Masters Program in **Geospatial Technologies**

Supported by:
ERASMUS MUNDUS

AUGMENTING PEDESTRIAN NAVIGATION SYSTEMS WITH CONTEXT-AWARE DISPLAY OF POIS

A thesis submitted in fulfillment of the requirements

for the degree of Master of Science in Geospatial Technologies

in the

GEOTEC

Dept. Lenguajes y Sistemas Informaticos

Augmenting Pedestrian Navigation Systems With Context-Aware Display of POIs

Author:

Birhane Guesh

Supervised by:

Dr. Carlos Granell

Co-Supervised by:

Prof. Dr. Christian Kray and Dr. Roberto Henriques

March 7, 2017

Declaration of Authorship

I, Birhane Guesh, declare that this thesis titled, " Augmenting Pedestrian Navigation Systems With Context-Aware Display of POIs " and the work presented in it are my own. I confirm that:

- Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated.
- Where I have consulted the published work of others, this is always clearly attributed.
- Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.
- I have acknowledged all main sources of help.

Signed:

Date:

Abstract

Birhane Guesh

Augmenting Pedestrian Navigation Systems With

Context-Aware Display of POIs

Nowadays, pedestrian often relies on automated navigation systems to find their way in an unfamiliar environment at the expense of increasingly degrading one's spatial knowledge and surrounding environment interaction. The reason for this is that because pedestrians are not required to solve spatial tasks along the route, they just depend on the abilities of the system, despite the fact that mental maps are built up from observations gathered during travel and direct interaction with the environment. This research investigated the augmentation of Google Maps turn-by-turn (TbT) pedestrian navigation system with context-aware visualization of the point of interests (POIs) along the path to enhance surrounding environment interaction and spatial knowledge of pedestrian. We conducted an experiment with six participant's using a prototype application with and without dynamic visualization of POIs to evaluate its effect on participant's spatial knowledge and interaction with the surrounding environment. Results suggested that participant's using a prototype application augmented with a context-aware display of POIs showed better spatial

knowledge and surrounding environment interaction compared to participant's who use a prototype application without context-aware display of POIs.

Acknowledgements

I would like to thank my supervisor, Dr. Carlos Granell, for the patient guidance, encouragement, and advice he has provided throughout my time as his student. I would also like to thank my co-supervisors; Prof. Dr. Christian Kray and Dr. Roberto Henriques for their guidance and valuable feedback.

I would also like to express my very profound gratitude to European Union Commission EACEA for their generosity and support. I am very honored to have been the recipient of the Erasmus Mundus Programme scholarship.

Many thanks to all academic and administrative staff of the Master program in Geospatial Technologies in Jaume I University (UJI), Institute for Geoinformatics (IFGI) - Muenster University, and NOVA Information Management School (NOVA IMS) for their indispensable help and support throughout the process of my study.

Last but not least I would like to express my heartfelt gratitude to my beloved family and friends who encouraged me morally in my school life. This accomplishment would not have been possible without them. Thank you.

Contents

List of Figures

List of Tables

List of Abbreviations

TbT	**T**urn **b**y **T**urn
GPS	**G**lobal **P**ositioning **S**ystem
YAH	**Y**ou **A**re **H**ere
LBS	**L**ocation **B**ased **S**ervices
POI	**P**oint **O**f **I**nterest
API	**A**pplication **P**rogramming **I**nterface
UCD	**U**ser **C**entered **D**esign
SBSOD	**S**anta **B**arbara **S**ense **O**f **D**irection
PDA	**P**ersonal **D**igital **A**ssistant
SD	**S**tandard **D**eviation
ANOVA	**A**nalysis **O**f **V**ariance
EACEA	**E**ducation , **A**diovisual and **C**ulture **E**xecutive **A**gency

Chapter 1

Introduction

1.1 Theoretical Framework

Spatial knowledge of the environment plays a vital role when people are dealing with geospatial problems such as the recognition of places, wayfinding, navigation, and orientation in a new environment (Richardson, Montello, and Hegarty, 1999; Tverksy, 2000; Lynch, 1960). This knowledge of the environment is composed of several elements: memorizing places in relation to a reference point, developing a sense of the sequence in which places occur, and understanding how multiple places relate to each other in ways that allow navigation in an unfamiliar place (Ishikawa and Montello, 2006). Spatial knowledge of the environment is acquired from observing the environment, collecting environmental stories during travel, direct interaction with the environment and from reading maps (Kuipers, 1978; Nitsche and Thomas, 2003; Willis et al., 2009a) and it is developed throughout the lifespan of a person. According to a research study conducted in (Mondschein, 2013; Mondschein, Blumenberg, and Taylor, 2010; Mondschein, Blumenberg, and Taylor, 2008) there are two categories of travelers; “cognitively-active” and “cognitively-passive”. People who actively engage with the surrounding environment by walking, driving and riding bikes develop strong mental maps of the surrounding environment being cognitively active travelers. People’s with an ultimate goal of reaching their destination with less or no interest of exploring the surrounding environment which results in a poor mental map, belong to cognitively passive travelers. Therefore, the way people interact with the surrounding environment shapes their mental map of the environment.

However, the increasing popularity of mobile navigation technology has transformed the way we get around cities in just a few years. As a result, almost all pedestrian’s who have smartphone often make use of mobile navigation systems to help them reach their destination in unfamiliar environments. Hence, pedestrian navigation has become an important research topic aiming to develop optimized wayfinding assistance system so that humans can find their way in built environments efficiently and with minimum confusion and disorientation.

Even though navigation assistance services can reduce wayfinders workload during navigation task, problem still exists because it has been researched as a cause of poor engagement in the surrounding environment, degradation of spatial knowledge and poor orientation skills (Parush, Ahuvia, and Erev, 2007; Giannopoulos, Kiefer, and Raubal, 2015; Watanabe, Kaji, and Kawaguchi, 2012). A study conducted in (Münzer et al., 2006) compared mobile navigation device (early version of Google Maps) vs a paper map on guiding the participants in a zoo. Their results demonstrated that paper map users scored better on the survey test and almost perfect on the route test. They argued that pedestrians who use computer navigation fail to envision, encode, and memorize the cognitive maps they otherwise would have. Similarly, a reseach study by (Ishikawa et al., 2008) confirmed that people using a GPS navigation system took longer routes, made more stops, walked more slowly, and drew poor map sketches compared to people who used paper maps. Recently researchers have investigated the negative impact of turn-by-turn navigation assistance on the pedestrians ability to remember an environment and reconstruct a geographical route (Anacta et al., 2016; Ishikawa and Takahashi, 2014) . As a result, many researchers are attempting to address this kind of problem: by incorporating landmarks in computer generated navigation instruction (Raubal and Winter, 2002; Waters and Winter, 2012; Watanabe, Kaji, and Kawaguchi, 2012; Li et al., 2014; Anacta et al., 2016), by designing pedestrian navigation assistance that supports spatial learning (Richter, Dara-Abrams, and Raubal, 2010) , and by involving the user with continuous position notification (Parush, Ahuvia, and Erev, 2007), and using user's gaze in navigation assistance to decide the turning points of the route (Giannopoulos, Kiefer, and Raubal, 2015), and by integrating on the fly photos of commonly known YAH maps with pedestrian navigation systems (Schöning et al., 2009).

In a similar way, in this research, we investigated the augmentation of Google Maps turn-by-turn (TbT) pedestrian navigation with context-aware display of POIs along the path aiming to improve the surrounding environment interaction and spatial knowledge of pedestrians who frequently use navigation system. The focus of this research is on Google Maps turn-by-turn navigation system since it is one of the mainly used navigation applications on mobile devices and it is easy to customize the map and the information to be displayed on the map using Google Maps JavaScript API. Hence, to achieve this we implemented two suggested solutions from (Delikostidis, 2011) based on their usability study on pedestrian navigation systems in our small prototype application. The prototype application visualizes POIs based on current location, the relevance of engagement in the surrounding environment, proximity (distance from current position) and movement of the user with a dynamic semi-transparent shadow covering the area where the POIs are selected.

The main condition of augmenting Google maps TbT navigation with context-aware visualization of POIs is on the premise that user's spatial knowledge and interaction with the surrounding environment will be improved. Hence, the hypothesis is that the dynamic visualization of POIs with semi-transparent shadow invokes the pedestrian for better interaction and engagement with the surrounding environment during the navigational task. The assumption is that any form of user involvement during navigation task contributes to their spatial learning process which is the innate behavior of humans. (Giannopoulos, Kiefer, and Raubal, 2015) introduced a novel gaze-based approach for pedestrian navigation which assist pedestrians in a non-distracting way as well as supports the spatial learning process by allowing them to keep their visual attention to the environment without interruption. The Photomap application by (Schöning et al., 2009) aims to integrate commonly found YAH maps with the Internet-based maps in order to involve the pedestrians with their surrounding environment and assist them with their ongoing navigation activity. YAH maps are the public maps found at universities, small natural parks that help people to navigate within those locations. The sequence of event interaction in real-time 3D games has been studied and defined as story map of space in a virtual environment which is an important aspect of a cognitive map of the players (Nitsche and Thomas, 2003).

1.2 Aim and Objective

The ultimate goal of this research is to investigate the influence of Google maps turn-by-turn (TbT) navigation systems enhanced with contextual display of POIs on pedestrian's spatial knowledge and interaction with the surrounding environment. To accomplish this main objective, the following smaller objectives has been addressed sequentially.

1. First we investigated and define methods to dynamically display POIs on the map based on location, proximite (distance) and importance of engagement in the surrounding.

2. Then the prototype application is implemented using Google Maps JavaScript API (*Google Maps JavaScript API | Google Developers*) and JavaScript programming.

3. Finally we conduct an empirical assessment with six participants to find out the effect of the prototype application on spatial knowledge and surrounding environment interaction of the participants. According to our statistical analysis of the collected data through the tasks and a post-task questionnaire completed by participants; it has shown a positive contribution of the prototype application with context-aware visualization of POI towards enhancing the participant's environmental interaction and their spatial knowledge in

comparison to the prototype application without dynamic visualization of POIs.

Generally, the results highlighted the positive outcome of augmenting pedestrian navigation with context-aware POIs visualization in understanding one's location with reference to the surrounding environment.

1.3 Thesis Outline

This introductory chapter presents the rationale and main research objective of the thesis work. Chapter 2 provides an overview of the topics and concepts related to pedestrian navigation assistance systems. Chapter 3 discusses the methods employed and data used to achieve the stated objective in chapter 1. Following this Chapter 4 provides the results found by analyzing the collected data in Chapter 3. Then the interpretation of the results and limitation that encounter during the course of the thesis work is presented in Chapter 5. Chapter 6 presents the summarization and future work of this research.

Chapter 2

Literature Review

This chapter presents the role of context-awareness, landmarks, and location-based services on spatial knowledge acquisition and surrounding environment interaction while using automated navigation systems.The overview of concepts and findings of the aforementioned topics and their role in automated navigation systems has been highlighted. By summarizing literature review of these topics we presented the highlight of their relevance to improving spatial knowledge and surrounding environment interaction of pedestrians who often rely on automated navigation systems.

2.1 Context Awareness and Navigation Systems

Despite the fact that several explanations and definitions of the term "context " by varying the description and the parameters they considered have been proposed by many researchers in the past, a comprehensive definition has been provided by (Sarjakoski and Nivala, 2005) . (Sarjakoski and Nivala, 2005) defined context as follows; "context is any information that can be used to characterize the situation of an entity and that is relevant to the interaction between a user and an application". According to a study conducted by (Abowd et al., 1999) location, identity, activity and time have been recognized to be more relevant context types in practice. Furthermore (Kaltz, Ziegler, and Lohmann, 2005) identified five categories of context parameters : user&role, process&task, location, time and device to cover a broad variety of mobile and web scenarios. (Abowd et al., 1999) also classified the system as being context-aware if it uses context to provide relevant information and/or services to the user, in which the importance is dependent on the user's task. A recent research on context-aware mobile tourism recommendation system by (Meehan et al., 2013) has investigated contextual elements (temperature, weather, time, sentiment and user preference) in addition to location to filter content.

In the case of map usage scenarios, the relevant contexts for map usage situation has been identified by (Nivala and Sarjakoski, 2003) based on their field based experimentation. According to their findings the most important context for mobile map applications are the user, system, physical, time and history. When a map is used in the field, the surrounding contexts that are important to define the type of the map the user needs consists of; location, orientation, time, history, purpose, social-cultural conditions, environmental configuration, device type and system-user interaction (Sarjakoski and Nivala, 2005). The goal of context-awareness in mobile cartographic map is to increase the user's mental, emotional and social experience with respect the functionality of the navigation system by considering the relevant contexts to the map usage situation (Delikostidis, 2011).

Therefore, the increasing interest of mobile users towards intelligent and easy to use navigation systems has led many researchers to investigate context-awareness in navigation. A recent study by (Pouryegan and Malek, 2015) claims that the context of use determines the kind of navigation services that can be provided to specific group of users. They also classified pedestrian navigation services into five categories: Location Finding , Optimal Path Finding, Orientation, Positioning and Wayfinding. Based on their survey and experimentation all present day navigation systems are one of these types. A new theoretical approach of understanding the needs of pedestrian in navigation services has been introduced in (Fang, Li, and Shaw, 2015). In their study, pedestrian needs during navigation process has been considered as three layers based on Maslow's theory: physical sense layer, physiological safety layer, and mental satisfaction layer.

1. The physical sense layer focuses on visual, auditory, tactile, and olfactory senses that pedestrians use to perceive navigation instructions.

2. The physiological safety layer concentrates on the safety perspectives of persons, routes, and environments in pedestrian navigation.

3. The mental satisfaction layer focuses on the satisfaction of pedestrians in the navigation process in terms of the requirements of comfort, confidence, and respect.

2.2 Landmarks and Navigation Systems

Many researchers have investigated the importance of landmarks to enhance the geographical spatial knowledge and orientation skills of automated navigation systems users'. The importance of landmarks as environmental features that support orientation, wayfinding, and navigation in urban areas has been studied by many researchers in the past (Lynch, 1960; Ishikawa and Montello, 2006). The relevance of local landmarks has been studied (Raubal and Winter, 2002) which suggested measurement methods to extract salient features of the environment that are helpful in wayfinding instructions. An algorithm has been developed in (Duckham, Winter, and Robinson, 2010) which generates route instruction with reference to local landmarks. A new classification scheme of landmarks based on human wayfinding instruction to support the formation of cognitive map in turn-by-turn navigation systems has been introduced (Anacta et al., 2016). According to this study local landmarks are not only needed to decide the turning points of the route but also facilities learning of geographical spatial knowledge along the route. A study conducted in (Waters and Winter, 2012) suggested that landmarks supported with wayfinding aids could be used as training and engagement role in the surrounding environment during navigational tasks. In general, humans can rely on both global and local landmarks during navigation and for creating and maintaining spatial mental models of environments (Steck and Mallot, 2000).

Particularly the interest towards selection and presentation methods of landmarks on mobile navigation assistance services has been increasing in the last few year aiming to improve the spatial knowledge and orientational skills of user. A prototype mobile application that displays distant landmarks on the edge of mobile devices has been introduced (Li et al., 2014) and illustrated the presentation of distant landmarks on the edge of mobile device supports for people with low sense of direction. Moreover a research study conducted (Delikostidis and Elzakker, 2009) aiming to understand the interaction between the users of mobile navigations systems, their cognitive map, reality and mobile map display device suggested that; landmarks play a vital role to learn the surrounding environment with respect location of the user and for better navigational performance of users. Hence, it is clear that inclusion of landmarks in route instruction could increase environmental engagement and thereby spatial knowledge given the fact that landmarks are noticeable features of an area. Generally, due to the reason that automated navigation systems hardly support geographical spatial learning and engagement as introduced in Chapter 1 , providing mobile navigation system users with cartographic interfaces based on landmarks has been a promising approach. Therefore the importance of landmarks in mobile navigation systems and wayfinding has been widely investigated and agreed upon. Hence, Obtaining a deeper understanding of the types of landmarks and other structural elements that users refer in real contexts in order to make spatial decisions and carry out spatial tasks would further support the development of more usable mobile navigation systems.

2.3 Location-based Service and Navigation Systems

One of the most widely known and researched types of map-based LBS is route information system that is the central concept of navigation systems (Gartner, 2004; Richter, Dara-Abrams, and Raubal, 2010). Hence, many researchers have been investigating the effectiveness of various presentation forms of LBS on mobile devices in terms of their navigation performance and spatial learning support during navigation. In order to evaluate the spatial knowledge acquisition using these presentation forms of LBS, participants often had to navigate in an unfamiliar environment with the help of mobile devices with LBS. The spatial knowledge acquired during the navigation task with the help of LBS is usually measured by image sorting and realization of the environment (real or virtual) they navigated, by pointing tasks, or by sketch map drawing task, and other relevant tasks. If the participant's score is higher on these tasks then, the LBS is considered as successful assistance systems.

In (Münzer et al., 2006) , participants navigated through a zoo either using a PDA or printed maps. The PDA had three different modes: 1) only visual information. When approaching an intersection an animation showed the relation of the previous, current and next intersection. A line on the intersection's photo then indicated the way to take. 2) The same as 1), but with the photo a verbal instruction was given. 3) Only the photo and verbal instruction. The printed maps only showed part of the environment at the same time. Results were that map users acquired much better route and survey knowledge than the PDA users. The presentation mode had no influence on the performance; animations did not help.

In (Parush, Ahuvia, and Erev, 2007) , participants navigated in a multi-level virtual environment. They had either continuous access to a map showing their position or could request to see it at all times. In both conditions participants either had to solve location quizzes (indicate current position on map) or not. Sixteen runs were performed with assistance (a run being the task to find a specific target from the current start position) and a final transition run without any assistance. Excess distance, the number of map requests, and performance in the quizzes were used as performance measures. Participants with continuous position indication performed best with regard to excess distance. However, for those requesting a map, excess distance and number of requests decreased with increasing number of runs, indicating that learning took place. The quizzes had no immediate effect on performance, but again learning took place, as participants got better in the quizzes with increasing number of runs. For the transition run, those having had continuous position indication and no quizzes performed worst, while those requesting maps and having quizzes performed best.

These studies illustrated that using mobile navigation systems lead users to be "mindless" of the surrounding environment. They do not learn the presented information and the information perceived in the environment to a sufficient level which results in great difficulties in acquiring both route and survey knowledge. This is caused by the lack of attention in the surrounding environment while using automated navigation systems, and a solely depending on abilities of the system, which decouples the actions to be performed from their spatial embedding. The experiments in(Parush, Ahuvia, and Erev, 2007) show that involving users more deeply in the navigation process results in a learning effect. LBS design should aim for a way of presenting information that is useful in the given situation and also fosters processing of that information, increasing users' confidence of "doing the right thing" and decreasing their dependency on the device (Willis et al., 2009b) . A recent study by (Delikostidis, Elzakker, and Kraak, 2016), a User Centered Design (UCD) approach was applied to fully understand the behavior, interaction, and performance of people during navigation and to extract existing knowledge about human wayfinding and human ways to communicate routes and navigation instructions. The result of their requirement engineering process was implemented in the development of a usable pedestrian navigation system prototype application. They performed an empirical, field-based experimentation of the prototype application to find out the possible usability problems, to measure the performance of participants and to collect qualitative behavioral information. Their findings have shown a significant improvement of participants in their sense of geo-identification while using the prototype application based on effectiveness, efficiency, and satisfaction test measurements. Showing local and global landmarks, route options based on time availability are some of the functionality that provided in the prototype. Generally, their result illustrated the advantage of applying User Centered Design (UCD) principles in designing and developing user oriented pedestrian navigation system.

Chapter 3

Methods and Data

This chapter provides the details of the methods and data that have been utilized to achieve the main objective of the research. In the beginning, we presented the tools, APIs, and software used to implement the prototype application. Secondly, we discussed the design and implementation of the experiment i.e. recruitment process of participants, the set-up and description of the experiment and the design and execution of tasks. Then we discussed the process of collecting the data through the task and questionnaire completed by participants. Finally, we provided the evaluation methods used in this experiment.

3.1 Prototype Implementation

The prototype application implemented two suggested solutions from a research study conducted by (Delikostidis, Elzakker, and Kraak, 2016). The main focus of their work was to improve the usability of pedestrian navigation systems and to support spatial knowledge learning during navigation task. First, they performed requirement engineering of pedestrian navigation systems by utilizing the user centered design (UCD) principles to develop their prototype application. Following this, they conducted empirical and field-based experimentation with the prototype application to find out the possible usability problems, to measure the performance of participants and to collect qualitative behavioral information. By analyzing the overall data they have collected they come up with the list of proposed solutions that are important to consider in the implementation of usable pedestrian navigation assistance system. Following this, we implemented two of these proposed solutions in our prototype application.

According to the first suggested solution, we introduced a semi-transparent shadow on the map to make the filter of POIs behind the user more obvious. The shadow covers the area where the POIs are selected as shown in (Figure 3.1, 3.3 and 3.4) and it is a 100-meter radius (distance) from the current position of the user. The semi-transparent shadow refreshes every 20-meters as the pedestrian navigates through the virtual environment. Both distance values are not empirically supported, it is the assumption made by the author that notifying POIs every 20 meters can engage the pedestrian in the surrounding environment. The POIs are selected within 100-meter radius (distance) from a current position of the user is also assumed to engage the pedestrian in the surrounding environment. Furthermore, a recent research by (Ranasinghe and Kray, 2016) investigated user's perception of their location and visualization preference with multiple options for presenting location uncertainty on mobile devices. They found out that presentation formats have indeed an influence on the perception of location information. According to their result, the circle was the preferred shape of showing location information.

The second suggestion was to use a richer database of landmarks (

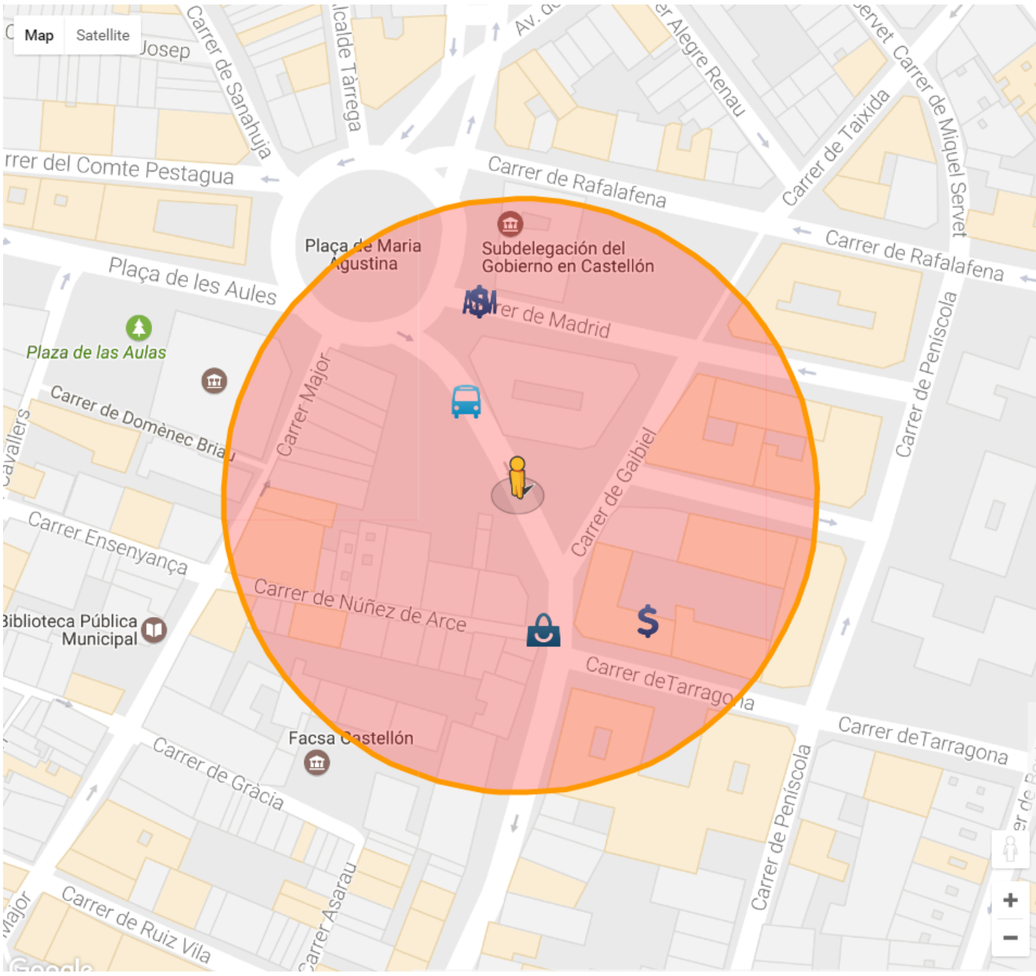

FIGURE 3.1: Dynamic visualization of Point of Interest .

POIs in our case) from which a larger number of local landmarks (POIs) should be presented to the user, automatically selected based on his current location. To achieve this firstly we hide all the business points of interest (POIs) and public transit icons on the map using Google Maps styling (*Google Maps JavaScript API | Google Developers*). Then using Google places API we implemented the dynamic display of top five nearby places (see Figure 3.1). The points of interest (POIs) are selected based on the proximity (distance) from the current location of the user, the importance of engagement in the surrounding environment. The importance of POIs to engage in the surrounding environment is mainly focusing on POIs that have been studied to have a significant role in the spatial knowledge learning of the user during navigation task (Delikostidis, Elzakker, and Kraak, 2016). According to this study 30 types of POIs and/or landmarks has been investigated that are important to support and facilitate the spatial knowledge acquisition and surrounding environment interaction of pedestrians who depend on navigation assistance systems. Moreover, similar studies have been done on the importance of landmarks in engaging travelers (Watanabe, Kaji, and Kawaguchi, 2012; Anacta et al., 2016) . Following these studies we used the following types of POIs based on Google places API for the dynamic visualization along the route; Academic/Library, Bank, Bridge (pedestrian), Bridge (vehicle), Bridge (mixed), City Center, Church , Commercial/office building , Fast food , Governmental office, Historical , Hotel, Medical building , Museum, Noticeable monument , Park ,Pedestrian crossing , Railroads , Restaurant , River/canal , Roundabout , Sports , Square , Station (bus) , Station (Metro) , Station (train) , Stop (bus), Stop (Metro), Stop (train), Residential.

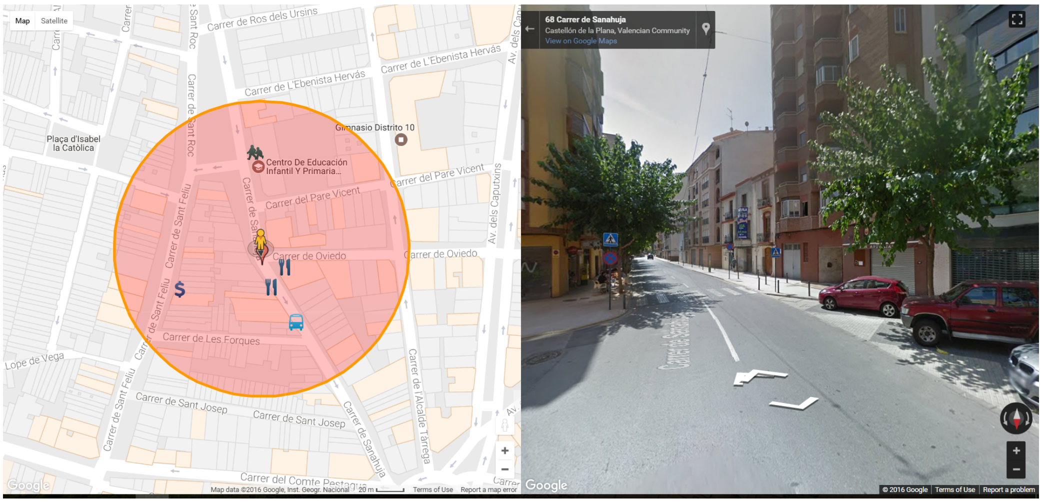

FIGURE 3.2: The laptop screen divided in two equal parts (map part and virtual environment) map shown on the left part of the screen and virtual reality on the right part of the screen.

3.1.1 Virtual Environment

We used Google Maps Street View images as a virtual environment for the lab-based navigation task. To accomplish this, first we divided the laptop screen in two parts as shown (Figure 3.2), the right portion displaying the map pinpointing the location of the user and the right half displaying the street view based on current position and orientation of the user on the map. The limitation of using Street View as virtual reality is that it was difficult to keeping track of participants exact footstep as they navigate on the virtual realty using the computer mouse and guide arrow of the virtual reality.

3.2 Experiment

3.2.1 Participants

The total number of participant's in our experiment were six. The participants were from a different culture (e.g Africa, Europe, and South America) and have different professional backgrounds (e.g student, teacher and supermarket worker). They were divided into two groups as explained later. The participants of the prototype application with context-aware visualization of POIs (3 male), two of them belong to the age group (25-30) and the third one were (31-40). The participants of the prototype application without context-aware display of POIs were (3 male), and all of them belong to the age group (25-30).

3.2.2 Experiment Design

The implementation described in the previous section was utilized to evaluate the effect of augmenting the turn-by-turn Google Maps navigation system with dynamic display of POIs and semi-transparent shadow as it is described in the previous section. We focused on Google Maps turn-by-turn navigation system since it is one of the mainly used navigation application on mobile devices for pedestrian and the simplicity of using Google Maps JavaScript API to customize the map and the information displayed on map. We have configured the prototype application for two different experimental conditions; the prototype application with dynamic visualization of POIs along the route being one condition as shown in (Figure 3.3 and 3.4). The second condition is the prototype application without dynamic visualization of POIs (see Figure 3.5 and 3.6). A between-subjects

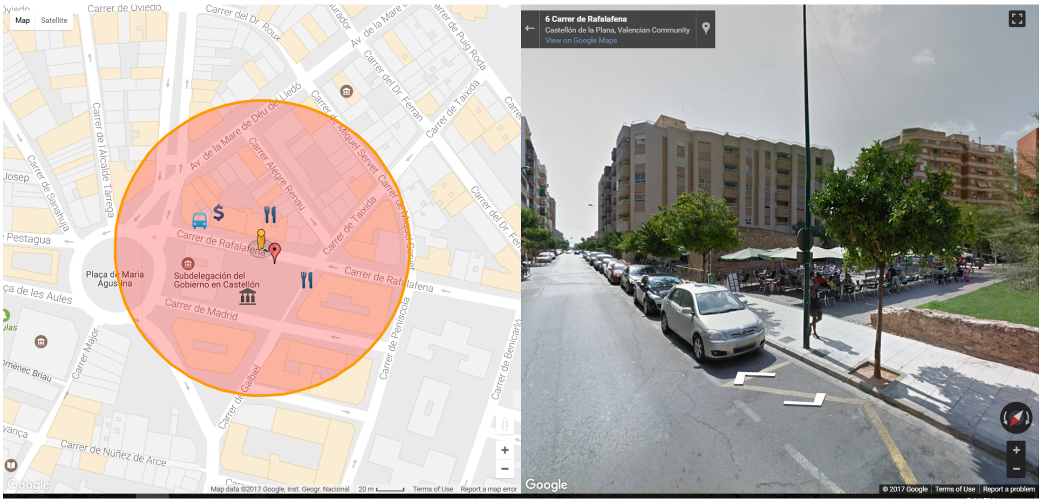

FIGURE 3.3: Screenshot of the place where participants of the context-aware visualization of POIs estimated the distance and direction to two different POIs.

design similar to a research study by (Giannopoulos, Kiefer, and Raubal, 2015) was utilized to evaluate the two conditions of the experiment. Each participant from both groups had to estimate distance and direction to two different POIs from the same location on the map and had to navigate through the same route in the same virtual environment once depending on the experimental condition he/she belong (see Figure 3.4 or 3.6). In both conditions, participants had to navigate using the guide arrow of the street view image presented on the right part of the computer screen. The path to follow was highlighted in blue color on the map on the left portion of the screen (Figure 3.4 and 3.6) in both experimental conditions. The pegman marker is used as an indicator of the current location of the user on the map and the street view virtual reality based on orientation and position of the pegman is displayed on right part of the screen. The route was selected with considerable turning points, having a different number of connections (see Figure 3.4 and 3.6) with the intention to investigate the

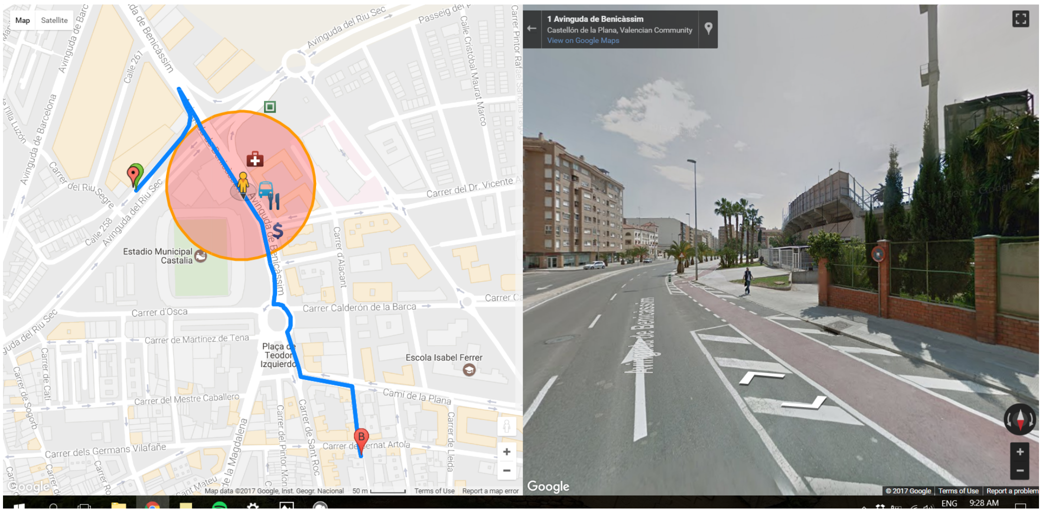

FIGURE 3.4: A route with Context-aware visualization of POIs.

effect of decision points with varying structure and complexity. Since the tested route covered different levels of complexity concerning the turning points as well as navigation directions towards all cardinal directions, there was no need to perform the experiment using a second route.

3.2.3 Experiment Description

Every experimental condition has four steps. In the first step, the test persons were required to provide their demographic information, their experience level with GPS systems, digital maps and Google Maps mobile navigation systems as well as to fill in a 5-point likert-type scale questionnaire for the self-estimation of their spatial abilities (Appendix A). The experimenter divided the participants into two groups (i.e participants with strong spatial abilities and participants with less strong spatial abilities) based on their self-reported data. In the second step, the experimenter

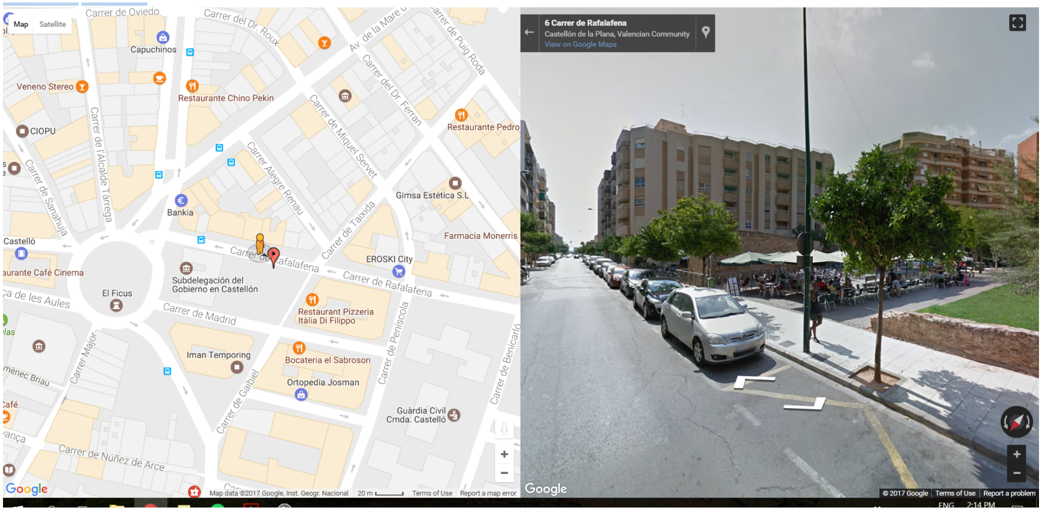

FIGURE 3.5: Screenshot of the place where participants without context-aware visualization of POIs estimated the distance and direction to two different POIs.

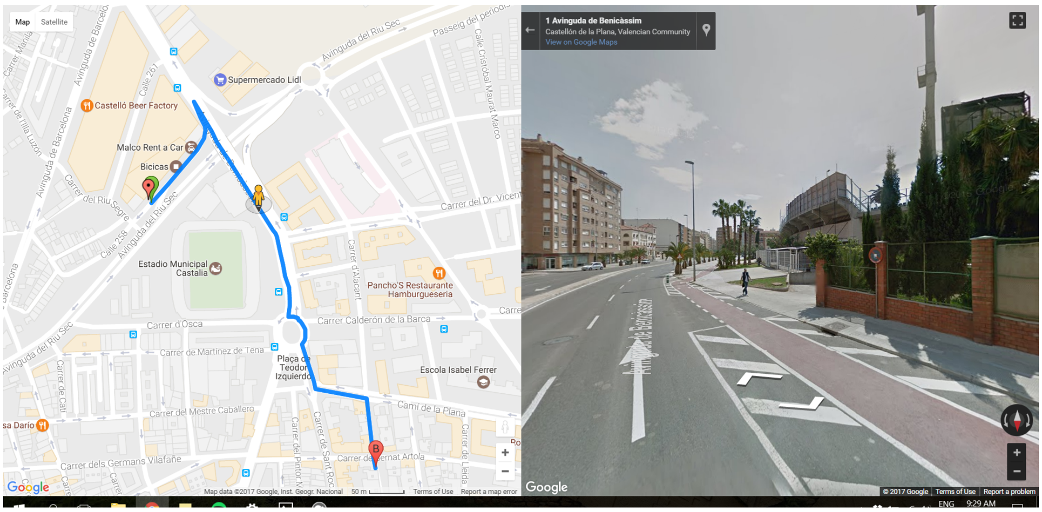

FIGURE 3.6: A route without Context-aware visualization of POIs.

presented a short description regarding the interaction controls of the prototype application, the virtual environment and the tasks (different to the one used in the next step) to each participant depending on the experiment condition they belong to.

The third step the participants were asked to complete two tasks, the first task was to estimate distance and direction to two different POI (to the nearest bus stop and a nearest POI other than bus stop) from the same location for each participant. Following this each participant navigated a route in the same virtual environment. The participants were informed to use the mouse and the guide arrow control to navigate through the environment (see Figure 3.7), to the target destination.

In the fourth step of the experiment, immediately after completing the navigation task, a set of 13 screenshot images (8 correct) were given to the participants. These screenshots were taken at different points along the route they navigated in the virtual environment. Their task was to choose the screenshot they thought to remember crossing during navigation. Finally, participants were asked to fill the post-task questionnaire to evaluate the prototype application and experiment condition they used to complete the task.

3.2.4 Evaluation Method

The experiment was designed to evaluate the impact of the prototype application on participants spatial knowledge and surrounding environment interaction improvement based on the following two aspects.

1. *Initial Geo-identification* - Participant's performance in directional and

FIGURE 3.7: Participant navigating in the virtual environment (The participant granted us his written permission to appear in our work).

distance estimation to near POIs is used to assess the ability of understanding one's location with reference to the surroundings.

2. *Local Spatial Learning* - Participant's performance of recognizing the correct screenshot image along the route they navigated and the post-task survey related to this task is used to assess the spatial knowledge acquisition during the experiment in the virtual environment.

3.3 Data Collection

The data was collected from the tasks completed by participants, and using the questionnaires completed by the participants. During the tasks the researcher was recording the estimated distance and direction and correct and wrong seen recognition made by the participants. The pre-task questionnaire completed by each participant has two sections (Appendix A). In the first section the participants had to fill their personal information. The second part was a 5-point scale to collect self-report data on participants experience with GPS systems and digital maps, with Google maps mobile application, and participants sense of direction spatial abilities (Appendix A). Sense of direction spatial abilities was measured using the Santa Barbara Sense of Direction Scale, a self-estimation of spatial abilities which provides a reliable, quantified assessment of spatial abilities by correlating with locating oneself in an environment and maintaining orientation during movement through an area (Hegarty et al., 2002). The spatial abilities survey were adapted to a 5-point liket-type scale and consists of 12 questions. When a participant's answers are summed and averaged, the resulting number between 1 and 5 is considered his or her spatial ability score. The post-task questionnaire was a 5-point liket-type scale and it was mainly used used to collect information on participants evaluations of the prototype application and experiment condition they used to complete the task (Appendix B).

Chapter 4

Results

This chapter presents the outcome of the research by analyzing all the collected data from chapter 3. Firstly the summary of participants self-assessment data from pre-task questionnaire has been presented. Following this, we provided the detailed analysis of the data collected using the task and post-task survey completed by participants. These analyses were mainly used to evaluate participants spatial knowledge acquisition along the route and their ability to understand the surrounding environment with reference their location.

4.1 Self Assessment Data Analysis

The summary of participant's self-assessment report of their environmental spatial ability, experience with GPS systems, digital maps, and Google Maps mobile application based on their self-assessment report data using pre-task questionnaire (Appendix A) is presented in Table 4.1.

Participant's environmental spatial ability showed a normal distribution, with the mean and the median (3.6) approximately the same. We used the mean (M=3.6) to classify participants in two even groups; The

TABLE 4.1: Descriptive statistics of all participant's self-assessed data (N=6).

Participants Spatial Ability (1=poor, 5=Excellent)	**Participants experience**
Mean: 3.61 Min/Max: 3.08/4.17 SD: 0.45	Mean: 4.17 Min/Max: 1.67/ 5 SD: 1.16

participating whose SBSOD score is above (3.6) group and below (3.6) group. Those who possess better spatial abilities had SBSOD score of (mean M=4.0 SD = 0.17) and those with less spatial abilities had SBSOD score of (mean M=3.22 SD = 0.18) based on participants self-assessment report data.

Almost all of the participants assessed themselves having greater experience of with GPS systems, digital maps and Google maps mobile application except one of the participants has mean value of (1.67) which is below the moderate value. We also examined the differences between participants environmental spatial abilities and their experience of using GPS system, digital map and Google maps using ANOVA to check if there is significant difference. The F ratio (0.37) was much smaller than the F critical (4.6), hence experience of participants with GPS system, digital maps and Google maps is not related to their environmental spatial abilities.

4.2 Initial Geo-identification

The data collected from participants performance on direction and distance estimation task and a post-task questionnaire related to this task were used to evaluate participants level of understanding their location with reference to the surroundings in the virtual environment. Estimation

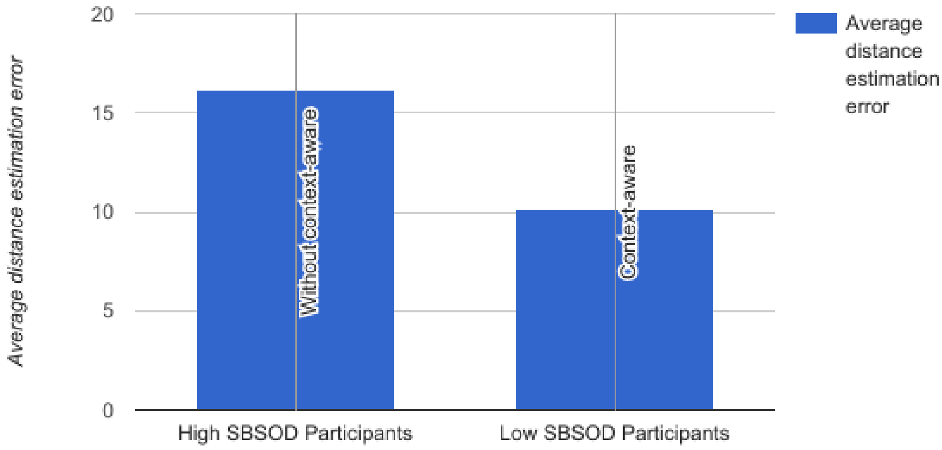

FIGURE 4.1: Average distance estimation error made by participants .

of direction and distance to two different POIs was done by comparing, combining and linking information provided from the prototype application.

Participants with less spatial abilities (SBSOD < 3.6) have shown better performance in distance estimation by using the prototype application application with dynamic visualization of POIs and semi-transparent shadowing around current location (Mean Distance Error MDE = 10.17, SD= 10.46) than participants possessing strong SBSOD using the prototype application without dynamic visualization of POIs and semi-transparent shadow (Mean Distance Error MDE = 16.17, SD =13.01) as shown in Figure 4.1.

Similarly, the directional estimation (Figure 4.2) illustrated better performance (Mean of Directional Accuracy MDA = 0.83, SD = 0.26) using the

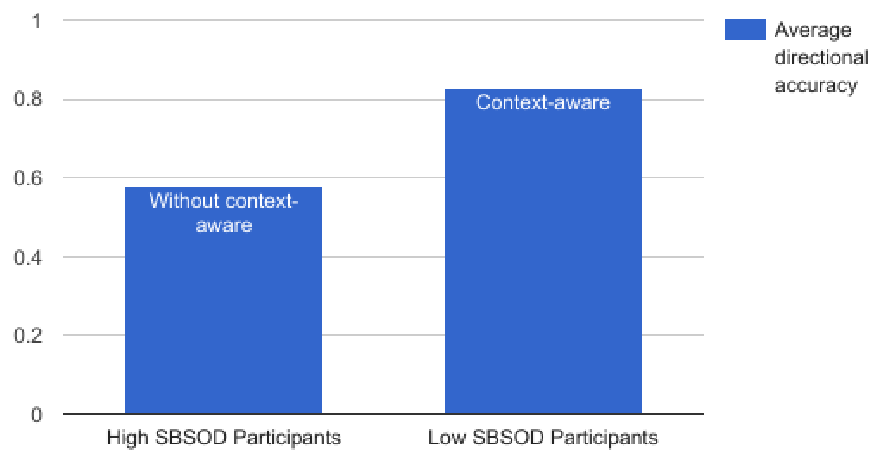

FIGURE 4.2: Average directional estimation accuracy made by participants .

prototype application with dynamic display of POIs and semi-transparent shadow than the participants using the second experiment condition (Mean of directional accuracy MDA = 0.58, SD=0.49). When all the direction estimation made by participants is correct then the mean directional accuracy = 1.

Furthermore, the post-task questionnaire asking the participant to rate " The difficulty of [estimating direction and distance , navigation] using the prototype application " (see Appendix A) has revealed that the prototype application with dynamic visualization of POIs was better (M = 3.10) for navigational task and estimation of distance and direction than the prototype application without dynamic visualization of POIs (M =2.70).

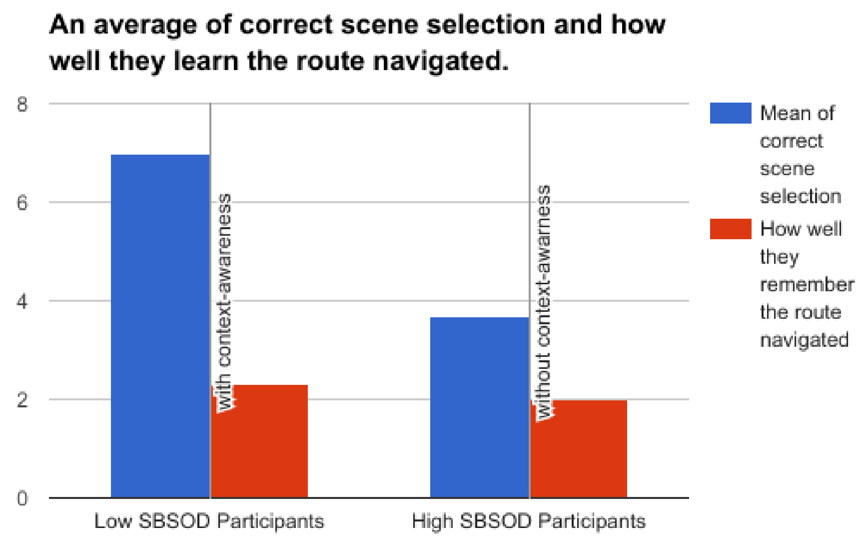

FIGURE 4.3: Participants correct scene selection and how well they remember the route they navigated.

4.3 Local Spatial Learning

To evaluate participants spatial knowledge of the surrounding environment along the route participants navigated in the virtual environment the screenshot image recognition task and the post-task survey related to this task has been analyzed. The analysis of the spatial learning task performed by participants revealed a significant difference between the two experimental test conditions in seen recognition task along the path (see Figure 4.3). Participants with low SBSOD (<3.6) was assigned to use the prototype application with dynamic visualization of POIs and they had a mean of 7.0 correct selections of screenshot images (min =4, max = 8, SD = 1.85). Participants using the prototype application with less context had a mean of 3.67 correct selections (min = 3, max = 5, SD = 2.073) (see Figure 4.3).

In Addition, the participants have been asked to rate how well they remember the route they navigated during the task in both experimental conditions. The context imposed map users demonstrated slight difference at learning the route navigated (mean = 2.33 SD = 1.53) than the normal map users (mean = 2.0 SD= 1.73) (see Figure 4.3).

Chapter 5

Discussion

In accordance with the main objective of this research, the statistical analysis of the collected data highlighted a positive contribution of the prototype application with dynamic visualization of POI and semi-transparent shadow to improve environmental spatial knowledge in comparison to the prototype application without dynamic visualization of POIs and semi-transparent. Since the dynamic visualization of POIs always stays on the map along the route which invokes the user's attention, users of this experiment condition have acquired better local spatial knowledge (screenshot recognition along the path) about the virtual environment than users who used the prototype application without dynamic visualization of POIs. Hence, it is clear that participants with low SBSOD benefited the most from the prototype application with context-aware visualization of POIs according to the results found. Furthermore, the participants have been informed regarding the distance (100-meter radius) of the semi-transparent shadow from the current position indicator on the map so they have shown better distance estimation to near POIs. In other words, participant's knowledge of the semi-transparent shadow distance (100-meter radius) helped them to have better distance estimation to the POIs. A recent research conducted by (Ranasinghe and Kray, 2016) investigated multiple options of visualizing location information on mobile devices. According to their result, the circle was the most preferred visualization option by users. Regarding directional estimation, there were not particular feature from the prototype application with context-aware visualization of POIs that was supposed to help them orient on the virtual environment. However, the participants were informed about the standard integrated compass indicator of the virtual reality. As a result, they have shown better performance in the direction estimation task.

The direction and distance estimation task have been used in previous researches (Willis et al., 2009b; Li et al., 2014; Giannopoulos, Kiefer, and Raubal, 2015; Delikostidis, 2011) to evaluate participants performance of understanding their surrounding environment while using different LBS on mobile devices. In these studies the distance estimation was mainly on real environment, in our case, the estimation task was done in the virtual reality. We are aware of the research conducted in (Daum and Hecht, 2009) which indicated that people underestimate distance in virtual environments in comparison to the real world, where they are reasonably accurate. On the other hand, a study conducted in (Ziemer et al., 2009; "The perception of egocentric distances in Virtual Environments") found no significant difference between the participants' distance estimation performance in virtual reality and real environment. Based their result study they suggested that the experience and the feeling of being there in either real or virtual environment plays an important role in distance estimation. Research conducted in (Giannopoulos, Kiefer, and Raubal, 2015) mainly used printed out egocentric images to assess participants local spatial knowledge in the virtual environment they navigated and (Li et al., 2014) focused on landmark recall task along the route participants navigated to evaluate spatial learning using the designed mobile prototype application. Similar to these studies, the results found in this research using the tasks and post-task questionnaires are used to evaluate participants spatial knowledge and environmental interaction in the virtual environment.

The results from the tasks and post-task surveys illustrated that participants who use the prototype application (with more context) have acquired some spatial knowledge and better surrounding environment interaction. Nevertheless, it should be noted that participant's impressions of what features or characteristics they attended to during the experiment in virtual reality may not be accurate with respect to actual cognitive processes in real environment. Moreover, the total number of participants were small and gender biased since there were not female participants. Hence the result is useful as an initial insight towards investigating the important context information of pedestrians that should be considered for developing pedestrian navigation systems that can help pedestrians to have a better understanding of their surrounding environment during navigation task.

Chapter 6

Conclusion

In this research, the augmentation of pedestrian navigation systems with context-aware visualization of POIs has been investigated to support pedestrians interaction in the surrounding environment and spatial learning process along the path. In the first step, we implemented a prototype that displays POIs based on the following context of the user; current position of the user, the relevance of POIs to engage in the surrounding environment, proximity (distance from current position), and movement of the user with dynamic semi-transparent shadow covering the area where the POIs are selected. Based on our empirical experiment in a virtual environment, we found the positive effect of the prototype application with context-aware visualization of POIs on supporting person's interaction with the surrounding environment and spatial learning while using pedestrian navigation system.

However, the prototype application holds many limitations that need further work in the future. The first limitation is that the contexts applied to filter and contextually visualize POIs require very careful work in the future. This includes the investigation of additional contexts such as visibility of POIs, user preference, and user sentimental information that is important to dynamically filter and visualize POIs during navigation. Splitting the computer screen into two parts is not also based on any previous studies. Therefore, the effect of showing the virtual reality and the map side by side on the same computer screen requires further investigation. The area coverage of the semi-transparent shadow is not empirically supported hence further case study is required to investigate more appropriate area coverage around the current position of the user. Moreover, the automatic visualization of POI every 20 meter is not also based on case study, therefore the movement of pedestrians can be evaluated based on empirical studies.

The second biggest limitation of the experiment is the validity of lab-based experiments. It is very difficult to control every single different variable in virtual environments setting that might affect the results in a real environment since all the contextual factors of real environments cannot be represented in virtual environments (Giannopoulos, Kiefer, and Raubal, 2015). On the other hand, a research study conducted by (Parush, Ahuvia, and Erev, 2007; Delikostidis et al., 2015) suggested that such lab study can also be carried out in the real world, in comparison with a virtual environment, to further verify the findings and theoretical implications of the study. Another issue that is worth mentioning in this lab experiment is that participants were supposed to navigate in an unnatural way, which is using a computer mouse (hand control) and guide arrow in the virtual reality. The reason we utilized a lab-based study is due to the limitations of the prototype application, as we mentioned earlier the application is not full fledged. Besides the sample size (3 volunteer participants for each group) was very small to draw a firm conclusion based on the inferential statistics hence recruiting participants with an incentive is recommended for future work. Both experimental conditions were tested in the same virtual environment, therefore all these limitations apply to both conditions. Therefore, in our future work, we plan to develop mobile application addressing all the aforementioned limitations to conduct a comparative study in a real environment to reveal the potential of the prototype application with context-aware visualization of POIs along the route.

Appendix A

Pre-task Questionnaire

Dear volunteer participant,

My name is Birhane Guesh and I am currently doing my Master thesis at Universitat Jaume I. My research topic aims to improve the surrounding environment interaction and spatial knowledge of pedestrians who rely on navigation assistance services.

I will conduct an experiment from 19, Monday to 22, Friday with the prototype navigation system at Espitec, the 5th floor which will take a maximum of 15 minutes each person, so I am kindly asking you to email me your convenient time.

I am kindly asking for your kind contribution by filling this questionnaire which will provide me with valuable feedback to setup my experiment.

Please click the link to fill the questionnaire.

https://goo.gl/forms/iN55FjdeuxVXBGBo2

With best regards,

This questionnaire has two sections, the first part is about your personal information. The second part consists of several statements about your spatial and navigational abilities, preferences, and experiences. After each statement, you should mark on the radio button to indicate your level of agreement with the statement. The scale of rating is defined as 1= Poor , 2=Fair , 3=Good, 4=Very good , 5=Excellent.
All the information provided in this questionnaire will be strictly kept private and any reference to the participants will be done later using codes (P1, P2, P3...) and not their real names.

1. Please write your full name ?

   ....

2. Please indicate your gender?

   O Male O Female

3. Please select the age group you fit in?

   O 18-24 O 25-30 O 31-40 O 41-50 O 51-60

4. Where are you from?

   ....

5. What is your profession/studies :

   ....

6. How long have you stayed in Castellon ?

   ....

Remember the scale of rating is interpreted as follows: 1= Poor , 2=Fair , 3=Good, 4=Very good , 5=Excellent.

1. Please rate your experience of using GPS systems.

   O 1 O 2 O 3 O 4 O 5

2. Please rate your experience of using digital maps.

   O 1 O 2 O 3 O 4 O 5

3. Please rate your experience of using Google Maps mobile application?

   O 1 O 2 O 3 O 4 O 5

4. Please rate your ability of giving directions.

   O 1 O 2 O 3 O 4 O 5

5. Please rate your ability of judging distance.

   O 1 O 2 O 3 O 4 O 5

6. Please rate your ability to memorize places that you visited recently.

   O 1 O 2 O 3 O 4 O 5

7. Please rate your "sense of direction" skill.

   O 1 O 2 O 3 O 4 O 5

8. Please rate your ability of judging your environment in terms of cardinal directions (N, S, E, W).

   O 1 O 2 O 3 O 4 O 5

9. Please rate your ability to orient and navigate in a place that you visited for the first time.

   O 1 O 2 O 3 O 4 O 5

10. Please rate your level of enjoyment while reading maps.

    O 1 O 2 O 3 O 4 O 5

11. Please rate your ability of understanding directions.

    O 1 O 2 O 3 O 4 O 5

12. Please rate your ability of reading maps.

    O 1 O 2 O 3 O 4 O 5

13. Please rate your level of enjoyment while giving directions.

    O 1 O 2 O 3 O 4 O 5

14. Please rate your ability to remember a new route after you have traveled it only once.

    O 1 O 2 O 3 O 4 O 5

15. Please rate your "mental map" knowledge of your environment.

    O 1 O 2 O 3 O 4 O 5

Appendix B

Post-task Questionnaire

Please complete the the follow questionnaire. if there is any ambiguity you can ask to the author.

1. Please rate the difficulty of using the computer for this activity.
   O 1 (very difficult) O 2 O 3 O 4 O 5 (not at all difficult)

2. Please rate the difficulty of estimating direction on the map.
   O 1 (very difficult) O 2 O 3 O 4 O 5 (not at all difficult)

3. Please rate the ease of use of using this map to navigate.
   O 1 (very easy) O 2 O 3 O 4 O 5 (not at all easy)

4. Please rate the difficulty of orienting in terms of cardinal directions (N, S, E, W) with the application.
   O 1 (very difficult) O 2 O 3 O 4 O 5 (not at all difficult)

5. How familiar are you with the route that you navigated using the application?

O 1 (very familiar) O 2 O 3 O 4 O 5 (not at all familiar)

6. Please rate the ease of understanding directions on the application.

   O 1 (very easy) O 2 O 3 O 4 O 5 (not at all easy)

7. What characteristics of the application did you find most helpful for identifying features?

   ....

8. What characteristics of the application did you find most useful for orienting your self ?

   ....

Bibliography

Abowd, Gregory D et al. (1999). “Towards a better understanding of context and context-awareness”. In: *International Symposium on Handheld and Ubiquitous Computing*. Springer, pp. 304–307.

Anacta, Vanessa Joy A et al. (2016). “Orientation information in wayfinding instructions: evidences from human verbal and visual instructions”. In: *GeoJournal*, pp. 1–17.

Daum, S Oliver and Heiko Hecht (2009). “Distance estimation in vista space”. In: *Attention, Perception, & Psychophysics* 71.5, pp. 1127–1137.

Delikostidis, Ioannis (2011). “Improving the usability of pedestrian navigation systems”. In: *Enschede, University of Twente, Faculty of Geo-Information and Earth Observation (ITC)*.

Delikostidis, Ioannis and Corné PJM van Elzakker (2009). “User-centred mobile navigation system interface development for improved personal geo-identification and navigation”. In: *The World’s Geo-Spatial Solutions, Conference Proceedings, 24th International Cartographic Conference*, pp. 15–21.

Delikostidis, Ioannis, Corné PJM van Elzakker, and Menno-Jan Kraak (2016). “Overcoming challenges in developing more usable pedestrian navigation systems”. In: *Cartography and Geographic Information Science* 43.3, pp. 189–207.

Delikostidis, Ioannis et al. (2015). "Bridging the gap between field-and lab-based user studies for location-based services". In: *Progress in Location-Based Services 2014*. Springer, pp. 257–271.

Duckham, Matt, Stephan Winter, and Michelle Robinson (2010). "Including landmarks in routing instructions". In: *Journal of Location Based Services* 4.1, pp. 28–52.

Fang, Zhixiang, Qingquan Li, and Shih-Lung Shaw (2015). "What about people in pedestrian navigation?" In: *Geo-spatial Information Science* 18.4, pp. 135–150.

Gartner, Georg (2004). *Location-based mobile pedestrian navigation services-the role of multimedia cartography*. na.

Giannopoulos, Ioannis, Peter Kiefer, and Martin Raubal (2015). "GazeNav: gaze-based pedestrian navigation". In: *Proceedings of the 17th International Conference on Human-Computer Interaction with Mobile Devices and Services*. ACM, pp. 337–346.

Google Maps JavaScript API | Google Developers. URL: https://developers.google.com/maps/documentation/javascript/styling.

Hegarty, Mary et al. (2002). "Development of a self-report measure of environmental spatial ability". In: *Intelligence* 30.5, pp. 425–447.

Ishikawa, Toru and Daniel R Montello (2006). "Spatial knowledge acquisition from direct experience in the environment: Individual differences in the development of metric knowledge and the integration of separately learned places". In: *Cognitive psychology* 52.2, pp. 93–129.

Ishikawa, Toru and Kazunori Takahashi (2014). "Relationships between Methods for Presenting Information on Navigation Tools and Users' Wayfinding Behavior". In: *Cartographic Perspectives* 75, pp. 17–28.

Ishikawa, Toru et al. (2008). "Wayfinding with a GPS-based mobile navigation system: A comparison with maps and direct experience". In: *Journal of Environmental Psychology* 28.1, pp. 74–82.

Kaltz, J Wolfgang, Jürgen Ziegler, and Steffen Lohmann (2005). "Context-aware Web engineering: Modeling and applications". In: *Revue d'intelligence artificielle* 19.3, pp. 439–458.

Kuipers, Benjamin (1978). "Modeling spatial knowledge". In: *Cognitive science* 2.2, pp. 129–153.

Li, Rui et al. (2014). "Visualising distant off-screen landmarks on mobile devices to support spatial orientation". In: *Journal of Location Based Services* 8.3, pp. 166–178.

Lynch, Kevin (1960). *The image of the city (Vol. 11)*.

Meehan, Kevin et al. (2013). "Context-aware intelligent recommendation system for tourism". In: *Pervasive Computing and Communications Workshops (PERCOM Workshops), 2013 IEEE International Conference on*. IEEE, pp. 328–331.

Mondschein, Andrew, Evelyn Blumenberg, and Brian Taylor (2010). "Accessibility and cognition: the effect of transport mode on spatial knowledge". In: *Urban Studies* 47.4, pp. 845–866.

Mondschein, Andrew, Evelyn Blumenberg, and Brian D Taylor (2008). "Accessibility and cognition: the effect of transportation mode on spatial knowledge". In: *University of California Transportation Center*.

Mondschein, Andrew Samuel (2013). "The Personal City: The Experiential, Cognitive Nature of Travel and Activity and Implications for Accessibility". In:

Münzer, Stefan et al. (2006). "Computer-assisted navigation and the acquisition of route and survey knowledge". In: *Journal of environmental psychology* 26.4, pp. 300–308.

Nitsche, Michael and Maureen Thomas (2003). "Stories in space: the concept of the story map". In: *International Conference on Virtual Storytelling*. Springer, pp. 85–93.

Nivala, Annu-Maaria and L Tiina Sarjakoski (2003). "Need for Context-Aware Topographic Maps in Mobile Devices." In: *ScanGIS*. Citeseer, pp. 15–29.

Parush, Avi, Shir Ahuvia, and Ido Erev (2007). "Degradation in spatial knowledge acquisition when using automatic navigation systems". In: *International Conference on Spatial Information Theory*. Springer, pp. 238–254.

Pouryegan, Mohammad and Mohammad Reza Malek (2015). "A context-aware pedestrian navigation system". In: *Journal of Ambient Intelligence and Smart Environments* 7.4, pp. 415–424.

Ranasinghe, Champika Manel and Christian Kray (2016). "Visualizing Location Uncertainty on Mobile Devices: Assessing Users' Perception and Preferences". In: *Geospatial Data in a Changing World*. Springer, pp. 315–333.

Raubal, Martin and Stephan Winter (2002). "Enriching wayfinding instructions with local landmarks". In: *International Conference on Geographic Information Science*. Springer, pp. 243–259.

Renner, R, B Velichkovsky, and J Helmert. "The perception of egocentric distances in Virtual Environments". In: *ACM Comput. Surv.(to appear, 2014)*.

Richardson, Anthony E, Daniel R Montello, and Mary Hegarty (1999). "Spatial knowledge acquisition from maps and from navigation in real and virtual environments". In: *Memory & cognition* 27.4, pp. 741–750.

Richter, Kai-Florian, Drew Dara-Abrams, and Martin Raubal (2010). "Navigating and learning with location based services: A user-centric design". In: *Proceedings of the 7th International Symposium on LBS and Telecartography*, pp. 261–276.

Sarjakoski, L Tiina and Annu-Maaria Nivala (2005). "Adaptation to context—a way to improve the usability of mobile maps". In: *Map-based mobile services*. Springer, pp. 107–123.

Schöning, Johannes et al. (2009). "PhotoMap: using spontaneously taken images of public maps for pedestrian navigation tasks on mobile devices". In: *Proceedings of the 11th international Conference on Human-Computer interaction with Mobile Devices and Services*. ACM, p. 14.

Steck, Sibylle D and Hanspeter A Mallot (2000). "The role of global and local landmarks in virtual environment navigation". In: *Presence: Teleoperators and Virtual Environments* 9.1, pp. 69–83.

Tverksy, Barbara (2000). "Levels and structure of spatial knowledge". In: *Cognitive mapping: past, present and future. Routledge, New York*.

Watanabe, Shota, Katsuhiko Kaji, and Nobuo Kawaguchi (2012). "A proposal of landmark-conscious voice navigation". In: *The Sixth International Conference on Mobile Computing and Ubiquitous Networking (ICMU 2012)*. Citeseer, pp. 56–61.

Waters, Wilfred and Stephan Winter (2012). "A wayfinding aid to increase navigator independence". In: *Journal of Spatial Information Science* 2011.3, pp. 103–122.

Willis, Katharine S et al. (2009a). "A comparison of spatial knowledge acquisition with maps and mobile maps". In: *Computers, Environment and Urban Systems* 33.2, pp. 100–110.

— (2009b). "A comparison of spatial knowledge acquisition with maps and mobile maps". In: *Computers, Environment and Urban Systems* 33.2, pp. 100–110.

Ziemer, Christine J et al. (2009). "Estimating distance in real and virtual environments: Does order make a difference?" In: *Attention, Perception, & Psychophysics* 71.5, pp. 1095–1106.