Spatial Knowledge Acquisition in the Context of GPS-based Pedestrian Navigation

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Abstract

GPS-based pedestrian navigation systems have become more and more popular in recent years. This paper reports a work in progress on investigating the differences of spatial knowledge acquisition with different interface technologies in the context of GPS-based pedestrian navigation. The acquisition of spatial knowledge based on mobile map, augmented reality, and voice is analysed and compared in a field test in the city centre of Salzburg (Austria). This paper presents the methodology and interprets the results. The results raise some hints for future mobile navigation system development, which might need to consider not only how to effectively assist users' navigation tasks, but also how these systems affect users' spatial knowledge acquisition.

Keywords: spatial knowledge acquisition, mobile pedestrian navigation, field study

1. Introduction

People in unfamiliar environments often need assistance to reach a specific destination. Mobile pedestrian navigation systems are designed for this purpose. In order to facilitate pedestrians' navigation tasks, navigation systems need to effectively communicate/convey route information (directions) to pedestrians.

Map is an important interface technology when communicating route information. It can help users to get an overview of the area. Radoczky (2004) showed that maps, even presented on mobile devices with small screen, are the most efficient tool for describing route directions. Voice-based guidance is also a useful tool for navigation. In additional to metric-based instructions that are often used in car navigation systems, semantic-based instructions enriched with landmark information are also proposed for route communication (Rehrl et al. 2010). Recently, mobile augmented reality (AR), which enhances the real world camera view with virtual information overlays, is another promising approach for conveying route information. Walther-Franks (2007) shows that AR is very suitable for navigation as it puts route instructions directly into the real visual context of a user.

Spatial knowledge acquisition is needed to build mental representations that are essential for wayfinding and other spatial tasks. With sufficient spatial knowledge about an environment, people can still find their way when navigation systems fail. Currently, more and more people are relying (or even over-relying) on mobile navigation systems. Therefore, in additional to the effectiveness in supporting wayfinding, it is also very important to investigate how these systems affect the acquisition of spatial knowledge.

There is some research focusing on empirically studying the acquisition of spatial knowledge in the context of pedestrian navigation. Gartner and Hiller (2009) investigated maps with different display sizes, and show that display size influences spatial knowledge acquisition during navigation. Ortag (2005) studied the differences of spatial knowledge acquisition with map and voice when guiding wayfinders. Krüger et al. (2004) compared the impact of different modalities (i.e., audio and graphics (specially, images indicating route directions)) on spatial knowledge acquisition during navigating in a zoo, and conclude that the acquisition of route knowledge is much better than that of survey knowledge. In Aslan et al (2006), the differences in acquiring spatial knowledge with and without technology (e.g., mobile maps vs. paper maps) were studied. It is important to note that most of the above studies employed the “Wizard of Oz” prototyping (Wikipedia 2011) (e.g., without using the GPS). In contrast, Ishikawa et al. (2008) compared the acquisition of spatial knowledge with GPS-based systems, paper maps and direct experience of routes, and show a poorer performance of subjects using GPS-based system. However, to the best of our knowledge, none of the field test compares the influence of mobile map, AR, and voice on spatial knowledge acquisition in the context of GPS-based pedestrian navigation.

This paper presents an on-going work on empirically studying the differences in spatial knowledge acquisition with different interface technologies, comparing mobile maps, AR, and voice in the context of GPS-based pedestrian navigation. This research is part of the ways2navigate project, which is a project of Vienna University of Technology, Salzburg Research, FACTUM, TraffiCon and Walk-Space Mobilität. It aims to investigate the suitability of voice-based and AR-based interface technologies in comparison to mobile maps for conveying navigation and route information to pedestrians. Two iterative field tests are planned in the ways2navigate project. For each field test, we are interested in the questions of how these technologies can help to reduce cognitive load during wayfinding, and how these technologies influence the acquisition of spatial knowledge. This paper will report the methodology and results of the first experiment, with a focus on comparison of spatial knowledge acquisition with these interface technologies.

2. Study design

2.1 Study route and participants

A route in the city centre of Salzburg (Austria) was selected for the empirical test. It was divided into three sub-routes, each with 9 decision points (e.g., intersections where multiple outgoing choices exist). The three sub-routes are slightly different in length. The surroundings of these sub-routes are characterized by residential and business areas.

24 participants took part in the study (12 female and 12 male). The mean age was about 40 years (range 22-66). They were paid for their participation. All of them are German-speaking people.

2.2 Navigation prototypes

For studying wayfinding performance and spatial knowledge acquisition with different interface technologies, we used three self-implemented mobile navigation prototypes running on Apple's iPhone 4. These prototypes used map-based, AR-based, and voice-based interfaces respectively. Recent findings on pedestrian navigation from literature were integrated and considered when developing these prototypes.

Figure 1 shows a screenshot of the map-based prototype. The route is visualized as a red line filled with small white arrows pointing the forward direction. The past path is dyed in a lighter colour to be clearly separated from the future path. The real-time position is determined by GPS, improved by a route matching algorithm. A "track-up" egocentric map view is provided and its centre is adapted automatically to the current location. When a user is close to a decision point, a semi-transparent, blue-white directional arrow appears at the bottom-right of the screen. The arrow shows the directions based on the 7-sector model proposed by Klippel et al. (2004). Some other functions are also provided, such as zooming and panning.

Fig. 1. A screenshot of the map-based prototype, with an egocentric view, distinction between past and future path, turn direction arrow, and zooming and panning function, etc.

In the AR-based prototype, route information is overlaid on the real world camera view. GPS module, magnetometer, and the tilt sensor on the mobile devices are used to calculate the position of the overlay information. Depending on the distance to the next decision point (DP), the overlay information changes from a red circle making the position of the DP, to a bigger red circle showing remaining distance to the DP, and finally to a bigger red ring enclosing the waypoint to be entered. By changing the style and enlarging the size of the overlay, we expect users to get a feeling of crossing a portal. In additional to the graphical interface, a vibration alarm is raised when a decision point is reached. A screenshot of the AR-based prototype is given in *Figure 2*.

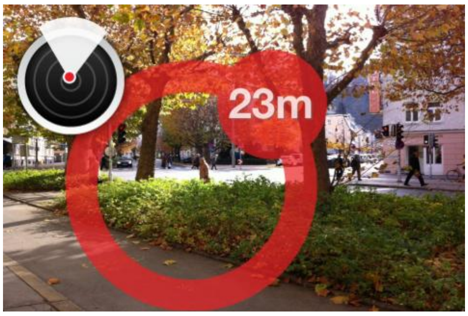

Fig. 2. A screenshot of the AR-based prototype, showing a ring. The distance to the next decision point is shown on the left of the ring to indicate a left turn at the current decision point.

The development of the voice-based prototype was based on the semantic-based model developed in the previous project SemWay (Rehrl et al. 2010). Based on the model, semantic-based route instructions instead of metric-based route instructions can be provided, for example, “walk straight, pass the theatre, and walk to the crossing" instead of "walk straight for 103 meters". Verbal instructions for each decision point of the test route were automatically generated by using the semantic-based model (Rehrl et al. 2010). The interface of the voice-based prototype includes a single screen with a slider for controlling the sound volume and a button for repeating the last instruction. When a user gets close to a decision point, the mobile device vibrates, and plays the voice instruction describing the actions from this decision point to the next.

2.3 Design and procedure

Participants were randomly divided into three groups. A within subject design and a counterbalancing consideration were used for the test, i.e., for each sub-route, these three groups each used one of the navigation prototypes (mobile map, AR, and voice). When they reached the next sub-route, they switched to another prototype. Each participant was accompanied by two researchers. One observed the test run and guided through the interviews and the other collected quantitative and qualitative performance measures (e.g., number of stops, duration of stops, and reasons of stops). Participants' movement, interaction with the navigation prototypes, task completion time, and GPS accuracy were also logged on mobile phones.

At the beginning of the test session, we explained the basic usage of the pedestrian navigation prototypes to the participants and gave a short demonstration of the prototypes on the mobile phones. After a brief training session, participants were led to the starting point of the first sub-route. The task for them was to navigate to the end of the sub-route. If participants decided wrongly at a decision point, the observing researcher used gestures to indicate the correct choice. No other assistance was given during navigation. In order to avoid any influence on participants, the researchers walked several metres behind participants. When reaching the end of the sub-route, participants were asked to answer questionnaires assessing usability and task load, and give some further qualitative feedback and experiences. In addition, they were asked to solve some tasks assessing spatial knowledge acquisition:

- pointing task: to give an approximate direction to the starting point of the current sub-route, measured in degree via a digital compass on mobile phones;
- sketching map: to draw a sketch map of the area they just passed as precisely as possible, focusing on the route and landmarks;
- marking task: to mark the half of the sub-route on their sketch maps;
- familiarity with the current sub-route.

When finishing all these tasks, participants switched to another prototype, and the same procedure was repeated for the next sub-route. In total, the test for each participant was completed within 1 hour.

3. Results and discussion

The field experiment was completed on Nov. 2010. All the participants successfully finished the tasks. The results of the experiment include two parts: wayfinding performance and user experience, and spatial knowledge acquisition. Results assessing wayfinding performance and user experience can be found in Rehrl et al. (2011). In this paper, we report the results of spatial knowledge acquisition.

The results on the aspect of spatial knowledge acquisition were analysed by focusing on sense of direction (the pointing task), sketch maps (topological aspects: sketched landmarks, errors in sketching turns (missing/wrong/unnecessary turns)), and sense of distance (marking half of the route). We only considered the results from participants who were unfamiliar with the sub-routes. In total, we got 24 participant/sub-route pairs (8 for mobile map, 8 for voice, and 8 for AR)[1]. The male-female ratios were similar in the three groups. In the following, we present and discuss the results.

3.1 Sense of direction (the pointing task)

The sense of direction was measured as the deviation between actual directions and pointed directions in the pointing task. The deviations were measured in degrees. *Figure 3* shows the results of sense of direction, comparing mobile map, AR, and voice.

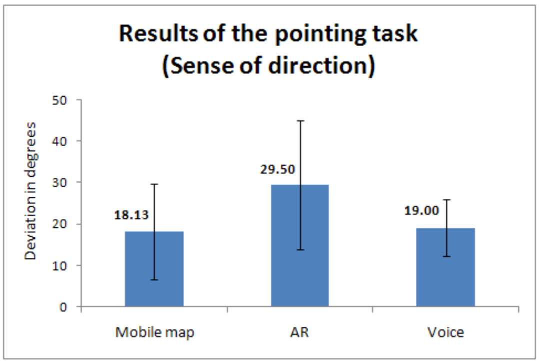

Fig. 3. How the sense of direction differs among different navigation conditions. Vertical bars denote 95% confidence intervals.

[1] The spatial knowledge acquisition test was conducted within a framework including many other tests, in which familiarity was not the only criterion in choosing test persons. Therefore, only 24 participant/sub-route pairs were "unfamiliar".

The results in *Figure 3* show that map users and voice users performed considerably better in pointing to the start compared to AR users. The results for AR users were not surprising, because the AR-based prototype suffered from the poor GPS signal (in both the map-based and voice-based prototypes, some route matching algorithms can be used to improve the GPS accuracy) and poor compass accuracy, and thus brought some confusion to the users. However, map users did not perform considerably better than voice users, which is inconsistent with our expectation. A possible explanation is that map users did not make full use of the map-based prototype, e.g., according to the usage log, they seldom used the zooming function to get an "overview map". We also did a one-way ANOVA (analysis of variance) test[2]. According to the test, the difference among these three navigation conditions was not significant ($F(2,21) = 1.60$, $p = 0.23$).

3.2 Sketched landmarks

Literature has shown that it is useful to stick to topological interpretation of sketch maps only (Lynch 1960, Gartner and Hiller 2009). Therefore, the analysis of sketch maps focused on two topological aspects: sketched landmarks (landmark names), and errors in sketching turns. The later aspect will be discussed in next section. In this section, the results of sketched landmarks are presented. *Figure 4* shows the mean number of sketched landmarks in these navigation conditions.

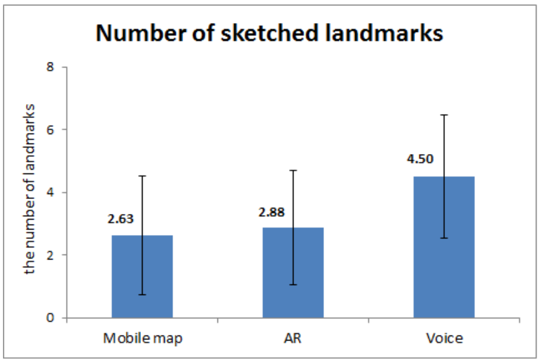

Fig. 4. How the number of sketched landmarks differs among different navigation conditions. Vertical bars denote 95% confidence intervals.

[2] The surroundings of each sub-route are characterized by residential and business areas. In addition, the three sub-routes have comparable length and complexity (in terms of the number of decision points). Therefore, we did not consider sub-routes as a factor when comparing the performance among different navigation conditions, and a one-way ANOVA was used.

According to *Figure 4*, voice users drew more landmarks in their sketch maps compared to AR users and map users. We also found that 78% of the landmarks sketched by voice users were mentioned/included in the verbal wayfinding instructions. Therefore, the reason why map users and AR users drew fewer landmarks may be that: for the map-based and AR-based prototypes, landmarks were not explicitly highlighted (e.g., they were displayed in the background map in the map-based prototype, and were not visualized in the AR-based prototype). While for the voice-based prototype, landmarks were explicitly included in the verbal instructions. However, there was no significant difference in the number of sketched landmarks across different navigation conditions ($F(2,21) = 1.63$, $p = 0.22$).

3.3 Errors in sketching turns (missing/wrong/unnecessary turns in sketch maps)

The other aspect from the analysis of sketch maps was errors in sketching turns. We compared each sketch map with the OpenStreetMap (OSM) map (the real world) to check whether there were any missing turns, any wrong turns (e.g., right turn in OSM map, while left turn in sketch maps), and any unnecessary turns. Each missing/wrong/unnecessary turn was counted as an error in sketching turn. *Figure 5* shows the mean number of errors in sketching turns.

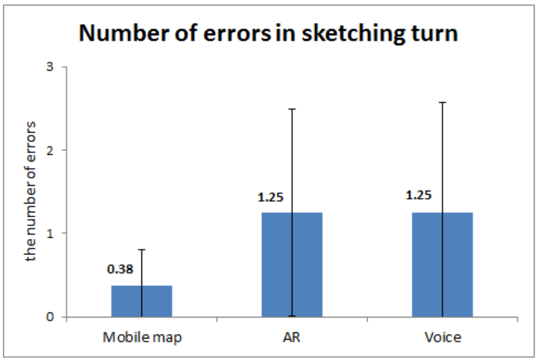

Fig. 5. How the number of errors in sketching turns differs among different navigation conditions. Vertical bars denote 95% confidence intervals.

Figure 5 shows that map users made considerably fewer errors in sketching turns compared to AR users and voice users. This is consistent with our expectation: in the AR-based and voice-based prototypes, turns were not conveyed/presented in a spatial-related overview context. As a result, AR users and voice users would make more errors in sketching turns. However, the difference among these three navigation conditions was not significant (F(2,21) =1.23, p = 0.31).

3.4 Sense of distance (marking the half of the sub-routes)

In the test session, we asked participants to mark the half of the sub-routes on their sketch maps. A grading system was developed to measure these marks. Every sub-route was equally divided into 20 segments, which were named as “1”, “2” … “9”, “10”, “10”, “9” … “2”, “1” respectively. A participant’s mark was graded as the name of the segment where it was located. Therefore, the grades scaled from 1 (worst) to 10 (best). *Figure 6* shows the mean grade for each navigation condition.

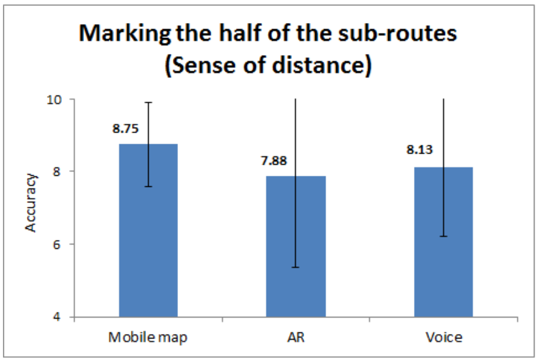

Fig. 6. How the sense of distance differs among different navigation conditions. Vertical bars denote 95% confidence intervals.

The results in *Figure 6* show that map users performed better in marking the half of the sub-route compared to AR users and voice users. However, the differences among them were not significant as we expected. An explanation may be that map users did not make full use of the map-based prototype. As a result, for all three navigation conditions, the knowledge about sense of distance was mainly gained from sensual perception of the real world (without the acquisition of spatial knowledge from the navigation prototypes). The comparable results of three navigation conditions might be also due to the poor differentiation of the grading system.

According to the ANOVA test, the difference among these three navigation conditions was not significant (F(2,21) = 0.30, p = 0.74).

4. Summary and future work

This paper reported a work in progress on comparing spatial knowledge acquisition with mobile map, augmented reality (AR), and voice in the context of GPS-based pedestrian navigation. Results of a field test were presented and discussed. In summary, the current results show that, among different navigation prototypes (map-based, AR-based, and voice-based), using the map-based prototype led to more accuracy in pointing to the start (sense of direction), more accuracy in sketching turns, and more accuracy in marking the half of the route (sense of distance). However, it is important to note that no significant differences were found for the above aspects. This may due to the small set of test persons. More research needs to be done on this issue.

Currently, we are planning another field experiment to investigate the differences of spatial knowledge acquisition with mobile map, AR, and voice in more details. More participants who are unfamiliar with the environment will be recruited. In addition, we will differentiate three kinds of spatial knowledge, namely landmark, route, and survey knowledge (Siegel and White 1975), and study how these interface technologies influence the acquisition of each of them.

The field test also opens several important research questions for future navigation system development: "do users care about spatial knowledge acquisition during navigation", and "if yes, how can we design a navigation system that not only reduces users' cognitive load during wayfinding, but also enables them to acquire spatial knowledge". Related findings of spatial cognition and human wayfinding together with usability studies need to be integrated to address these questions.

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