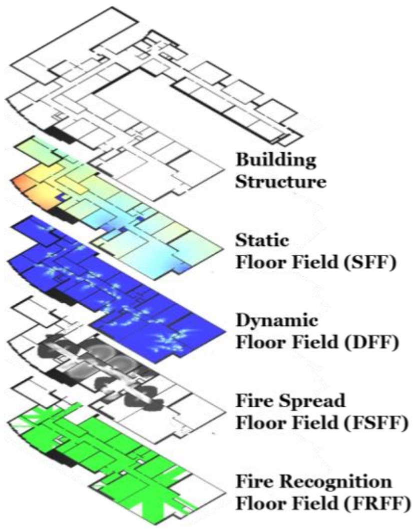


Figure 2. Structure of the improved FFM

This study proposed the improved FFM by adding a fire spread floor field (FSFF) and a fire recognition floor field (FRFF). Fire spread data are calculated by FDS and they store heat, density of smoke and field of view in seconds. FSFF is generated from fire spread data and refers to the fire spread at certain height. FSFF is updated every second to describe fire spread. Figure 1 (a) shows a fire spread data in FDS and (b) shows FSFF in FFM.

Although FSFF visualizes fire spread, agent can't realize fire before the fire a rrives in eight adjacent cells. Therefore, this study made FRFF, which refer a space where agents can visually identify fire. FRFF is generated by the expa nsion of field to the eight-way directions from cell where heat and smoke exi st in FSFF. Expansion of field on each direction proceeds only for the walka ble cells and it ends when an unwalkable cell appears. When FSFF is renewe d every second, FRFF is renewed through the above processes. *Figure 2* sho ws the structure of the improved FFM including FSFF and FRFF.

2.2. Detour algorithm

In the improved FFM, agents entering FRFF take a detour to avoid the effects of fire. The detour algorithm describes process of exit selection in the graph data structure of IndoorGML. The graph data forms a hierarchical relationship with cell data. The space is divided into subdivisions and each subdivision becomes a node. The edge means connectivity between nodes and stores the distance between nodes. When fire breaks out, the edge stores the distance along with risk weight. For risk weight, edge belonging to FRFF has W and edge belonging to FSFF has W^2. The value saved in edge is evacuation cost and it is renewed along with spread of fire. *Figure 3 (a)* shows graph data in normal and *(b)* shows graph data when fire exists. When an agent enters FRFF, a detour to the exit with minimum evacuation cost is calculated by Dijkstra algorithm.

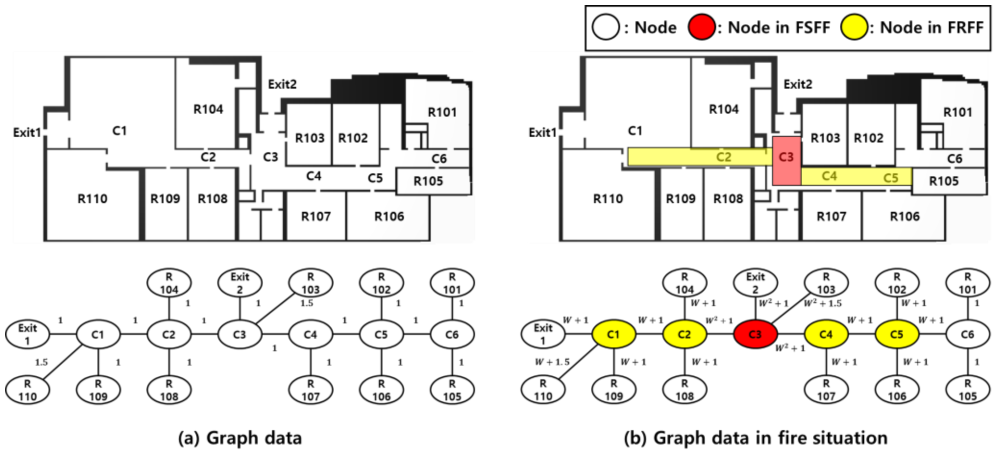


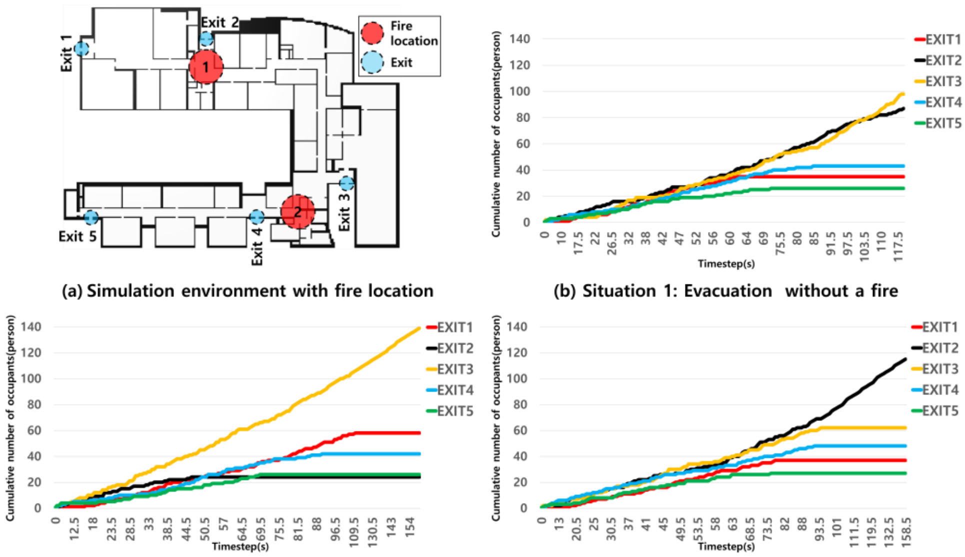
Figure 3. Graph data in normal and fire situation

2.3. Occupants Distribution

In this study, occupants distribution located in the actual building was counted and used as agents distribution for the evacuation simulations. This study divided space into subdivisions based on graph data of IndoorGML and installed people counting sensors on the entrance of subdivision spaces. Sensors collect occupants distribution data by checking people's accesses. *Figure 4 (a)* shows subdivision spaces of the experimental space and *(b)* are infrared beam type people counting sensors.

(a) Subdivision spaces (b) People counting sensors

Figure 4. Subdivision spaces and people counting sensors



(a) Simulation environment with fire location

(b) Situation 1: Evacuation without a fire

(c) Situation 2: Evacuation when a fire initiated at location 1

(d) Situation 3: Evacuation when a fire initiated at location 2

Figure 5. Simulation environment and results of evacuation simulation

3. Evacuation simulation suing EgresSIM

Evacuation simulations were performed by using EgresSIM (Nam et al. 2016), a cellular automata-based evacuation simulator. The 21st century building, on the University of Seoul, served as the site for simulations. *Figure 5 (a)* is the IndoorGML data corresponding to first floor of the 21st century building. Agents were placed by occupants distribution data obtained from sensors in an experimental space. Simulations were conducted under three scenarios. Scenario 1 was a case without a fire. Scenario 2 was when a fire initiated at location #1 on *Figure 5 (a)*. Scenario 3 was when a fire initiated at location #2 on *Figure 5 (a)*. Results of simulation are shown as *Figure 5 (b), (c), (d)*. Graphs in *Figure5* mean cumulative number of occupants per exit by time.

4. Conclusion

In this study, an evacuation simulation is proposed considering fire spread and pedestrian movement simultaneously by using FFM and FDS. Simulations were performed under various scenarios by using EgresSIM. When the results of simulation were compared, the number of evacuees at each exit varied a lot due to the detour of agents and the evacuation time of each exit clearly increased or decreased. If the evacuation simulation relates to real-time occupants distribution data, it is expected that evacuation simulation can be applied to real-time evacuation route planning.

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A location-based service for planning tool

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Abstract. The social vulnerability concept links the environment to human life and makes it clear to understand how distinct social groups are affected by disasters. In this context, the assessment of location-based social vulnerability (LBSV) in GIsystems will play an important role not only to understand the affected social groups but also to predict their geographic location to facilitate effective decision-making and rescue process. Therefore, in this paper, we looked at this concept as a base of developing location-based service for rescue purposes. This paper represents part of research which is in progress. Within this framework, the paper aims to apply a proven method for assessing social vulnerability in GIsystem to earthquakes in East Azerbaijan province in Iran. The methodology is based on Social Vulnerability Index (SoVI) approach with 23 customized variables. For validation, results were compared to the Ahar-Varzegan earthquake that happened in 2012. This research provides useful information for identifying the places most likely to experience casualties due to socioeconomic and demographic characteristics. So this information is useful for planning rescue teams. Also, results are useful for making better development plans.

Keywords. Location-based, Natural hazard, social vulnerability

1. Introduction

Vulnerability is the state of susceptibility to harm from exposure to stresses associated with environmental and social change and from the absence of capacity to adapt to the situation. The soul of the social vulnerability concept correlates with the modern planning model (Lee, 2014). Location-based vulnerability assessment helps to identify people or property that is susceptible to suffer due to disaster risks (UNISDR, 2015).

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Over the past decade, social vulnerability indices have emerged as a leading tool to quantify and map human dimensions of hazard vulnerability (Rufat, Tate et al., 2015). This makes it clear to understand how distinct social groups are differently impacted by disasters (de Loyola Hummell et al., 2016). Social vulnerability is the product of social and place inequalities (Cutter et al., 2003). Therefore, assessing of location-based social vulnerability (LBSV) in Geographic Information System (GIS) may better reveal those social and place inequalities in different regions.

After natural hazards estimating the number of injured and killed people and predicting location of those will play a vital role in reducing amount of casualties. To reach this goal, at first, we have to assess places that are more vulnerable to natural hazards and then use this information in location-based rescue system to manage rescue teams. In this paper we did first part. So, we used the social vulnerability index to predict more vulnerable places to earthquakes. To do this, East Azerbaijan province was selected as a study area (see *Figure 1*), and the social vulnerability index (SoVI) was used in the GIS environment to assess social vulnerability. SoIV has gained general acceptance as one of the leading tools for quantifying social vulnerability due to its fair robustness.

2. Materials and methods

In this paper, demography data of the year 2011 of Iranian population and census is used. This data made it possible to validate research's final results by comparing it to Ahar-Varzagan twin earthquakes that happened on the 11th of August 2012 with 6.4 and 6.3 on the moment magnitude scale.

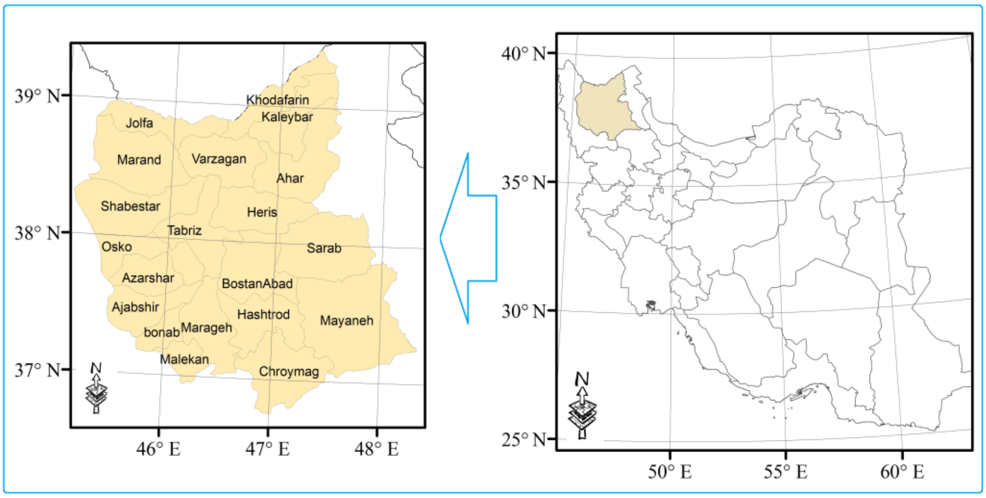

Figure 1. The study area of this research

2.1. Construction of social vulnerability indicators

In this paper, 23 variables were chosen according to the data available in East Azerbaijan that represent the socio-economic conditions (see *Table 1*). Having different measurement units, the z-score statistical method was used to normalize variables and convert them to a common scale with a mean of zero and standard deviation. To select the proper criterion, factor analysis is executed. To check the validity of this analysis, the sampling adequacy was measured using Kaiser-Meyer-Olkin (KMO). Since KMO was greater than 0.6, it was used for factor analysis.

Concept	No	Description
Family structure	1	Family with 1 component
	2	Family with more than 6 components
Education	3	Higher education index
Socioeconomic status	4	Containment index
	5	The ratio of the poor
	6	Attraction index
	7	Commuting rate
Employment	8	Female labor force employed
	9	Labor force employed
	10	Unemployment rate
Age	11	Rate of children < 14 years
	12	Rate of old > 65 years
	13	Aging index
	14	Dependency ratio
Population growth	15	Population density
	16	Urbanized index for residential use
	17	Crowding index
Race/Ethnicity	18	Foreign residents
Medical Services	19	The percentage of disable people
	20	People with social problems
	21	Total Hospital bed
	22	Percentage labor force working in human health and social work services
Quality of the built environment	23	Building quality

Table 1. Variables used in the Social Vulnerability Index (SoVI)

A factor analysis, using principal component analysis (PCA), was implemented using Kaiser Normalization and Varimax rotation to drive the most robust set of independent factors that explain the social vulnerability characteristics for East Azerbaijan. For interpretation purposes, the most significant indicators (with correlations over 0.6 and less than -0.6) were assumed as drivers of each component and provided the rationale for the naming conventions and corresponding positive or negative cardinality according to their influence on social vulnerability. Positive values mean increment in levels of vulnerability, while negative values reduce levels of vulnerability. Location-based SoVI was then calculated in the GIS environment by the sum of the components for each municipality. After the construction of the location-based SoVI it was classified based on five class according to the standard deviation: very low (< -1.5); low (-1.5 to -0.5); medium (-0.5 to 0.5); high (0.5 to 1.5) and very high (> 1.5).

3. Results and discussion

Three factors with an eigenvalue greater than one, resulting from the statistical analysis for SoVI explain 85.134 % of the variance. The parameters, their effects and the correlation of different factors in three principal components are listed in *Table 2*.

Component	Factors and their effect[1]	Correlation
C1	The ratio of the poor (+)	0.928
	Female labor force employed (-)	0.974
	Population density (+)	0.952
	Foreign residents (+)	0.986
	Building quality (-)	0.675
	The percentage of disabled people (+)	0.984
	People with social problems (+)	0.976
	Total Hospital bed (-)	0.977
	Percent of the labor force working in human health and social services (-)	0.974
C2	Commuting rate (+)	0.656
	Rate of children < 14 years (+)	-0.87
	Urbanized index for residential use (+)	0.627
	Crowding index (+)	-0.91
C3	Attraction index (-)	0.886

[1] Increment (+) and reduction (-) of SoVI

Component	Factors and their effect1	Correlation
	Rate of old > 65 years (+)	0.867

Table 2. Main factors and direction of influence to the SoVI (±)

Constructing the SoVI revealed that it varies from +4.457 (very high vulnerability) to -3.918 (very low vulnerability). Most part of the study area has a medium social vulnerability (*Figure 2*). These regions cover 33.25 percent of the whole study area (*Table 3*). 22.84 percent of the study area falls into a very high social vulnerability group.

Vulnerability class	Area (Km^2)	%
Very high (>1.5 Std. Dev)	10391.67	22.84
High (1.5 < Std. Dev < 0.5)	3660.32	8.05
Medium (-0.5 < Std. Dev < 0.5)	15124.26	33.25
Low (-1.5 < Std. Dev < -0.5)	10311.55	22.67
Very low (< -1.5 Std. Dev)	6003.12	13.20

Table 3. Percentage of different classes of social vulnerability in East Azerbaijan

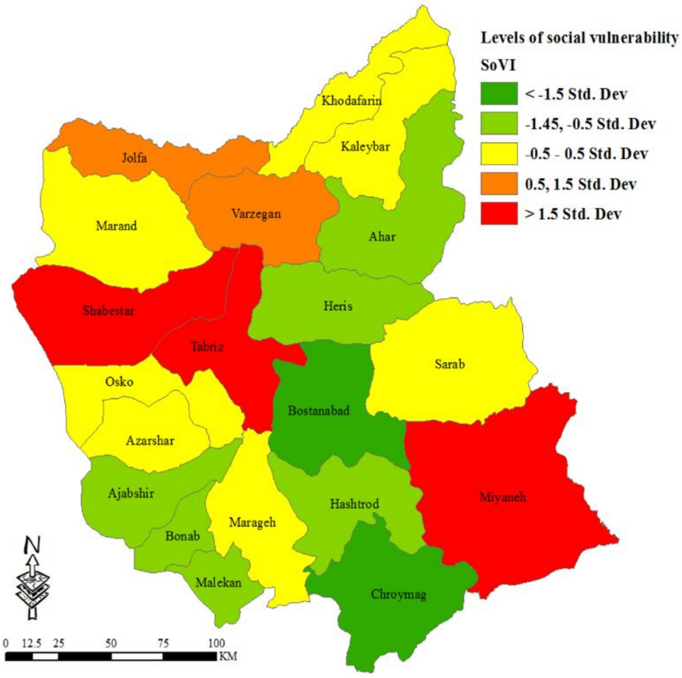

Figure 2. The study area of this research

To validate the results, the number of casualties caused by the real Ahar-Varzagan earthquake were used. At 12:23 coordinated universal time (UTC) of 11th of August 2012 two earthquakes of 6.4 and 6.3 on the moment magnitude scale occurred nearby Ahar and Verzegan (Ranjbar et al., 2016). In that earthquake, more than 20 villages have completely destroyed and cities of Verzegan and Ahar suffered different levels of damage (Ranjbar et al., 2016). The earthquake killed 74 people in Varzegan and a total of 43 men and women in Ahar.

4. Conclusion

This research is a part of our main research in developing location-based rescue planning services for natural disasters. To manage rescue teams after hazards it is necessary to estimate places with high possible injured people. So to find these places we used the SoVI method with variable customization in a GIS environment.

The SoVI map could serve as a location-based service (LBS) play a game-changing role in territorial planning and emergency management by providing an evidence-based understanding of regional and local differences in the capacities to prepare for, respond to, and recover from natural hazards.

For further research, it is recommended to use large scale maps to predict more precise places that are more vulnerable to natural hazards.

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Claiming Space Through Language: Conceptualizing a Location Based Cultural Space Experience

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Abstract. In a hyperconnected world, language heavily impacts the human experience and sense of community by how relationships are built and how knowledge is shared through space. LBS methods allow the visualization of the intersections between language, specific spaces and social phenomena. A mapping of such interactions could impact and deepen the cultural lives of citizens and most importantly nurture a space to become a conduit of dialogue by making visible the invisible through meaningful connections. This paper describes the work plan for conceptualizing a cultural space experience, within museums, art galleries, historic houses, and other cultural institutions where interrelations of differences and similarities come together.

Keywords. experimentation, digital humanities, spaces

1 Introduction

Over the past years, language has been adopted as an essential model to conceptualize the embedded power of spaces. The tight and ever growing relationship between language, information and space has caught the interest of areas involved in policy-making and academic studies such as the digital humanities. This enhanced sensitivity regarding language as the object of politics has broaden the conceptions of spatiality, especially the relevance of the *“entanglement-focused, territoriality-, (de)attachment-*

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and connectivity-" conceptualizations in the environment (Jani Vuolteenaho, 2012). Moreover, the interdisciplinary nature of linguistics and space enables new collaborative networks for knowledge transfer, for example, by the utilization of Location Based Services for meaningful connections together with cultural continuity.

The increase in personal and spatial information constructs new digital geographies that are more personal and can empower or overpower people, places and institutions. Recent studies described representations of spaces, specifically in the urban realm, as information landscapes (Matthew Zook, 2000). Physical and virtual interactions with language shape people's experience in places. As more people are living closer and are more connected than ever before, the inequalities of information trace imaginary geographies through space and impact our understanding of a place (Seth M. Low, 2011). In a hyperconnected world, language heavily impacts the human experience and sense of community by how relationships are built and how knowledge is shared through space.

This paper describes the process for conceptualizing a cultural space experience as part of museums, art galleries, historic houses, and other cultural institutions within the framework of Exploration Space, (reference: https://www.oeaw.ac.at/acdh/about/core-units/core-unit-4/) a space for innovation and experimentation at the Austrian Academy of Sciences, Austrian Centre for Digital Humanities. Here we aim to explore the relationships between demographic characteristics, language and spaces.

We ask several questions:

1. How does linking language to LBS could help us understand better space and place?
2. How LBS shape our perception of the urban environment?

The goal is to exploit methods of LBS in a co-design process and develop an interactive tool to make our data accessible in places where they are related to. Thus, we aim to visualize how the "agency of spaces" and the moments of social inclusion and exclusion. The mapping of such interactions impact and deepen the cultural lives of citizens and most importantly nurture a space to be a conduit of dialogue by making visible the invisible through meaningful connections.

2 Background

2.1 Exploration space

Embedded into the Core Group "Methods and Innovation" it acts as an open space for the networked humanities, "with the aim of stimulating, designing, enabling and scientifically analyzing new forms of knowledge production at the interface of science, technology and society."

The actors explore methods and practices of the Open Innovation paradigm on a global scale. Exploration space is a best practice example for Open Innovation by the Austrian government (link: http://openinnovation.gv.at/portfolio/oeaw-exploration-space/).

2.2 LBS and the concept of language constituting space

Language is a negotiation between identity and environment, where identities are seen as a process circumscribed by the continuous struggle between the individual need for self-fulfillment and the demands of social structure and collective consciousness. Identities are subjected to constant negotiations that are here assessed through central role of a range of sociocultural and demographic factors that intervene in the relationship between humans, languages, and the physical environments in which communities live. However, language dominance offers the opportunity to choose layers of societal engagement, as well as the pace for understanding through its rhythm dynamics (Will Kymlicka, 2010). An important component of the platform that brings new to how language is systematically hidden within the workings of spaces is the visualization of data.

LBS functions as a layer that bridges the qualitative narratives with behavioral patterns happening in mobility platforms and languages spoken in social platforms. A new understanding on relationships that have been previously hidden in data is potentialized, such as the intertwining of historical patterns, psychology and political systems that perpetuate inequalities, silences and disadvantages.

3 Theoretical Framework: From the margins to the center through intersectionality

The theoretical framework chosen for this project departs from the lens of feminist studies, intersectionality and mixed methods as a research method. We applied Bell Hooks' notions of space, language and power as a main compass to set the foundations for the work plan. Hooks recognizes the primacy of voices that are often silenced and the importance of presenting a space as a space of learning (Bell Hooks, 1994). Thus through group-centered research we aim to bring in the experiences of marginalized groups who have generally been absent and 'give voice' while highlighting their unique experiences.

4 Methods: Exploratory sequential mixed methods, 'thinking with care' is a vital for collective thinking

Our research is a collaborative journey driven by collective processes and design research. In an iterative co-design process, as the conceptualization moves forward, so does the level of engagement of participants by examining the practices, evaluating the methods used in the design experiment process and most importantly in shifting the powers (Cameron, 2019).

The main objective is to develop a set of research tools and materials through collective experiences center on people's stories. The project seeks to empower participants by giving them the chance to take charge of their own narrative and engage and bring it to the center along with other participants as the process moves forward. Therefore, all activities part of the methodology aims to bring the narratives to the center and remove intermediaries from the spotlight.

An exploratory sequential mixed methods research (MMR) design will be implemented in order to broadly explore and understand, behaviors, and preferences from participants. In an exploratory design, qualitative data is first collected and analyzed, thus, this method is the most fitting for this project, since the qualitative methods and the narratives will later determine our scope for a quantitative instrument to further explore the research.

4.1 Qualitative methods: narratives from the margin to the center

4.1.1 In-depth interviews: From one-sided conversations to back to back connections

An approach will be made to at least six persons and through these qualitative interviews we will examine how race and gender influenced spaces and places experiences. The interviews focus on the complexity of relationships among social groups within and across spaces and places in the city of Vienna and how their experience with has been impacted through language.

4.1.2 Workshops: Journey mapping, ecosystem mapping and scenario building

We aim to conduct four workshops in total over the course of two months months with different people from the same group within the community. In an iterative process, we seek to develop strategies and tools for each workshop based on the people's feedback and responses and develop based on our learnings a meaningful framework.

We hope to get an insight to the stories of these people and function as a platform for sharing experiences. We want to create engaging and safe spaces and activities so that diverse non-native german speaking people from different career and life stages could discuss their experiences in Vienna from different perspectives. These workshops function as an exchange of conversations where time, space and emotions are discussed. As conversations get interlaced so does the interactions. This gives away power to the participants to take charge of the conversation and lead the narratives. By learning about the relationship with physical space, these exercises can be a tool to reflect on people's lives. It might highlight power relationships, as well as the rhetorics and stories that people use to interpret and process their experience in a specific context.

4.2 Quantitative methods: location data and time-of-day constraints

Self-reported positioning from people within the city of Vienna will help us to locate locations and time of the day check-ins as well as the language regarding these places. LBS then holds a role as a facilitating layer that feeds on the narratives gathered from the qualitative research phases, complimenting in complexity and in details the story we are trying to map.

5 Consequences, expected challenges and results

We aim to reach a piloting step during the project runtime (01.07.2019-31.03.2020) and develop based on our learnings a meaningful follow up project proposal. After developing this work plan, through the driven results an interactive installation is expected to launch in the city of Vienna in locations where key narratives from our research developed, thus, intertwining the different realities that exist through space and places.

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