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Spatial Ability, Urban Wayfinding and Location-Based Services: a review and first results

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Abstract

Location-Based Services (LBS) are a new industry at the core of which are GIS and spatial databases. With increasing mobility of individuals, the anticipated availability of broadband communications for mobile devices and growing volumes of location specific information available in databases there will inevitably be an increase in demand for services providing location related information to people on the move. New Information and Communication Technologies (NICTs) are providing enhanced possibilities for navigating "smart cities". Urban environments, meanwhile, have increasing spatial complexity. Navigating urban environments is becoming an important issue. The time is ripe for a re-appraisal of urban wayfinding. This paper critically reviews the current LBS applications and raises a series of questions with regard to LBS for urban wayfinding. Research is being carried out to measure individuals' spatial ability/awareness and their degree of preference for using LBS in wayfinding. The methodology includes both the use of questionnaires and a virtual reality CAVE. Presented here are the results of the questionnaire survey which indicate the relationships between individuals' spatial ability, use of NICTs and mode preference for receiving wayfinding cues. Also discussed are our future research directions on LBS, particular on issues of urban wayfinding using NICTs.

Keywords: Urban wayfinding, Location-Based Services, Information and communication technologies.

Introduction

Digital technology, throughout its development, has followed a consistent path of miniaturisation and decentralisation with increasing focus on the individual and niche applications. Significant has been a convergence of computers with communications ensuring that the delivery and interaction mechanisms for software and information are now focused on networks of individuals in mobile contexts. With such massive convergence, new applications define the cutting edge. As computers are being increasingly tailored to individual niches, then new digital services are emerging, many of which represent applications which hitherto did not exist or at best were rarely focused on a mass market. Location-based services (LBS) form one such application.

Over the last few decades, most urban landscapes have been utterly transformed. Cities are becoming ever-increasingly complex requiring citizens to become ever more sophisticated in navigating urban spaces by foot, public transport or in private vehicles. The scale and pace of change in urban areas through expansion, infill, re-development and changing use continues to increase (Ward *et al*., 2000). Together this creates further uncertainties in the way that we structure and navigate through urban space. Thus urban wayfinding is an increasingly complicated task. With the advent of the New Information Communication Technologies (NITCs) coupled with the increasing mobility they afford to people, navigation/wayfinding needs in urban environments are framing LBS as attractive commercial propositions that are being brought to the market. From a geographical information systems (GIS) perspective, spatial databases and fast response to spatial queries lie at the heart of LBS.

In this paper we start by reviewing the concept of LBS and its current applications. A series of critical questions with regard to LBS for urban wayfinding are then raised. A study is being carried out to measure individuals' spatial ability/awareness, their degree of preference for using NICT-based LBS in wayfinding and preference for the form of wayfinding instructions. This paper concludes by mapping our future research directions on LBS, particular on issues of urban wayfinding using NICTs by use of a virtual reality environment.

Concept of LBS and its applications

The rise of the knowledge society and the informational economy has been documented and discussed in detail, *inter alia*, by Castells (1989, 1996). We have become a "network society" founded upon modern information and communication technologies (ICT). By the end of the 20^{th} Century, the number of mobile telephone users had reached 700 million worldwide. The increasing mobility of individuals, the anticipated availability of broadband communications for mobile devices and the growing volumes of location specific information available in databases will inevitably lead to the demand for services that will deliver location related information to individuals on the move. Such services are generally referred to as Location-based services (LBS) and although in the early stage of development, are expected to play important part in people's lives.

The main driver of LBS in the United States is the Federal Communications Commission's adoption of enhanced 911 (E911) mandate. E911 mandate aims to improve the quality and reliability of the emergency services by locating wireless 911 callers (www.fcc.gov/e911/). The requirement is to ensure 50 metres accuracy for 67% of calls (150 metres for 95% of calls) for handset-based solutions, 100 metres for 67% (300 metres for 95%) for network-based solutions by October 2001. The E911 mandate incentive is that it provides the basis for a wide range of additional, value-added location based services. Similar concerns for locating wireless emergency calls in Europe only started from 2000. Nevertheless, there has been fast development and deployment of both wireless and location-aware networks. Also in 2000, mobile network operators, after their immense investment on 3G licenses, began to look into content driven services. Thus LBS in Europe are driven by the motivation to provide differentiating and value-added services in a competitive marketplace.

Over the past few years, the number of mobile device users has been increasing rapidly. More than 40% of the population in Europe and nearly 70% in the UK over the age 12 owns a mobile device. There are over 700 million subscribers world-wide. This number is predicted to reach 1 billion by 2003 and 1.5 billion by the end of 2005 (EMC world cellular database, calculated 15/01/2001). IDC (www.idc.com) predicts that by year 2005, almost 50% of European mobile subscribers will use LBS. Also the 2001 surveys by Jupiter and McKinsey reported that 38% of wireless users would like navigation services. Figure 1 demonstrates the range of applications and their perceived ranking by mobile users over time according to the data from ARC Group.

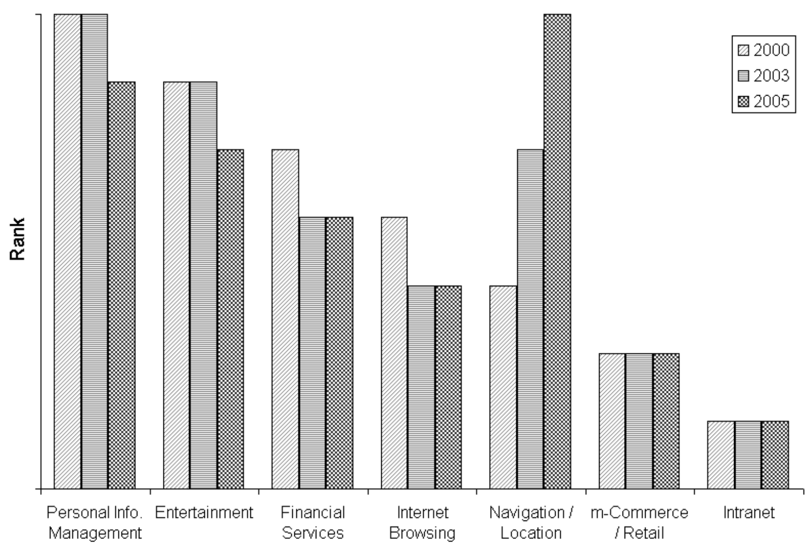


Figure 1: Perceived ranking of LBS applications by mobile users over time (source: ARC Group)

LBS can be defined as to the provision of geographically-orientated data and information services to users across mobile telecommunication networks. LBS can be seen as the convergence of New Information and Communication Technologies (NICTs) such as mobile telecommunication system, location aware technologies and handheld devices with the Internet, GIS and spatial databases (Figure 2). Current LBS applications can be divided into pushed online advertising, user-solicited information (e.g. local traffic information, weather forecasts and local services), instant messaging for communication with people within the same or nearby localities, real-time tracking, mapping/route guidance for directing people to reach their destination, emergency services for stationary location and location-based tariffs (Hunter, 2001). Some of these applications are currently being developed and some are already commercially available.

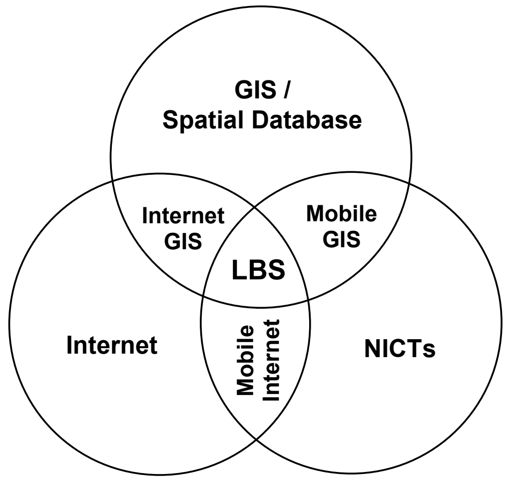


Figure 2: Convergence of technologies to create LBS (Brimicombe, 2002)

Personal profiling has been regarded as a way to enrich and enhance LBS and supply people with the information that they are likely to need or welcome. Such ‘tailor made’ LBS are considered to a be significant development in the mobile data market, which will deliver information specifically compiled for the individual according to his/her interests, history and location. Information related to an individual and their location has been suggested as classifiable into short-, middle- and long-term, where recent spatial and temporal trends are considered as short-term information, personal preferences as middle-term information and the person's identity as long-term information (Mountain & Raper, 2000; Mountain & Raper, 2001). Personal profiling would clearly be attractive to marketeers in their pursuit of ‘one to one’ marketing of products and services.

A range of input and output methods have been proposed for LBS applications in attempts to identify the desirable and effective way of delivering information. Voice has been suggested as user a friendly method for inputting requests and giving instructions. Using speech via mobile phone for navigation instructions while driving, as in the “Mobile Navigation” product by Yeoman Group, is but one of the examples. Phonetic transcriptions of city names, street names and Points of Interest (POI) to digital maps is another example for requesting information by voice (van Es, 2001).

Critical questions raised from the current LBS

It is commonly understood that LBS applications must be able to integrate mapping, routing, searching and address location functionality with user-specified content. Also location information should be provided in a range of formats such as graphical, textual and voice. Concerns are focused on the capability and the diversity of devices to deliver and access location information. There are also discussions based upon the effectiveness and user friendliness of the way to deliver location based information, such as “speak and listen”, maps and text. However, very few systematic studies have been carried out of this aspect, particularly individual preferences with regard to cognitive abilities, spatial awareness, prior knowledge of the location, map reading ability, expertise in using NICTs and so on.

Given that the demand for real-time, fast-changing information is increasing, people will require more relevant, timely information in various forms. What information do people need in the new “mobile age”, and therefore what kind of data are needed? Personal needs are being emphasised. There are also questions on how to provide access to large numbers of people in high transaction environments in LBS. The dynamic changes and complexity in the urban area are another consideration, particularly with regard to selecting POI and landmarks for giving navigation instructions to the mobile users. Important fundamental questions concern what the relevant and meaningful information are to people who need to complete wayfinding tasks through the assistant of NICTs. For example what are the preferred landmarks sent via a mobile device that allow people to make wayfinding decisions? These questions remain untested and therefore unanswered.

Another area of possible difficulty is the semantics of communication between individuals and a database with or without the intermediary of a call operator. In the navigation LBS applications, instructions are given to people by means of maps, spoken word and text. It is envisaged that various landmarks, POI and key features of neighbourhood environments might be provided as spatial cues via NICTs. On the other hand, people’s ability to answer spatial questions may be limited either through lack of awareness or confusion over vocabulary and map reading. This strikes at the traditional core principles of GIS such as data modelling, data handling, generalisation, cartography and navigation. To what extent can objects be described in terms of neighbouring features in exactly the same way that people might from looking at a map? Can we arrive at a common semantic for spatial descriptive terms such a ‘near’, ‘nearby’ or even ‘ahead’ when the user might be looking in the wrong direction.

Despite many of the proposed applications of wireless services, LBS is still in the earliest stages of deploying mobile solutions. Many of the assumptions concerning usage and behaviour are untested and should not be taken for granted.

Wayfinding and issues of LBS

There is a considerable body of literature on wayfinding and on the nature and development of cognitive maps (Lloyd, 1989; Gopal & Smith, 1990; Crampton, 1992; Golledge *et al*., 1995; Golledge & Stimson, 1997; Golledge, 1999). Much of the work has focused on the nature of cognitive maps, how they are developed and how information is retrieved from them. Cognitive maps, as internal spatial representations, are general regarded as wayfinding tools. But cognitive maps do not always fit well with reality. When people acquire, encode, manipulate, store and represent spatial information, errors in their cognitive maps such as distortion, incompleteness and fragmentation occur (Siegel *et al.* 1979; Downs 1981; Gale 1985; Buttenfield 1986; Bryant et al. 1992; Tversky 1992). Therefore there is no precise and complete spatial knowledge of the real environment that can be developed in a human’s internal representation. Furthermore, when encountering a new environment, people are likely to need various information source such as maps, photos, images written/verbal information (Golledge, 1999). Related areas are spatial ability, spatial knowledge and wayfinding, in which people are considered to have different levels of familiarity with an environment, preferences for features and a range of wayfinding abilities. The processes involved are not at all clear with a range of results emerging from literature (Lorenze & Neisser, 1986; Allen & Ondracek, 1995; Allen *et al.*, 1996) .

On the other hand, the fast-emerging fields of LBS distributed services, allied to GIS, provide the technological setting to enhanced peoples abilities to navigate urban environments. New geo-information services are being introduced to the market in both a traditional mapping sense or at a conceptual level using 'next generation' technology. However, there is little indication that the design of new wayfinding aids is itself cognisant of the ways that citizens use spatial cues to navigate (Allen, 1999). Moreover, there has been too little systematic study of how new information and communication technologies (NICTs) can assist our understanding of how knowledge is acquired, valued, communicated and applied.

Our research aims to address the ways in which urban cognition might be created and supplemented by navigational cues supplied through NICTs. Moreover, while previous studies have focused on the paper map as a learning tool (MacEachren, 1992; Lloyd, 1999), there are fundamental differences between paper maps and digital maps (Goodchild, 2000) in communicating real-time wayfinding information. Technology now offers the possibility of supplementing the digital map with satellite imagery and photo stills. Interaction with such spatial information in a problem solving process has until recently been limited to pointing and typing (Blaser *et al.*, 2000) whereas technology can also facilitate speech interaction and speech and/or textual outputs as map supplements.

The complexity and variability of both urban environments and the wayfinding abilities (spatial acuity, familiarity) of individuals poses a methodological challenge to separate out and study the specific aspects. Our research will develop a range of experimental designs using virtual reality and simulated location-based GIS delivered through NICTs. A range of urban morphologies will be simulated using sample locations from UK cities. Using these framework data, the arrangement, type and distinctiveness of landmarks, routes and general reference frames would be specifically designed and the corresponding spatial database constructed. It will thus be possible to evaluate respondents on a range of environments for a range of NICT simulations. In order to inform this experimental research, a preliminary study has been carried out. The use of questionnaire has allowed us to explore the relationship between people's spatial ability, their use of NICTs and their preferences on LBS wayfinding applications. Some initial findings are provided here.

Initial study and findings

Questionnaire measurement can be applied to reveal people's sense of direction, spatial attitude, spatial preferences and spatial anxieties. It therefore indicates some level of understanding of the individual's spatial representation and spatial ability. Applying questionnaire in this way can be found in various research, such as the "self-report environmental spatial-style questions" (Montello *et al.*, 1999) and the questionnaire used to measure individual's direction and orientation ability, preference for landmark, route or survey-centred representations (Pazzaglia and de Beni, 2001).

In this research, the questionnaire was structured into four parts:

- indicating people's spatial ability;
- the use of NICTs;
- willingness of using wayfinding service through mobile devices;
- preference for forms of wayfinding instruction.

For measuring people's spatial ability, seven aspects or dimensions were probed through 21 questions. These seven dimensions are listed in Table 1 and also shown in the following diagrams as D1 - D7. Answers were made on a 6 point scales according to the level of agreement with the question posed. The second part of the questionnaire was set up for measuring the level of individual's usage of mobile devices, text messaging and Internet map/travel sites. Part three of the questionnaire aimed at the level of willingness of people would use and pay for LBS wayfinding services. The final part probed preferences for forms of wayfinding instructions to be received through a mobile phone or PDA. There were a total of 89 participants of which 40% were female and 60% male. Age range was from 18 to 60+ and age group under 30 was 47.2% of the data set.

D1	sense of direction
D2	preference of image thinking
D3	preference of verbal thinking
D4	tendency towards map (survey) knowledge
D5	map use and reading
D6	general spatial ability, such as judging distance, wayfinding
D7	spatial awareness and spatial anxiety

Table 1: Seven dimensions used to measure participants' spatial ability

Spatial ability groupings

Ward's method (Ward, 1963) with Euclidean distance was used to classify the participants' spatial ability and spatial awareness. The method is an analysis of variance approach and is generally regarded as effective with tendency to create small size clusters. From the results shown in Figure 3, there is considerable linkage distance between three broad groups G1, G2 and G3. These three groups are established based upon the characteristics of spatial ability and awareness.

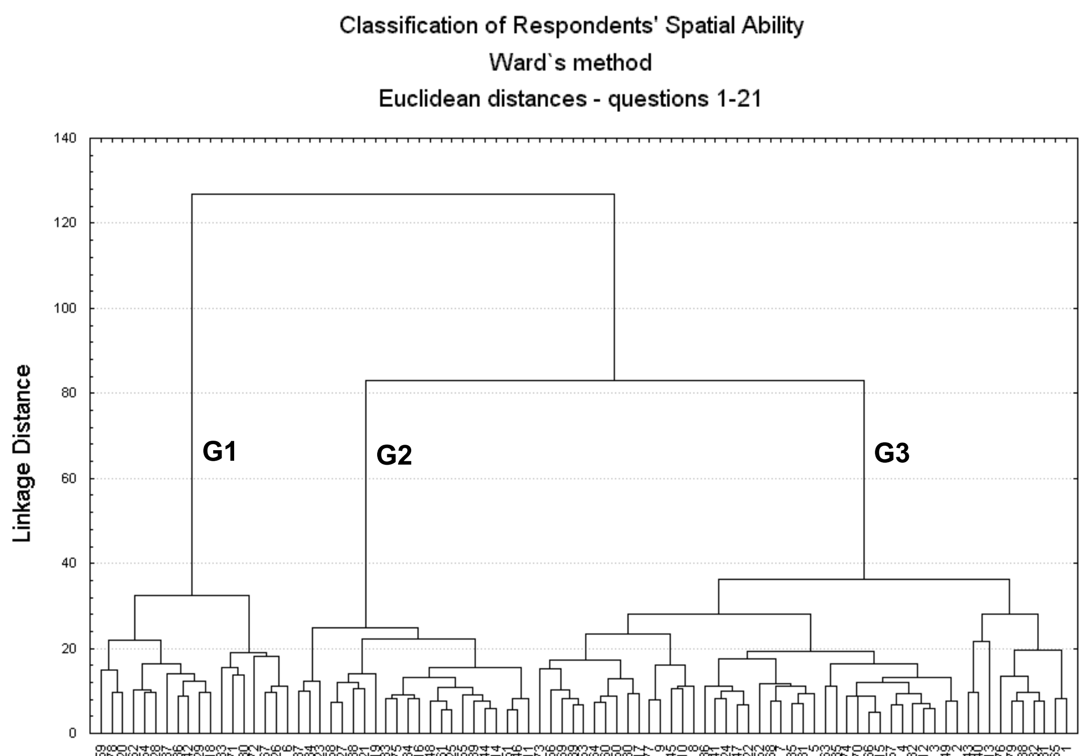


Figure 3: Classification based on participants' spatial ability

For these three groups of participants, the levels of the differences in their spatial ability are illustrated in the radar diagram in Figure 4 against the seven dimensions (D1 -D7) of spatial ability. Group 1 (G1) rates comparatively low on nearly all seven dimensions except D2 which is a preference for thinking in imagery. The level of Group 2 (G2) is relatively high on all dimensions whilst Group 3 (G3) is consistently intermediate.

Willingness to use wayfinding services through mobile devices

In Figure 5 a further two variables, willingness to use the LBS wayfinding services and paying a modest fee for such service, are added into the radar diagram. The results suggest that there is not much difference on these two variables between the three groups of participants despite the clear differences in spatial ability between them. However, all participants showed positive interest in using wayfinding services through mobile device given most of them have not yet experienced any such service. The willingness to pay for such service is middling.

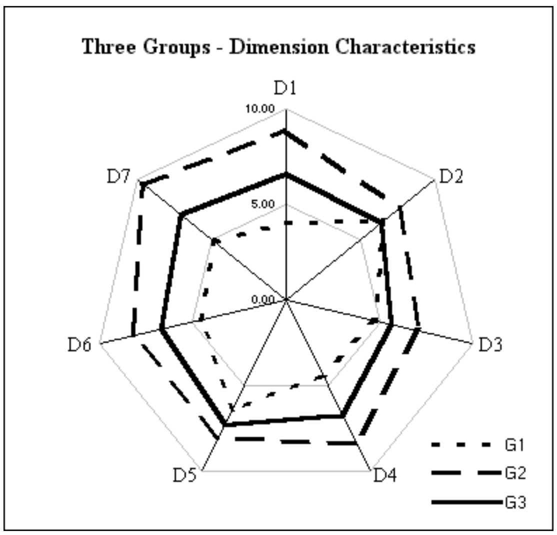


Figure 4: Three groups vs. dimensions of spatial ability

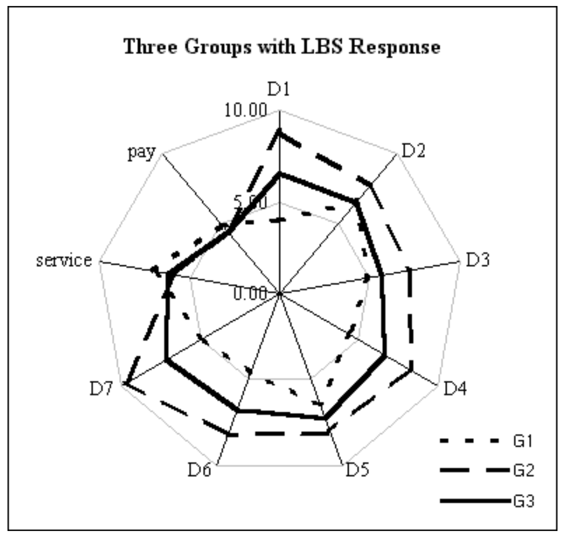
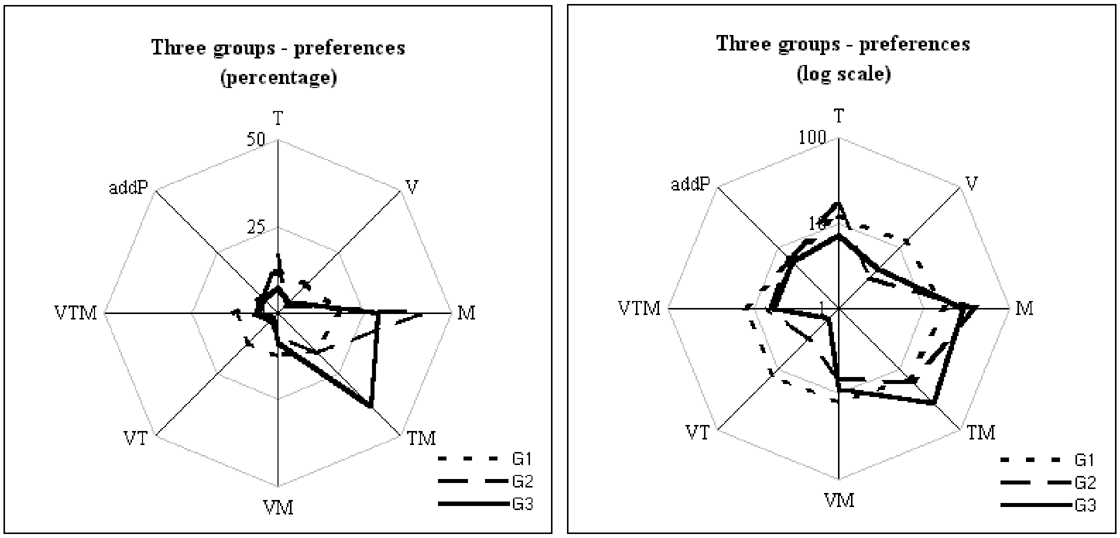


Figure 5: Three groups from Fig. 4 vs. willingness to use wayfinding services

Spatial ability vs. preferences for the form of wayfinding information

There were eight preferences for receiving wayfinding instructions via mobile device tested by the questionnaire: text instruction (T), voice instruction (V), map instruction (M), combined text and map (TM), combined voice and map (VM), combined voice and text (VT), combined voice, text and map (VTM) and with added pictures (addP). As shown in Figure 6a, group G2 (high spatial ability) has much strong preference for receiving wayfinding instruction in map form. Group G3, with intermediate score on spatial ability, shows strong preference firstly for a combination of text and map and then for maps on their own. For the group G1 with relatively low score on spatial ability, the result suggests that they has no particular preference for any of these eight forms. This is demonstrated more clearly on the logarithm scaled diagram in Figure 6b.



(a) in percentage scale (b) in log scale

Figure 6: Preference for forms of wayfinding instruction

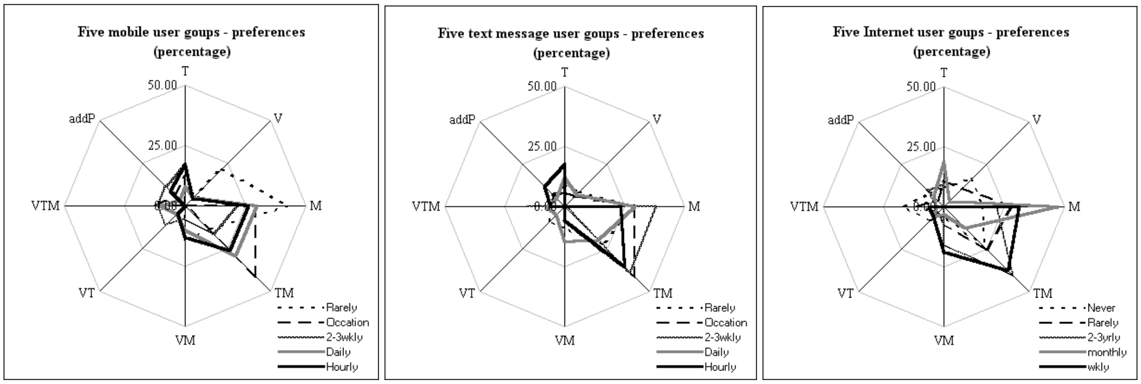
Usage of NICTs vs. preferences for the form of wayfinding information

For the usage of mobile phone and text messaging, the participants were divided into five groups: rarely, occasionally, 2-3 time a week, daily and hourly. For the usage of Internet map/travel information, the participants are divided into five similar groups: never, rarely, 2-3 time a year, monthly and weekly. The preference for the forms of receiving wayfinding instructions are investigated for each group.

The results shown in Figure 7a suggest that there are different preferences among the five mobile phone use groups. The frequent usage groups ('daily' and 'hourly') show an equal preference for maps only and a combination of text and map. The 'occasional use' group has a greater preference for the combination of text and map. The 'rarely use' group interestingly shows a clear preference for maps only followed by voice only.

For the text messaging group illustrated in Figure 7b, the preference of the most frequent use group ('hourly') is the combination of text and map format. The 'daily use' group shows the preference towards maps, then similar preference for combinations of text and map (TM) and voice and map (VM). For the 'occasional use' and 'rarely use' groups, the results suggest a preference for a combination of text and map.

Figure 7c, showing the Internet map/travel information use group, suggests that the 'monthly use' group has preference for maps. However, the 'weekly use' group has the combination of text and map as first preference and then maps only as a close second. The 'rarely use' group also has maps only followed by text and map combination as its preference. The 'never use' group shows a preference for a combination of text and map followed by voice only. In general, voice only does not appear as a high preference for receiving wayfinding instructions, nor does text by itself. This has implications for the design and use of mobile phones for wayfinding.



(a) mobile phone (b) text messaging (c) Internet map/travel info.

Figure 7: Different user groups' preference for forms of wayfinding instruction

Future research direction

The initial study and findings in this paper have suggested that the preference for the form of wayfinding information is related with people's spatial ability in some degree. There is a need for more systematic research on the issues such as what kind of information people need from LBS to assist them for making wayfinding decisions and in what form people would like to receive the information from their mobile devices. There are a series of research questions raised here which will be the focus of the future direction of this research:

- *When and where do individuals require navigational information when negotiating urban environments?* Mobile positioning devices, such as hand-held or embedded GPS may be of limited use in heavily built-up urban environments and it is important to identify the relative merits and effectiveness of technological versus cognitive solutions to navigation in such circumstances.
- In a more general sense, *how is wayfinding influenced by street pattern* (e.g. grid patterning versus other regular geometric arrangements, and both compared to the irregularity of all unplanned cities)?
- Given the importance of landmarks and the estimated space-time between them in wayfinding (Golledge & Stimson, 1997; Allen, 1999), *are there consistent preferences for landmark types* (e.g. churches, pubs, fast food outlets) that should be identified and populated within the relevant databases?
- *How can NICTs and high resolution databases assist people in navigating urban environments?* Relevant technologies include GIS or spatial databases, GPS, mobile phones and PDA. Given the growing prevalence of NICTs, it would be timely to study the preference structures for receiving navigational information as land cover/use maps, images, text and/or spoken word. Furthermore, it may be possible to generalise about the preference structures of different groups.

Conclusion

This paper has focused on wayfinding applications of LBS. LBS have arisen from a convergence of technologies and the widespread availability of NICTs. A critical review of current state-of-the-art has raised a number research questions regarding the use of NICTs and wayfinding as envisaged in LBS. This work is part of larger research programme and aims to inform specifics of the proposed research methodology. A questionnaire survey has been carried out to assess spatial ability in relation to NICT usage and preference for the form in which wayfinding information might be communicated via a NICT. Three levels of spatial ability emerged, two of which had distinct preferences for the form of wayfinding information. These have implications for the design and delivery of LBS.

References

Allen G. L. and Ondracek, P. J. (1995) Age-sensitive cognitive abilities related to children's acquisition of spatial knowledge. Developmental Psychology 31: 934-945

Allen, G. L. (1999) Spatial abilities, cognitive maps, and wayfinding: bases for individual differences in spatial cognition and behavior. In Golledge (ed.) *Wayfinding Behavior: Cognitive Mapping and Other Spatial Processes*. The Johns Hopkins University Press, Baltimore: 46-80

Allen, G. L., Kirasic, K. C., Dobson, S. H., Long, R. G. and Beck, S. (1996) Predicting environmental learning from spatial abilities: An indirect route. Intelligence 22: 327-355

Blaser A., Sester M. and Egenhofer M. (2000) Visualization in an early stage of the problem-solving process in GIS. *Computer and Geoscience* 26: 57-66

Brimicombe, A. J. (2002) GIS: Where are the frontiers now? *Proceedings GIS 2002*, Bahrain: 33-45

Bryant, D. J. Tversky, B. and Franklin, N. (1992) Internal and external spatial frameworks representing described scenes. Journal of Memory and Language 31: 79-98

Buttenfield, B. P. (1986) Comparing distortion on sketch maps and MDS configurations. *Professional Geographer* 38: 238-246

Castells, M. (1989) *The Informational City*. Blackwell, Oxford.

Castells, M. (1996) *The Rise of the Network Society*. Blackwell, Oxford.

Crampton, J. (1992) A cognitive analysis of wayfinding expertise. *Cartographca* 29(3&4): 46-65

Downs, R. M. (1981) Maps and metaphors. *The Professional Geographer* 87: 287-293

Federal Communications Commission (2001) FCC wireless 911 requirements. *www.fcc.gov/e911/* as viewed on 3/01/2002

Gale, N. D. (1985) Route learning by children in real and simulated environments. Unpublished Ph.D. dissertation, Department of Geography, University of California, Santa Barbara.

Golledge, R. G. (1999) Human wayfinding and cognitive maps. In Golledge (ed.) *Wayfinding Behavior: Cognitive Mapping and Other Spatial Processes*. The Johns Hopkins University Press, Baltimore: 5-45

Golledge, R. G. and Stimson R.J. (1997) *Spatial Behaviour: a Geographical Perspective*. Guilford Press, New York.

Golledge, R. G., Dougherty V. and Bell S. (1995) Acquiring spatial knowledge: survey versus route-based knowledge in unfamiliar environments. *Annals of the Association of American Geographers* 85(1): 134-158

Goodchild, M. (2000) Communicating geographic information in a digital age. *Annals of the Association of American Geographers* 90(2): 344-355

Gopal, S. and Smith, T. R. (1990) Human way-finding in an urban environment: a performance analysis of a computational process model. *Environment & Planning A* 22: 169-191

Hunter, P. (2001) Location, Location, Location. *Computer Weekly* May Issue: 64

Lloyd R. (1999) Organisation of feature-, time-, or location-based mental models. *The Professional Geographer* 51(4): 525-538

Lloyd, R. (1989) Cognitive maps: encoding and decoding information. *Annals of the Association of American Geographers* 79(1): 101-124

Lorenze, C. A. and Neisser, U. (1986) *Ecological and psychometric dimensions of spatial ability*. Technical Report No. 10 Atlantic, GA: Emory Cognition Project, Emory University.

MacEachren A. M. (1992) Application of environmental learning theory to spatial knowledge acquisition from maps. *Annals of the Association of American Geographers* 82(2): 245-274

Montello, D. R., Lovelace, K. L., Golledge, R. G. and Self, C. M. (1999) Sex-related differences and similarities in geographic and environmental spatial abilities. *Annals of the Association of American Geographers* 89: 515-534

Mountain, D. and Raper J. (2000) Designing geolocation services for next generation mobile phone systems. Workshop2.4 *Proceedings GIS 2000*, Earls Court on CD

Mountain, D. and Raper J. (2001) Spatio-temporal representations of individual human movement for personalising Location Based Services. *Proceedings GISRUK 2001*, University of Glamorgan: 579-582

Pazzaglia, F. and de Beni, R. (2001) Strategies of processing spatial information in survey and landmark-centred individuals. *European Journal of cognitive Psychology* 13: 493-508

Siegel, A. W., Herman, J. F., Allen, G. L. and Kirasic, K. C. (1979) The development of cognitive maps in large- and small-scale spaces. *Child Development* 50: 582-585

Tversky, B. (1992) Distortions in cognitive maps. Geoforum 23: 131-138

van Es, P. (2001) Where is the LBS industry heading to? *GI News* April/May Issue: 3-5

Ward D. Phinn S. R. and Murray A. T. (2000) Monitoring growth in rapidly urbanizing areas using remotely sensed data. *The Professional Geographer* 52(3): 371-386

Ward, J. H. (1963) hierarchical grouping to optimize an objective function. *Journal of the American Statistical Association* 58: 236