Investigating design issues of context-aware mobile guides for people with visual impairments

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ABSTRACT

While mobile wayfinding systems for visually impaired people offer huge potential, the differences between visual impairments and contextual environments have not been sufficiently addressed, and the capabilities of context-awareness have not been fully explored. These usability issues need to be investigated if *independent mobility* is to be achieved. Participants experiencing a loss of central vision, loss of peripheral vision, and total vision loss made up three groups. Our multidisciplinary model of context was used to design a user study, which involved asking participants to walk to pre-determined outdoor and indoor landmarks. Significant differences were found between groups relating to information requirements, and the environmental cues encoded and used to orientate and navigate. The study also found differences between indoor and outdoor contexts. It was concluded that what is meaningful to one form of visual impairment is incidental to another. These issues need to be captured and accounted for in design if wayfinding systems are to be usable.

Keywords

Context-aware computing; mobile guides; navigation; visually impaired people.

1. INTRODUCTION

Within the last decade, a variety of mobile wayfinding GPS-based systems have been developed to address the distant navigation requirements of visually impaired people. These include the MOBIC Travel Aid [1], (ii) the Personal Guidance System [2], and (iii) the Navigation System for the Blind [3].

'Independent mobility' is an ideology where visually impaired people can travel freely through the environment, without being constrained to familiar routes or known destinations. While mobile wayfinding systems offer huge potential to visually impaired people, most fall short of this ideology for four main reasons:

(i) Contextual information which would be of use to visually impaired people (such as road widths, differences in ground textures, people identification, traffic direction, etc) is not provided by existing travel databases [4].

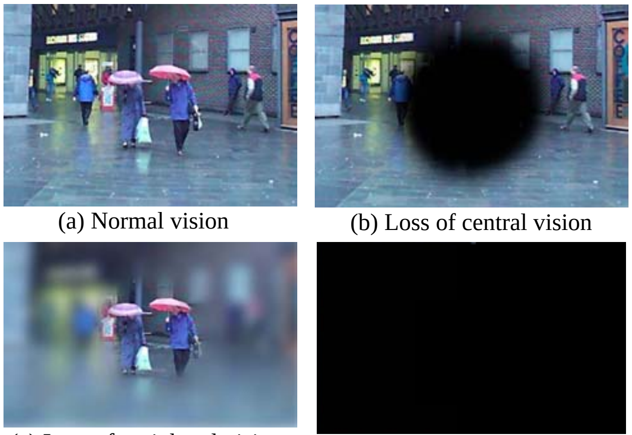
(ii) All systems have not considered the extreme diversity of the severity and form of visual impairments. Wayfinding systems, until now, either have been designed for totally blind people who form a small proportion of the visually impaired community, or have been designed to transmit the same information to all visually impaired travellers.

(iii) Multi-context navigation is not well supported. Information is rarely adapted to support both indoor and outdoor navigation, as well as different modes of travel (e.g. walking, bus, train).

(iv) 'Context-awareness is not well supported' [5] - the level of service is mostly centred on location-awareness. In order to provide more useful and relevant information/services, mobile guides need to draw upon richer context databases containing information about people and traffic flows, nearby excavation work, expected weather conditions, etc. Further, unexpected events or dynamically changing environments are not well supported [4], such as cars parked on pavement, overhanging branches, etc.

The notion of context-awareness moves closer to this ideology of independent mobility by combining sensing technologies to discover more about the user's context. While most wayfinding systems use just contextual sensing, context-awareness extends the capabilities that could be made available through contextual augmentation, adaptation, and resource discovery [6].

For these capabilities to be realized, we turned our attention to the notion of 'cognitive mapping' which refers to 'an individual's knowledge of spatial and environmental relations, and the cognitive processes associated with the encoding and retrieval of the information from which it is composed' [7]. Cognitive mapping research is vital for understanding spatial behaviour, and based upon Figure 1, people with different visual impairments are likely to encode spatial information differently.



(a) Normal vision (b) Loss of central vision

(c) Loss of peripheral vision (d) Total vision loss

Figure 1. Representations of different visual impairments.

People with a central vision loss, shown in part (b) of Figure 1, may have difficulty reading text on street signs, whereas people with peripheral vision loss, shown in part (c), may have difficulty sensing movement.

The study hypothesis is that *there will be, firstly, differences between how people with different visual impairments encode spatial information to orientate and navigate, and, secondly, differences between how visually impaired people encode spatial information in different contexts*.

2. MODEL OF CONTEXT

Much of our recent work has involved developing a user-centred design framework to help design and build context-aware applications. The framework is built on our multidisciplinary model of context [8], and has been used to design this study. Theories within psychology, linguistics and computer science were merged to produce our model, which is shown in Figure 2.

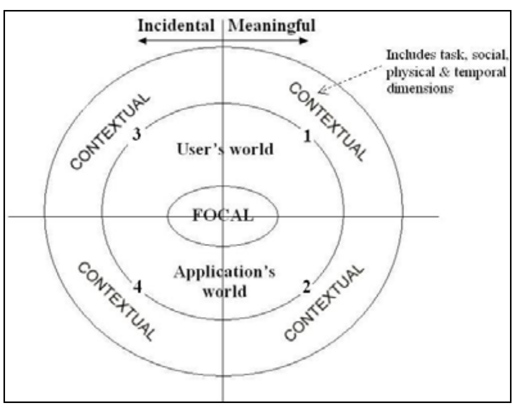


Figure 2. Our multidisciplinary model of context (outline version).

Firstly, the center horizontal line separates the 'user's world' from the 'application's world'. Two major differentiations of previous psychology research [9] are at the heart of the model:

- *Focal vs. contextual*: The oval shaped circle in the centre represents what is 'focal' to (i) the *user* with respect to carrying out actions in an attempt to achieve goals, and (ii) the *application* with respect to transmitting information/ services to the user. 'Contextual' represents anything in the task, physical, social, and temporal contexts that influence the process with which focal user actions are undertaken and/or focal application services are executed.
- *Meaningful vs. incidental context*: 'Meaningful' context is aspects of the environment that implicitly link to the user's primary goal, whereas 'incidental' context is aspects of the environment that just happen to be present.

A user may therefore undertake focal activities to negotiate incidental occurrences (e.g. walking past temporary road works), whereas the application maybe inferring incidental services that are not part of the user's meaningful goal (e.g. informing the user of a friend in a nearby café).

The processes that link the contextual world to the focal world for both the user and application can be interpreted through linguistics research. An utterance produced from a conversation is constructed through a task, social, physical and temporal context [10]. Instead of an utterance, a pattern of interaction between a user and computer has similarly been constructed through these dimensions of context.

3. METHODOLOGY

A total of 15 participants (8 male and 7 female) between the ages of 27 to 74 were recruited, all of whom are resident in Greater Glasgow. Our contacts at the RNIB and Low Vision Unit at Caledonian University suggested that 3 groups of visually impaired participants[1] should be used: (i) people with a loss of central vision (e.g. macular degeneration), (ii) people with a loss of peripheral vision (e.g. retinitis pigmentosa, glaucoma), and (iii) people who are registered blind (e.g. optic nerve hypoplasia).

It should be noted that the 5 participants making up each group all experience different severities of visual impairment. Within the registered blind group, 3 participants still have slight light/dark perception, whereas the other 2 experience total vision loss. This, unfortunately, will always be a difficult parameter to control when involving visually impaired people in experiments. The length of time each participant had been visually impaired and the type of mobility aid used are shown in Table 1.

Table 1. Length of time impaired and mobility aid used

	Length of time impaired (years)					Mobility Aid		
Group	**Under 2**	**3-7**	**8-15**	**Over 16**	**Birth**	**Cane**	**Guide Dog**	**None**
Loss of central vision	0	3	2	0	0	4	0	1
Loss of peripheral vision	1	3	1	0	0	2	0	3
Registered blind	0	1	1	2	1	2	3	0

[1] Participants were contacted through the RNIB, the Macular Disease Society, and the Retinitis Pigmentosa Society.

The study involved asking each participant to walk to three predetermined outdoor and indoor landmarks, all of which took around five minutes to reach. Participants encountered a typical contextually rich city-centre urban environment whilst walking to outdoor landmarks, and experienced a typical indoor setting through one of the main buildings of Strathclyde University.

Whilst en route to each landmark, participants were encouraged to ask questions regarding the environment - questions which would enable them to reach each landmark safely, efficiently and effectively. The content and frequency of questions was investigated by videoing the journey using a digital camcorder.

High-level instructions were read to them before setting off to each landmark. An example is provided below:

> *"Continue down towards George square and turn first right. Walk uphill passing the Student Union until you meet Cathedral Street. On your right will be the Department of Chemistry, the second landmark."*

On arriving to each landmark, participants were also asked to comment on the environmental cues they were using to orientate and navigate.

4. RESULTS

Three groups consisting of participants with a loss of central vision (CV), participants with a loss of peripheral vision (PV), and participants who are registered blind walked to three landmarks outside and then three landmarks inside. The results of each route are illustrated in the first two sections, and then compared in the third section.

4.1 Outdoor route

The outdoor landmarks which were walked to by each participant are illustrated in Figure 3, and as an example the questions and mistakes made by blind participants are represented. The number lying next to each question and mistake indicates its type, which can be discovered from Figure 4.

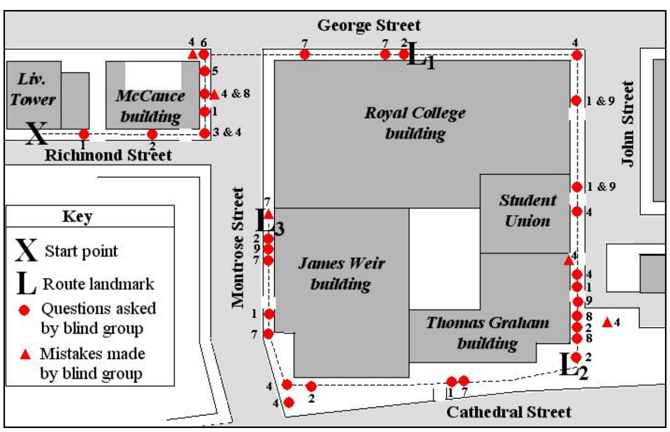


Figure 3. Questions asked, and mistakes made, by blind participants during outdoor route.

The mean number of questions asked relating to each category is illustrated in Figure 4 for each group of participants.

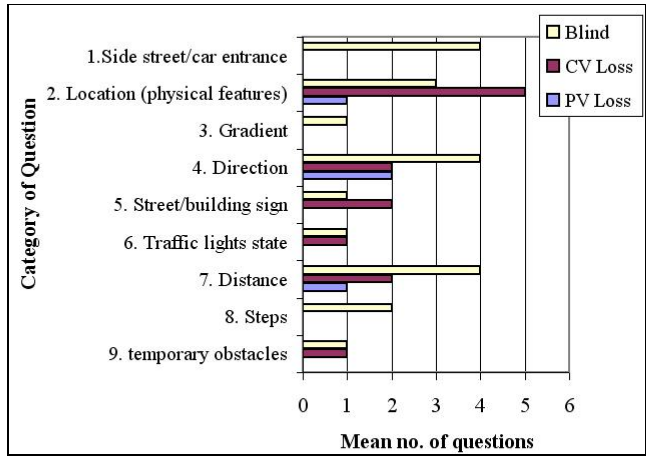


Figure 4. Mean number of questions asked relating to each category for each group.

The key results from this graph, together with statistical data in Table 2 from a one factor independent measures ANOVA test [where $F(2, 12) = 6.93$ at $p<0.01$] and Tukey's test [where q has a value of 5.05 at $p<0.01$], are as follows:

- Blind participants asked questions regarding side streets and steps (1) which were not asked by the other two groups. This result is highly significant ($F = 80>6.93$).
- The mean number of questions regarding location (2) and street/building signs (5) asked by participants with a CV loss was greater than participants with a PV loss. This difference between the means is slightly significant for both categories (3.8>HSD, 2>HSD).
- Blind participants and participants with a CV loss asked questions regarding the state of traffic lights (6) which were not asked by participants with a PV loss. This is a highly significant result ($F = 65535>6.93$).
- The mean number of questions regarding distance (7) asked by blind participants is twice as much as the mean number of questions asked by participants with a CV loss, and four times greater than participants with a PV loss. This difference between the blind group's mean with the other two groups is significant (2.2>HSD, 3>HSD).
- Blind participants asked questions regarding steps (8) which were not asked by the other two groups. This result is highly significant ($F = 26>6.93$).
- The PV loss group did not ask any questions relating to temporary obstacles (9) in the environment.
- The most commonly asked categories of question across all groups were location (2), direction (4), and distance (7). Questions were asked within all categories by the blind group, within 6 categories by the CV loss group, and within 3 categories by the PV loss group.

Table 2. Testing for significance (shaded cells show a significant result)

	ANOVA	Tukey test			
Category Q No.	Variance ratio (F)	HSD	B & CV	B & PV	CV & PV
			Val	Val	Val
1	80	1.30	4	4	0
2	9.76	3.14	1.2	2.6	3.8
3	2.8				
4	5.14				
5	12.15	1.49	1.4	0.6	2
6	65535	0	0	1	1
7	21.29	1.70	2.2	3	0.8
8	26	1.09	1.8	2	0.2
9	2.92				

The blind group made a total of 8 mistakes outside, the CV loss group made 3 mistakes, and the PV loss group made no mistakes.

On arriving to each landmark, participants commented on what type of environmental cues they used to orientate and navigate to walk to each landmark. Figure 5 illustrates the percentage of participants within each group who use each type of environmental cue.

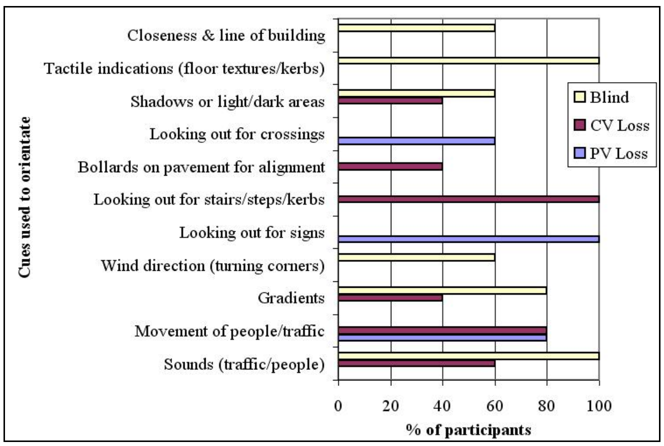


Figure 5. Percentage of participants within each group who use each type of cue to orientate and navigate.

As illustrated in Figure 5, only the blind group used the closeness of buildings (60%), tactile markings (100%), and wind direction (60%). Signs (100%) and crossings (60%) were only used by the PV loss group, whereas pavement bollards (40%) and stairs (100%) were only used by the CV loss group.

Shadows, gradients, and sounds were all used by the blind and CV loss group but not by the PV loss group. Whereas, people/traffic movement was used by the CV and PV loss groups but not by the blind group.

4.2 Indoor route

The indoor landmarks are illustrated in Figure 6, and similarly, as an example the questions and mistakes made by blind participants are represented. Similarly, the type of questions and mistakes made can be seen in Figure 7.

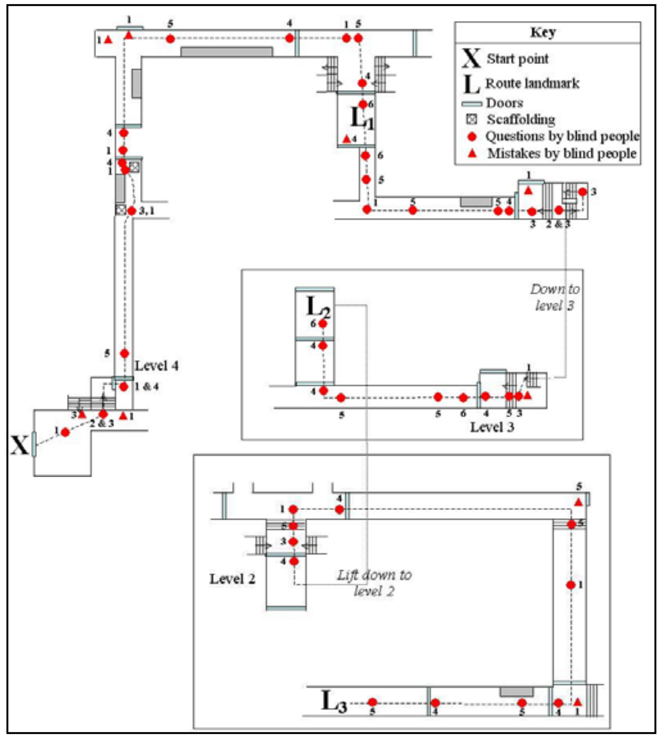


Figure 6. Questions asked, and mistakes made, by blind participants during indoor route.

The mean number of questions asked relating to each category is illustrated in Figure 7 for each group of participants.

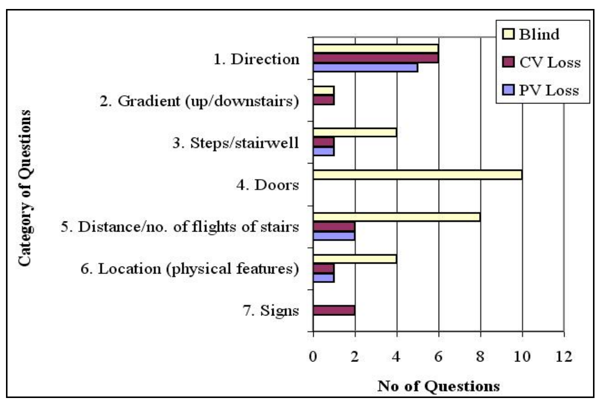


Figure 7. Mean number of questions asked relating to each category for each group.

The key results from this graph, together with statistical data in Table 3 from a one factor independent measures ANOVA test [where $F(2, 12) = 6.93$ at $p<0.01$] and Tukey's test [where q has a value of 5.05 at $p<0.01$], are as follows:

- The mean number of questions regarding stairs (3) and distance (5) asked by blind participants is approximately 3 times greater for both categories than the mean number of questions asked by CV loss and PV loss participants. For the distance category, there is a significant difference between the blind group mean and the CV loss group mean (6.8>HSD) and PV group mean (6.8>HSD). For the stairs category, only the difference between the blind group mean and PV loss group mean is slightly significant (3.6>HSD).

- Blind participants asked many questions regarding doors – a category of question not used by both other groups. Also, the mean (10) was higher than for any other category across all groups. This result is highly significant (F = 38.6>6.93).
- Participants with a CV loss asked questions regarding signs (8) which were not asked by the other two groups. This result is highly significant (F = 12.52>6.93).
- The most commonly asked questions across all groups were direction (1), and distance (5). Questions were asked within six out of seven categories by the blind and CV loss groups, and within 4 categories by the PV loss group.

Table 3. Testing for significance (shaded cells show a significant result)

	ANOVA	Tukey test			
Category Q No.	Variance ratio (F)	HSD	B & CV	B & PV	CV & PV
			Val	Val	Val
1	0.72				
2	3.13				
3	8.34	3.45	3.2	3.6	0.4
4	38.60	4.65	9.8	10	0.2
5	42.81	3.03	6.8	6.8	0
6	6.78				
7	12.52	1.98	2.4	0	2.4

The blind group made a total of 20 mistakes indoor, the CV loss group made 7 mistakes, and PV loss group made 1 mistake.

The percentage of participants within each group who use each type of environmental cue to orientate and navigate inside is illustrated in Figure 8.

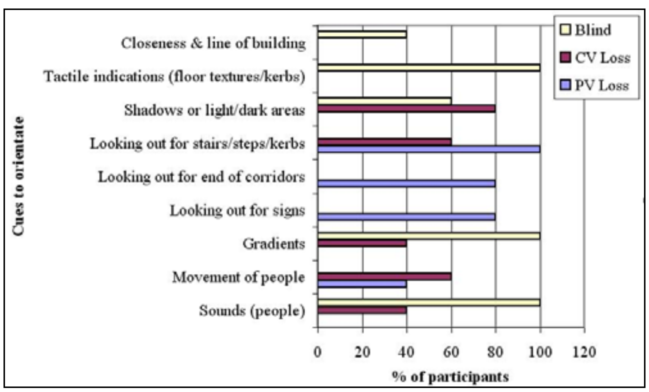


Figure 8. Percentage of participants within each group who use each type of cue to orientate and navigate.

Figure 8 illustrates that only the blind group used the closeness of buildings (40%) and tactile markings (100%), whereas looking for signs (80%) and the end of corridors (80%) were only used by the PV loss group. All blind participants and 2 people within the CV loss group used gradients and sounds. The PV loss group used neither, and also did not use shadows, which were also used by the other two groups. The PV loss and CV loss groups, however, used the movement of people (40%, 60%) and stairs (100%, 60%), neither of which were used by blind participants.

4.3 Contrasting contexts

When comparing the results for outdoor and indoor routes it can be seen that more categories of questions were asked outside (9 vs. 7). However, participants asked far more questions indoor than they did outdoor (61.5% more within the blind group, 14.5% more in the CV loss group, 131.6% more in the PV loss group).

Different types of questions were also asked in each context, and some of those categories that are the same are proportionately greater or lesser in either context. Blind participants, for instance, asked a proportionately greater amount of questions about distance inside.

Similarly, this trend is further evident in the environmental cues participants used to orientate. Light/dark cues were proportionately higher indoor for the CV loss group, gradients were higher indoor for the blind group, and sounds were lower for the CV loss group indoor.

5. DISCUSSSION & CONCLUSIONS

The study hypothesis has been supported in that differences have been found between (i) people with different visual impairments, and (ii) different contexts.

Blind people asked categories of question and used environmental cues not used by the other two groups. Questions were asked about side streets, steps, and doors, while tactile markings and wind direction were used for environmental cues. The blind group also asked significantly more questions regarding distance, and a greater percentage used sounds to orientate. Blind people therefore require a richer variety of contextual information possibly due to their more restricted level of vision, making them more dependent on other sensory cues, such as sound and touch.

There were also differences between the CV loss and PV loss groups. The CV loss group asked far more questions generally and within additional categories relating to signs and traffic lights. Expressed difficulties in reading text and directly viewing or fixating on objects without central vision may explain this finding. In contrast, people with a PV loss will therefore be able to fixate on more distant landmarks, such as signs, crossings, distance to turnings, etc. Interestingly, people with a CV loss used light-dark contrasts to orientate, indicating a greater dependency on peripheral vision which is used for light sensitivity. This in turn explains why people with a PV loss experience a high degree of usable vision during the day, but at night experience night blindness. We plan to investigate this important usability issue in a further study.

Differences between contexts were also found. More questions were asked inside than outside (the greatest increase by the PV loss group). For some categories, the number of questions asked became proportionately greater, such as distance for the blind group. Some environmental cues were used by a greater percentage of participants indoor, such as light-dark areas for the CV loss group. These differences may be due to participants having to negotiate a richer and more rapidly occurring contextual environment whilst navigating indoor. The CV loss group, for instance, used the light shining through windows to indicate the side or end of corridors. More research is required in order to investigate these differences in more contextual environments (e.g. urban vs. rural).

With respect to our multidisciplinary model of context, the differences reported illustrate how some cues in the environment are meaningful to one form of visual impairment but incidental to another, meaning that people will form different cognitive maps of the environment. Further, incidental occurrences, such as a gust of wind turning a corner (i.e. part of the physical context in the contextual layer) may remain incidental to some but be used as a meaningful cue to others. Investigating these issues provides a foundation in which the application's world can be built, and places the user at the center of design and development.

Overall, the results offer valuable guidance for designers. When distance vision becomes more restrictive (PV loss to CV loss to blind), it would suggest that other or additional sensory input becomes more meaningful, and information regarding the immediate and incidental environment becomes more significant. Blind and CV loss people therefore require more contextual information to confirm, or *orientate* in, the environment, whereas PV loss people predominantly use information to *navigate*. So, for instance, a wayfinding device may need to give information regarding traffic flow, since traffic noise is often used by blind people to indicate their direction and position on the pavement.

To conclude, the design of wayfinding systems for visually impaired people needs to account for the significant differences in how people with different visual impairments encode and use spatial information within different contexts. Ideally, context-awareness needs to be incorporated as it enables the device to sense more in the user's environment, offering the potential to provide more useful and relevant information and services.

Our future study involves using the timing and proportions of questions attained from each group to design three conditions of verbal messages, which will be transmitted to visually impaired participants using a GPS-enabled IPAQ. The purpose will be to see whether participants are more effective and efficient using information derived from participants with the same category of visual impairment as themselves. Further studies may also involve investigating different temporal contexts (time of day – day/night) and the number of times the same route is experienced.

6. ACKNOWLEDGMENTS

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7. REFERENCES

[1] Strothotte, T., Fritz, S., Michel, R., Raab, A., Petrie, H., Johnson, V., Reichert, L. and Schalt, A. Development of Dialogue Systems for the Mobility Aid for Blind People: Initial Design and Usability Testing. In *Proceedings of ASSETS '96*, Vancouver, British Columbia, Canada. 1996, pp. 139-144.

[2] Golledge, R.G., Klatzky, R.L., Loomis, J.M., Speigle, J. and Tietz, J. A geographical information system for a GPS based personal guidance system. In *International Journal of Geographical Information Science*, **12** (7), 727-749, 1998.

[3] Makino, H., Ishii, I. and Nakashizuka, M. Development of navigation system for the blind using GPS and mobile phone combination. In *Proceedings of the 18th Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, Volume 18, Pts 1-5, 1997.

[4] LaGrow, S. and Weessies, M. Orientation & Mobility: Techniques for Independence. The Dunmore Press Limited, New Zealand, p.9, 1994.

[5] Helal, A.S., Moore, S.E. and Ramachandran, B. Drishti: An integrated Navigation System for Visually Impaired and Disabled. In the *5th International Symposium on Wearable Computers*, Zurich, Switzerland, 2001.

[6] Pascoe, J. Adding Generic Contextual Capabilities to Wearable Computers. In *Proceedings of 2nd International Symposium on Wearable Computers*, 92-99, 1998.

[7] Kitchin, R.M. & Blades, M. The Cognition of Geographic Space. I.B. Tauris: London, 2002, pp. 33-57.

[8] Bradley, N.A. and Dunlop, M.D. Towards a user-centric multidisciplinary design framework for context-aware applications. In *Proceedings of UbiNet workshop*, Imperial College, London. 25-26th September 2003.

[9] Smith, S. Environmental Context – Dependent Memory. Chapter 2. In: Davies, G.M. & Thomson, D.M. *Memory in context; context in memory.* John Wiley & Sons. Chichester. 1988. p.13-34.

[10] Bunt, H. Context and Dialogue Control. In *Proceedings of the 1st International and Interdisciplinary Conference on Modeling and Using Context, CONTEXT 1997,* Rio de Aliceiro, Brazil. 1997. p.130-149.