Acquisition of Spatial Knowledge in Location Aware Mobile Pedestrian Navigation Systems

Ilhan Aslan[1], Maximilian Schwalm[2], Jörg Baus[12], Antonio Krüger[13] and Tim Schwartz[2]
[1]DFKI GmbH, Saarbrücken, Germany [2]Saarland University , Germany [3]University of Münster, Germany
{aslan, baus, schwartz}@cs.uni-sb.de, antonio.krüger@uni-münster.de

ABSTRACT
In this paper we regard the navigation aid provided by mobile navigation systems in a real environment and the effects of these mobile assistants to the development of spatial knowledge. Therefore, we report on a user study concerning the acquisition of spatial knowledge. This study sets up on a former study described by Krüger and colleagues and sheds light on problems concerning the acquisition of survey knowledge while being navigated by a mobile handheld PC.

Categories and Subject Descriptors
H5.2 [**User Interfaces**]: Graphical user interfaces (GUI)

General Terms
Design, Experimentation, Human Factors.

Keywords
User study, navigation, PDA

1. INTRODUCTION
Personal devices are utilized to present location and situation aware information to their users [1][9][3]. Hereby the personal devices are used to interpret data from different sensors (i.e. GPS, IR, and RFID). It is undeniable that PDAs provide helpful information during navigation to their users. However, the content and the presentation modality of the information provided by a PDA should be fitted not only to the temporary needs of the users but also consider effects of the presented information in the long run. For example, during the task of navigation a PDA should present information in a way that not only helps to follow a route but also improves the amount of acquired spatial knowledge by the user. Because spatial knowledge is used to reorient, judge distances and recall geographical places, it is the knowledge we rely on if either the infrastructure, sensors in the environment (i.e. RFID tags, infrared beacons or even GPS satellites) or our mobile personal device fails (i.e. low battery or damaged). To find out the effects of pedestrian navigation on the acquisition of spatial knowledge, three user studies were carried out. In the first study, described in detail in [8], emphasize was put in investigating the effects of different output media (i.e. PDA display, glasses display) and different output modalities (i.e. auditive and visual) on the acquisition of route (e.g. which direction to go at which landmark) and survey knowledge (relative geographic positions of landmarks). The results revealed no significant difference between output media and no evident difference between output modality on the successfully acquisition of route knowledge. The results showed that the subjects had a major lack of survey knowledge (e.g. subjects could not place landmarks in correct geographic relations to each other). The second and third studies are described in detail in the paper at hand. For the second study we developed new ways to present spatial information to the user in order to support building up survey knowledge. In the end we conducted a small scale third study, in which we used paper-based maps to look for differences in acquired spatial knowledge with and without using technology. In the following we will describe in detail the user studies (i.e. design of the study, evaluation of the results) and present our results.

MobileHCI'06, September 12–15, 2006, Helsinki, Finland.

Figure 1: A) subject and experimenter B) Landmarks and pathway segments

2. STUDY DESCRIPTION
2.1 Procedure
The study was carried out in a zoo; all subjects were not familiar with the pathways in the zoo. Subjects were 24 male and 24 female, recruited from the campus of the university. Every subject had to walk a pre-chosen route. A mobile PDA was handed to the subject and the subject was instructed to follow the route instructions given by the handheld system. The experimenter followed the subject at a distant of approximately 20 meters and provided location information to the handheld system of the subject (see figure 3A). The subjects did not know that their PDA was "remote controlled" by the experimenter. The route the subjects were guided through consisted of 16 landmarks (in this paper we refer to landmarks as crossings with unique

appearances) and 15 pathway segments that connected the 16 landmarks (see figure 2B). We decided to present information to the subjects for short static time periods (e.g. 12 seconds) just before reaching a landmark, because 1. It is known that landmark knowledge is only encoded at so called "active intersections" (i.e. crossings) and not in between [13] 2. The subject should be not distracted by the navigation system while "visiting" the zoo. The start of a new route instruction was indicated by a to the subjects with a simple audio signal. Therefore we handed every subject a headset. The presentation was on a PDA in landscape mode and 640x480 pixel resolutions. In average, the practical navigation part through the zoo took 25 minutes. After the walkthrough the subjects had to perform some recall tests where subjects had to recall different aspects of the route they were guided through. A notebook was used to proceed with the tests. In the user study we provided positioning in a Wizard of Oz like way, like also used in [4, 5]. In this method the experimenter remotely guides the subject through the zoo, by remote reporting the position of the subject via an ad-hoc wireless network between two Pocket PCs. This method is similar to the self-reported positioning method described in [10]. The experimenter only needed to press a hardware button of the Pocket PC to report the next landmark position on the route.

2.2 Modalities and Presented Information

Every subject was assigned to one of three groups. Each group consisted of 8 female and 8 male subjects. To one of the groups we refer as the control group. In the control group we decided to use the auditory modality from the first study (that is, route instructions at landmarks were presented in audio); because of two reasons: 1. In the first study no significant difference between the audio and visual presentation was found 2. Since a slight gender effect was observed in the auditory condition in the first study, we could use the control group to recheck our former results. To the other two groups we refer as the experimental groups. We presented preliminary additional information to the subjects of the experimental groups (see figure 2a and 2b). The additional information was only visual and represented the current part (a sub route) of the complete route. Our hypothesis was that we could increase the acquired survey knowledge by providing overview information. We agreed to present a three landmark encircling presentation of the overview map. That is, we present the location of the previous, the actual and the next landmark and the segments by which they are connected. It is known that people are able to mentally put together parts of a map into a single presentation of the whole map [14]. In figure 2 we present our principle idea. It is also known that accessing information from a misaligned cognitive map is more difficult than if it were aligned [6, 7, 11, 12]. Therefore we decided to highlight the route direction and the orientation of the subjects on the overview map with an animated fill effect.

2.3 Recall Test

After the practical walking part, the subjects had to perform an overall recall test on a tablet PC that consisted of three tasks. In the first recall task, we presented the subjects again the (plain, without route instruction) pictures of the landmarks in random order. The subjects were to recall which direction they went on the landmark and report if they felt sure of their decision. For the second and third recall task subjects had to place thumbnails of landmarks in correct relation to each other on an area (1. empty 2. with simple map) that represented the area they had walked, start position and first direction were given to the subjects in both recall tasks. Subjects could take as much time as they needed to carry out the tasks. Every subject was rewarded with 10 Euros.

Figure 2: 2a and 2b were presented additionally in the experimental groups

2.4 Results

For the first recall test we counted the relative number of correct directions in the landmark-direction task. Our results show significantly more correct answers (78%) in the landmark-direction task then incorrect answers (22%), $F(1, 45)=248,28$, $p<0.001$. But there was no sig. difference depending on the modalities (i.e. visual, auditory and control) we used, $F(2,45) = 0.853$, $p>0.05$, as well as no gender specific effect, $F(1,45) = 0.109$, $p>0.05$. When looking at the results of the landmark direction task, one may note that the memory for the directions on the specified landmarks was quite good. In the average 13 out of 16 directions were correctly remembered, even after walking the route only once. For the results of the second and third recall test we used the mean deviation (in pixel) from the replaced item and the correct position on the map to indicate weather or not survey knowledge had been acquired. As expected there was a significant difference between the condition with and without a background map, F(1,42)=42,093, p< 0.001. We observed no significant difference between the three modalities F(2,42) = 1.6780, p>0.05 (see figure 7) as well as no gender specific effect, F(1,42)=0.422, p>0.05. But when contrasting the experimental groups (the auditory together with the visual group) with the control group we could observe a slight effect, F(1,42)=3.313, p=0.075 at the recall tests, namely a worse performance of the subjects using the modality that provided additional survey information. This finding is interesting for two reasons: First this result would argue against our hypothesis and therefore we can assume that the results could not be questioned through the lack of power. Second, our suggested condition even seems to interfere with the acquisition of survey knowledge.

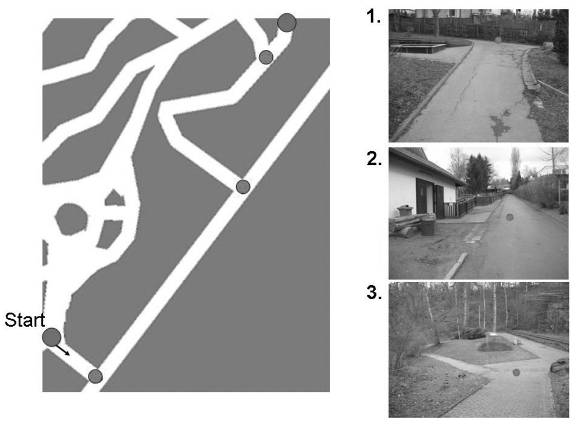

Figure 3: Paper-based information

3. MAP-BASED USER STUDY

The results of our second user study were very surprising and we had to check that acquisition of spatial knowledge is in general possible in the experimental environment we had provided; therefore, we conducted an additional user study with 16 subjects. Instead of presenting the subjects instructions on a PDA, subjects were given paper-based information identically to the information presented on the PDAs (see figure 3). The route was divided in four sub routes. Before the subjects started to walk one of the sub routes they were given overview/route information (see figure 3). Subjects had to confirm that they had understood the way they had to walk by drawing in the provided overview map which direction they had to go at which landmark. After their feedback the information sheet was taken away from them and they had to go the sub route from start to the end. After the last landmark on the sub route a new information sheet with the next sub route information was handed to them. After the practical walk through, subjects had to go through the same recall tests as in the former user study.

4. OVERALL RESULTS

The results of the first recall test revealed a significant increase in route memory accuracy for the map-based wayfinding condition compared to the conditions using technology-based navigation assistance (planned contrast; F (1, 60) = 19.54, p < 0.001). Route memory performance was good in the navigation assistance conditions, but it was nearly perfect in the map-based wayfinding condition (see figure 4.1). The results of the second and third recall test show a significant difference for the mean deviation in Pixel, F (3, 59) = 8.31, p < 0.001. A planned contrast showed that the map-based wayfinding condition differed significantly from the navigation assistance conditions (F (1, 59) = 22.85, p < 0.001) (see figure 4.2).

5. CONCLUSION AND DISCUSSION

In our first study we could show that mobile pedestrian navigation systems have the potential to convey landmark knowledge but fail to convey survey knowledge and this result could also be found in our second study.

According to the results from Aginsky, Harris, Rensink and Beusmans [2], our results seem to proof the assumption, that the dominant strategy of spatial orientation of humans is the visual recognition of the connection of landmark and directions rather than building up a mental map and accomplishing survey knowledge, especially in completely unknown environments. Our suggested condition to support building up survey knowledge seems to be not effective enough to help people building up a well elaborated mental map. Instead it even seems to interfere with the acquisition of survey knowledge. These results show that the link between presented map-like information and the acquisition of survey knowledge seems to be not as simple as previously thought. Adding new information, either abstracted or complete maps should be carefully considered and tested as well. It is clear that under paper based wayfinding conditions the user is able to build up survey knowledge. However, the connection between paper-based presentation and technology-based presentation need to be further investigated. It might be that a certain amount of active elaboration of the provided information is absolutely necessary. Instead of trying to reduce the amount of cognitive load whenever possible, it seems to be necessary to support the mental elaboration of specific information in a way adaptive to the situation.

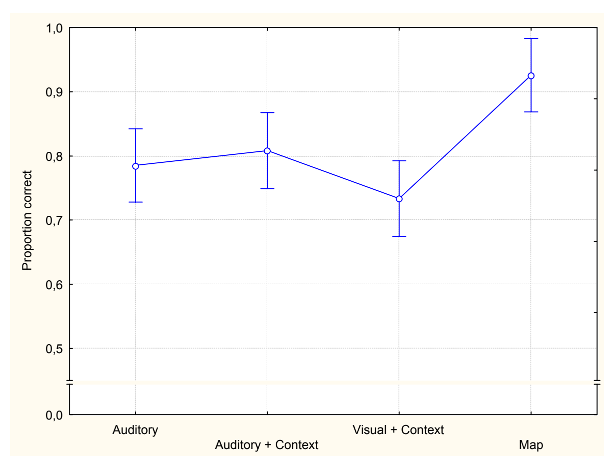

Figure 4.1: Results of the first recall test

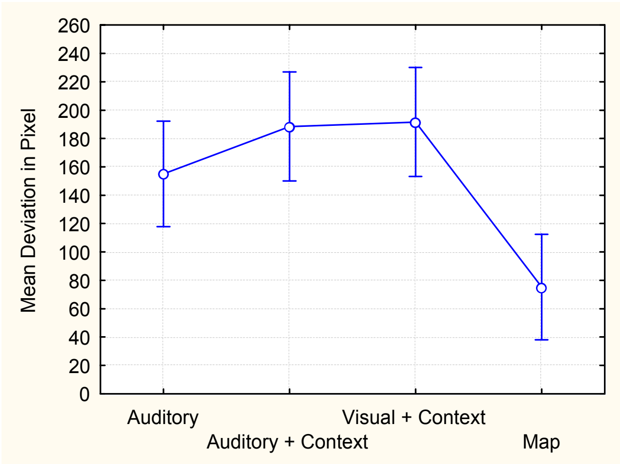

Figure 4.2: Results of the first recall test

6. REFERENCES

[1] Abowd, G.D., Atkeson, C. G., Hong, J., Long, S. Kooper, R. and Pinkerton, M. (1997). Cyberguide: a mobile context-aware tour guide, Wireless networks, Vol.3, No. 5, pp. 421-433.

[2] Aginsky, V., Harris, C., Rensink, R., and Beusmans, J. (1997). Two strategies for learning a route in a driving simulator. Journal of Environmental Psychology, 17, pp. 317-331.

[3] Baus J., Krüger A., and Wahlster W. (2002). A resource-adaptive mobile navigation system. Proceedings of the 6th International Conference on Intelligent User Interfaces (IUI-2002), San Francisco, CA

[4] Bohnenberger T., Jameson A., Krüger A. and Butz A. (2002). User Acceptance of a Decision-Theoretic Location-Aware Shopping Guide , Proceedings of the 6th International Conference on Intelligent User Interfaces (IUI-2002), San Francisco, CA

[5] Bohnenberger T., Jacobs O., Jameson. A. and Aslan I. (2005). DTP meets user requirements: Enhancements and studies of an intelligent shopping guide, Proceedings of the Third International Conference on Pervasive Computing (PERVASIV-05), Munich, Germany.

[6] Easton, R. D., & Sholl, M. J. (1995). Object-array structure, frames of reference, and retrieval of spatial knowledge. Journal of Experimental Psychology: Learning, Memory and Cognition, 21, pp. 483–500.

[7] Farrell, M. J., & Robertson, I. H. (1998). Mental rotation and the automatic updating of bodycentered spatial relationships. Journal of Experimental Psychology: Learning, Memory and Cognition, 24(1), pp. 227–233.

[8] Krüger A., Aslan I. Hubert D. Zimmer (2004). The Effects of Mobile Pedestrian Navigation Systems on the Concurrent Acquisition of Route and Survey Knowledge. Mobile HCI, pp. 446-450.

[9] Krüger A., Butz A., Müller C., Stahl C., Wasinger R., Steinberg K-E. and Dirschl A.(2004). The Connected User Interface: Realizing a Personal Situated Navigation Service, in Proceedings of IUI 2004, Madeira, Funchal, Portugal.

[10] Nigel Davies, Elizabeth D. Mynatt and Itiro Siio (2004). Ubiquitous Computing: 6th International Conference, Nottingham, UK, September 7-10, 2004. Proceedings. Lecture Notes in Computer Science 3205.

[11] Pick, H. L., Jr., & Rieser, J. J. (1982). Children's cognitive mappings. In M. Potegal (Ed.), Spatial orientation: Development and physiological bases. New York: Academic Press, pp. 107–128.

[12] Presson, C. C., & Montello, D. R. (1994). Updating after rotational and translational body movements: coordinate structure of perspective space. Perception, 23, 1447–1455.

[13] Werner S., Krieg-Brückner B., Herrmann T. (2000). Modelling navigational knowledge by route graphs. In: Ch. Freksa et al. (Eds): Spatial Cognition II 1849, pp. 295-316.

[14] Zimmer, H. (2004). The construction of mental maps based on a fragmentary view of physical maps. Journal of Educational Psychology, 96, pp. 603-610.