Pedestrian Navigation System in Mixed Indoor/Outdoor Environment – The NAVIO Project

Georg GARTNER & Andrew FRANK & Günther RETSCHER

Georg Gartner; Institut für Kartographie und Geomedientechnik, TU Wien, georg.gartner@tuwien.ac.at

Andrew Frank; Institut für Geoinformation und Landesvermessung, TU Wien, frank@geoinfo.tuwien.ac.at

Günther Retscher; Institut für Geodäsie und Geophysik, TU Wien, gretsch@pop.tuwien.ac.at

1 ABSTRACT

Pedestrians have often ways in unfamiliar urban environment or in complex buildings. In these cases they need guidance to reach their targets, for example a specific room in a local authorities' building, a counter, or an institute at an university. The goal of location-based mobile services is to provide such guidance on demand (anywhere, anytime), individually tailored to the actual information needs and presented in preferred forms. This project is focusing on the information aspect of location-based services, i.e., on the user's task at hand and the support of the user's decisions by information provided by such a service. Specifying a task ontology will yield context-dependent conceptualizations, activities, and references to directions from the user's perspective. These specifications will allow to:

- select appropriate sensor data and to integrate data when and where needed;
- propose context-dependent routes, fitting to partly conflicting interests and goals;
- select appropriate communication method in terms of supporting the user guiding by various multimedia cartography forms.

To test and to demonstrate the approach and results this project takes a use case scenario – guiding visitors to institutes of the Technical University Vienna – and develops a prototype.

2 MOBILE POSITIONING

2.1 Problems and State of the Art in Mobile Positioning

Pedestrian navigation has to work under any environmental condition in mixed indoor and outdoor areas as well as urban environments. Therefore challenging tasks that are dealt with in the project NAVIO are:

- the capability to track the movements of a pedestrian in real-time using different suitable location sensors and to obtain an optimal estimate of the current user's position,
- the possibility to locate the user in 3 dimensions with high precision (that includes to be able to determine the correct floor of user in a building), and
- the capability to achieve a seamless transition for continuous positioning determination between indoor and outdoor areas.

Thereby a navigation support must be able to provide location, orientation and movement of the user as well as related geographic information matching well with the real world situation experienced by pedestrians. Other challenging issues relating to the privacy and security of information about the current user's position, however, will not be addressed.

Nowadays for outdoor navigation, most commonly satellite-positioning technologies (GPS) are employed. Then the achievable positioning accuracies of the navigation system depend mainly on GPS, which provides accuracies on the few meters to 10 m level in standalone mode or sub-meter to a few meter level in differential mode (DGPS). If an insufficient number of satellites is available for a short period of time due to obstructions, then in a conventional approach observations of additional sensors are employed to bridge the loss of lock of satellite signals. For pedestrian navigation, sensors such as a low-cost attitude sensor (digital compass) giving the orientation and heading of the person being navigated and a digital step counter or accelerometers for travel distance measurements can be employed. Using these sensors, however, only relative position determination from a known start position (also referred as Dead Reckoning DR) is possible and the achievable accuracy depends on the type of movement tracking sensors used and the position prediction algorithms adopted.

For indoor positioning different techniques have been developed recently. They offer either absolute or relative positioning capabilities. Some of them are based on short-range or mid-range technologies (see e.g. Klinec and Volz, 2000) using sensors such as transponders or beacons installed in the building. An example are the so-called Local Positioning Systems (LPS) that have an operation principle similar to GPS. The LPS systems claim to achieve of about 0.3 to 1 m distance measurement accuracy (see e.g. Werb and Lanz, 2000; Sypniewski, 2000), but no details are given on the test results and the achievable accuracy on position fixing. Other indoor positioning systems currently under development include so-called Active Badge or Active Bats Systems (Hightower and Boriello, 2001). These systems are mainly employed for the location of people and finding things in buildings. Also Bluetooth, which has been originally developed for short range wireless communication, can be employed for locating mobile devices in a certain cell area that is represented by the range of the device. It can be employed for location determination using active landmarks. Locating the user on the correct floor of a multistory building is another challenging task. For more accurate determination of the user's position in vertical dimension an improvement might be achieved employing a barometric pressure sensor or digital altimeter additionally (Retscher and Skolaut, 2003).

As an alternative, mobile positioning services using cellular phones can be employed in both environments. Apart from describing the location of the user using the cell of the wireless network, more advanced positioning methods are under development. Most of them are based on classical terrestrial navigation methods where at least two observations are required to obtain a 2-D position fix (see e.g. Balbach, 2000; CPS, 2001; Drane et al., 1998; Hein et al., 2000; Retscher, 2002). The achievable positioning accuracy thereby depends mainly on the method and type of wireless network where accuracies are expected to be much lower in the current GSM[1] networks as in the future UMTS[2] networks. First manufacturer tests showed that a standard deviation of 50 m for 2-D position determination can be achieved using advanced methods in an ideal case. Further investigation on new developments and performance test results is especially required in this field.

2.2 Integrated positioning

For guidance of a pedestrian in 3-D space and updating of his route, continuous position determination is required with positioning accuracies on the few meter level or even higher, especially for navigation in buildings in vertical dimension (height) as the user must be located on the correct floor. The specialized research hypothesis of this work package in the project NAVIO is that a mathematical model for integrated positioning can be developed that provides the user with a continuous navigation support. Therefore appropriate location sensors have to be combined and integrated in a new multi-sensor fusion model.

Selection and test of appropriate location sensors

Newly developed sensors are available on the market which can provide various level of accuracy for position determination in navigation applications (see e.g. Ellum and El-Sheimy, 2000). Due to the obstructions of satellite signals in urban environment (Mok et al., 2000), a methodology has to be developed for position estimation under insufficient satellite availability condition. Besides a GPS or DGPS (Differential GPS) receiver other low-cost navigation sensors have to be integrated into the system design. It is proposed that at least the following relative dead reckoning (DR) sensors should be included: an attitude sensor (i.e. a digital compass) giving the orientation and heading of the person being navigated in combination with an inertial tracking sensor (e.g. a low-cost Inertial Measurement Unit IMU) including a three-axis accelerometer also employed for travel distance measurements as well as a digital barometer (i.e., barometric pressure sensor) for height determination (Retscher and Skolaut, 2003). Their performance and suitability has to be analyzed in detail.

For indoor positioning various technologies are currently being developed or in the development stage (see e.g. Hightower and Boriello, 2001). Further investigation concerning their suitability, accuracy potential and error budget is yet not addressed in detail. In addition, mobile phone location services should be employed. Depending on their availability a comparison with other technologies is required and further investigation on their suitability, reliability and accuracy potential is necessary.

Development of a Multi-sensor Fusion Model

A Kalman filter approach is particular suited for the integration and sensor fusion in real-time. Extending basic filter approaches, a centralized Kalman filter approach which integrates all observations from the different sensors will be developed. The model must be able to make full use of all available single observations of the sensors at a certain time to obtain an optimal estimate of the current user state (i.e., position, orientation and motion).

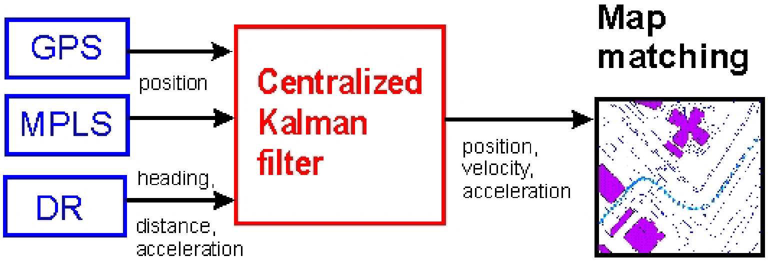

Figure 1: Centralized Kalman filter approach (after Retscher and Mok, 2003)

Figure 1 shows the concept of an approach for the integration of observations of sensors using a centralized Kalman filter. The concept has been introduced by Retscher and Mok (2001) for the integration and combined position determination of observations of

[1] GSM stands for Global System for Mobile Communication.

[2] UMTS stands for Universal Mobile Telecommunication Service.

GPS, mobile phone location services (MPLS) and dead reckoning (DR) sensors employed in vehicle navigation systems. An analysis based on simulations performed by Siegele (2001) has proven that this model is suitable for integration of different sensors in mobile positioning. Apart from the last step, i.e., matching of the positions obtained from the filter to a digital road map, the approach can also be employed in pedestrian navigation. A simulation study for the guidance of visitors of our University performed by Skolaut (2002) showed promising results for the adaptation of the filter model for pedestrian navigation. The algorithm is also open for the integration of other sensors than shown in Figure 1 and for further modification.

An improvement of the accuracy and reliability for position determination should be achieved in the model by integrating all single sensor observations available at a certain time (epoch). It is suggested to derive an extended filter model capable to calculate the user state from all available measurement data, also in the case, if only incomplete observations from a single sensor are available (e.g. if insufficient numbers of satellites for GPS positioning are available due to obstructions). Any single observation can then contribute to improve the previous state of a tracked user by updating the prediction in the filter model. This approach would provide the advantage to estimate the user state recursively also, if an individual positioning method would fail by refining the estimate of the solution using single observations (i.e., GPS pseudoranges, attitude parameters, traveled distance, velocity or acceleration and height difference) together with the observations of other sensors (e.g. in the case of availability range measurements to pseudolits[3], transponders, beacons or base transmitter stations of wireless phone networks). Such an extended Kalman filter approach has been firstly introduced by Welch and Bishop (1997) for an individual positioning method (i.e., an optoelectronic 3-D tracking system) and can be further adapted and modified for our application.

The proposed multi-sensor fusion model will be developed in a way that it is open for the integration of future developed sensors. It has to be implemented in a software package and will be analyzed and tested in detail using simulations and real observations from the senor tests. The model is capable to provide continuous information about the user’s position required for the route modelling and updating.

3 PEDESTRIAN ROUTE MODELLING

3.1 Problem and State of the Art of Route Modelling

Existing navigation services are based on technical feasibility instead on user´s needs. They are difficult to use, do not meet the pedestrian’s expectations, and can fail supporting human navigation (Chewar and McCrickard 2002, Geldof and Dale 2002). Mostly they optimize single search criteria or even use arbitrarily predefined routes.

An user-centered design approach will exploit the literature on pedestrian wayfinding behaviour and human route communication from disciplines like cognitive science (Freundschuh et al. 1990; Couclelis 1996), psychology (Lovelace et al. 1999), and linguistics (Herrmann and Schweizer 1998). For instance, Werner et al. summarize research for navigation strategies based on route graphs (2000). Denis et al. report on human subject testing for route communication (1999). Similar is done by Fontaine and Denis for complex built environments, especially in the vertical dimension (1999). People use landmarks in mental representations of space (Siegel and White 1975) and in the communication of route directions (Werner et al. 2000, Maaß and Schmauks 1998, Lovelace et al. 1999). Studies show that landmarks are selected for route directions preferably at decision points (Habel 1988, Michon and Denis 2001).

Davies et al. report from experiences with a catalog of route selection criteria in a tour guide (2001). A pedestrian is interested primarily in the shortest route (Golledge 1995). If alternative routes exist that are not too much longer, but show other qualities (e.g., safer, easier, or more interesting), groups of pedestrians prefer to be guided the other routes. The relevant selection criteria of pedestrians need to be identified (Golledge et al. 1998), and their combination in optimal route algorithms needs to be solved. Multi-criteria optimization, as investigated in Operations Research (Martins 1984; Ehrgott 2000), will be investigated for this problem.

There is a lack of a formal model of the diverse results of this literature. Such a formal model would provide a task ontology (Guarino 1998; Smith 1999) of pedestrians (Timpf 2001), or, in this context, of pedestrians navigating in unfamiliar urban environment to a desired destination. The restriction to specific tasks reduces the complexity of modelling the real world and possible users' intentions in this world. A formal ontology (Gruber 1993; Guarino 1995), represented in a functional language, can be checked for consistency and completeness, and can be used to simulate test cases for cognitive relevance and plausibility (Frank 1997; Raubal 2001).

Data provided by data warehouses were not collected for support of pedestrian navigation. It is structured for the physical large-scale space but not for the every-day space (Freundschuh and Egenhofer 1997; Golledge et al. 1998) or city-size spaces (Downs and Stea 1982). If the categorization of the real world into objects is task dependent (Frank 1997; Fonseca et al. 2000), and changes with the task, e.g., from a pedestrian’s perception to the perception of a user of public transport (Timpf 2001), then mappings are needed between objects of different ontologies. Moreover, the different tasks of navigation – planning, instructing, moving – require

[3] Pseudolits (short for “pseudo-satellites”) are ground-based transmitters at known location which transmit GPS signals.

different models of space (Timpf et al. 1992; Kuipers 2001). The resulting model will be useful to improve (pedestrian) navigation services. Moreover, with a formal approach based on ontology research we pioneer a new approach to modelling services and small GIS in general.

3.2 Route Modelling Ontology

The overall goal of the ontology is a model of pedestrian route modelling, based on the informal and unstructured findings in the research literature on human wayfinding: how do people select and represent routes? The model shall simulate the reported behaviour. The approach is formal ontology design. A formal ontology will identify and define formally the criteria, the actions, and the reference objects used by pedestrians in their reasoning for routes.

The research hypothesis of this work package is based on the idea that pedestrian route selection behaviour and route representation can be simulated successfully. We call a simulation successful if the 'behavior' of the specified model is acceptable for most users, and can easily be realized. The formal ontology, written in a formal language, can be executed and thus, tested for metric and cognitive plausibility. Plausibility of generated routes will be cross-checked with test persons in our use case scenario.

The ontology of pedestrian route selection will identify and define criteria to combine a route. We will develop qualitative and quantitative measures for the criteria that flow into multi-criteria optimization. Partly this work can profit from experience of modelling the generation of hiking trips (Cziferszky 2002, Winter 2002a). Another part of the ontology is the identification and definition of actions in pedestrian movements. This part will be developed by investigating the verbs in human route descriptions. Actions are related to functions and lead us to an algebraic specification of route directions (Frank 1999, Frank 2001). The third part of the ontology consists of the identification and definition of features pedestrians refer to in their mental representation or communication of routes. Here we will profit from our ongoing preparatory work on finding salient features in the urban environment (Raubal and Winter 2002, Nothegger 2002).

We expect that criteria, actions, and reference features will differ for outdoor and indoor navigation. Nevertheless, the commonalities of indoor and outdoor route selection and representation will motivate a hierarchic construction of the ontology. The more abstract level, derived from the common parts, is guiding towards a general ontology of navigation.

4 MULTIMEDIA CARTOGRAPHY ROUTE PRESENTATION

4.1 Problem and State of the Art of Multimedia Cartography Route Presentation

Guiding instructions for pedestrian navigation consist of spatially related information (Downs & Stea 1982). The main elements of guiding instructions for supporting pedestrian navigation are usually resulting from a general routing model (cp.1.2), where routing functions and, optionally, guiding functions along predefined routes can be executed. The main elements derivable from such routing models include starting point, target point, decision points, distances and route graphs (cp. FTW Project C1, 2001). In order to communicate the resulting elements they have to be combined and translated into "communicative guiding instructions". Such a translation has to be seen in the context of the problem of matching a guiding instruction with the reality by the guided person, which is dependent on various influencing parameters, including:

- the user´s task/situation;
- the skills of the guided person;
- the "quality" of the instruction in terms of semantic, geometrical, temporarily correctness or usability;
- the "potential" of the communication mode to transmit the information needed by the client; and
- the technical restrictions of output devices.

So far, such "translations" for the usage on wireless mobile devices are rarely based on user-centered approaches but on technical possibilities of existing mobile clients, using textual modes (Webraska 2001, Mogid 2000) or cartographical modes (EML 2001, WiGeoGIS 2001, Benefon 2001) only. The "validity" of the used modes (especially maps) and knowledge about different enhancements by using additional modes (e.g. images, VR-scenes, audio) or combined sets is aimed at in different projects, e.g. Lehto (2001), Hardy et. al. (2001), Wang et.al. (2001), Reichenbacher (2001), Sorrows & Hirtle (1999), Maaß (1996), Stocky (2002) and Davies et.al. (2001).

The FTW Project C1 - UMTS Application Development (FTW 2000, 2001; Brunner-Friedrich et. al. 2001, Uhlirz 2001), where the Department of Cartography of the Vienna University of Technology takes part in a research group (Forschungszentrum Telekommunikation Wien), has produced first results in this context. As a joined issue of the FTW-project, the development of a prototype of a location-based service for an UMTS environment is in progress. The application "LOL@", a guided tour through Vienna's 1st district, is meant as a service for foreign tourists. The user is guided along a pre-defined route or due to individual input to some of the most interesting places in Vienna's city center, where he can get multimedia (audio and visual) information about the tourist attractions via the Internet portal of the service. The application requires a wireless handheld as input/output device. In order to be able to develop a location based service in an UMTS environment, the project has to deal with four main parts: specifications of technical prerequisites as well as conceptual and method development for localization, positioning and routing, application development and application implementation (FTW 2000). The result (cp. Gartner & Uhlirz 2001, Pammer 2001 or http://www.ftw.at/projektC1_de.html) is based on the objective to develop a running prototype. The objectives defined in the NAVIO project have to be seen as closely adding on / taking advantage of the results of the project "Lol@". This is seen in the context of applying multimedia cartography methodology on the transmission of guiding instructions, which is based on the theory, e.g described in Cartwright et.al. (1999), Buziek (1997) or MacEachren (1995), that Multimedia cartography offers various methods and forms of communicating spatially related information with different potential of information transmission and user interactivity (Gartner 2000c).

4.2 Multimedia Cartography for Route Presentation

Telecommunication technologies developments (like GPRS, UMTS) are conceived to offer a wide range of new multimedia services to mobile users. The cartographic part of the NAVIO project aims at demonstrating the feasibility and efficiency of presenting space-related guiding instructions, derived from integrated positioning methods and pedestrian route models, to support pedestrians navigation by various methods of multimedia cartography. The research hypothesis to be investigated is: a multi-purpose defined selection of multimedia cartography presentations supports the wayfinding and navigation of pedestrians via a guidance system.

Within this hypothesis the evaluation of multimedia supported cartographic communication processes within the context of pedestrian navigation is guided by the idea, that the applying of multimedia on spatial communication processes is an improvement in terms of enabling individualization of interfaces and content presentations (Neuman et.al. 1999, Reichenbacher 2001, Bobrich & Otto 2002) and therefore increases the efficiency of information transmission.

In the context of pedestrian navigation the appropriate presentation form is dependent on the particular user situations and the specification of the user characteristics. It is assumed, that the appropriate form of communicating spatial guiding instructions will include primarily graphical coding and abstracting (maps, other forms), but also other kind of information transmission methods. An aim of the project is the investigation on a criteria catalogue of selecting the appropriate combinations of multimedia cartography presentations forms for particular user situations in the context of pedestrian navigation. A special focus is necessary on the role of active and/or passive landmarks and their derivation possibilities. A further aim is to investigate a suitable concept of deriving a metrical and semantic correct and feasible guiding instruction into different forms of multimedia cartography presentations.

In detail the objectives consist of:

- Identification of appropriate multimedia cartography presentation forms and various combinations
- Investigation of the range of applicability of presentations and/or presentations sets in the context of pedestrian navigation by defining characteristics and context/relation to guiding
- Analysis of range and methods of deriving and/or adapting guidance instructions into various communication forms including the role of determining input (user specifications) and output (device specifications) criterias
- Investigation of possible enhancements to the process of pedestrian guiding by embedding active and/or passive landmarks
- Testing of suitability

5 SUMMARY

The described project is aiming to analyze major aspects being important when concepting a pedestrian navigation service: integrated positioning, multi-criteria route planning, and multimedia route communication. As a result, a specific pedestrian navigation service as use case will derive the requirements on positioning, route planning, and communication. A prototype of the service will guide visitors to institutes and persons at the Technical University Vienna. This prototype will allow evaluating and demonstrating the usability of the service, and thus, prove the projects attempts. However, the focus of the NAVIO project is on developing the methodology such that the prove of the hypotheses, not on product development, is possible. Therefore, we will contribute to the integration of location sensors and seamless transition of positioning between indoor and outdoor areas; the ontological modelling of navigation tasks, deriving well founded criteria and optimization strategies in route selection; and models for context-dependent communication modes of route information; and, in general, to improvements in (pedestrian) navigation services.

6 REFERENCES

Balbach O., 2000: UMTS – Competing Navigation System and Supplemental Communication System to GNSS. in: Papers presented at ION GPS Meeting 2000, Salt Lake City, Utah, U.S.A., September 19-22, 2000.

Benefon, 2001: http://www.benefon.com, Website accessed 2001.

Bobrich, J. & S. Otto, 2002: Augmented Maps. In: Symp. on Geospatial Theory, Processing, Applications. Ottawa, 2002.

Brunner-Friedrich, B. & R. Kopetzky, M. Lechthaler, A. Pammer, 2001: Visualisierungskonzepte für die Entwicklung kartenbasierter Routing-Applikationen im UMTS-Bereich. In: Strobl, J. & T.Blaschke, G.Grieseneber (Hrsg.): Angewandte geographische Informationsverarbeitung XIII, Beiträge zum AGIT-Symposium 2001. Wichmann-Verlag.

Buziek, G., 1997: Das Potential moderner Informations- und Kommunikationstechnologien aus Sicht der Kartographie. In: Kartographische Schriften, Band 2. S. 17-26.

Cartwright, W. & M. P. Peterson, G. Gartner (Eds.), 1999: Multimedia Cartography. Berlin, New York, Springer.

Chewar, C.M.; McCrickard, D.S., 2002: Dynamic Route Descriptions: Tradeoffs by Usage Goals and User Characteristics, Proceedings of the International Symposium on Smart Graphics, Hawthorne, NY.

Couclelis, H., 1996: Verbal Directions for Way-Finding: Space, Cognition, and Language. In: Portugali, J. (Ed.), The Construction of Cognitive Maps, Kluwer, Dordrecht, pp. 133-153.

CPS (Cambridge Positioning Services Ltd.), 2001: Cursor™ Mobile Location System. Product Information at http://www.cursor-system.com/, Last access 12.2003.

Czifersky, A., 2002: Routenplanung anspruchsvoller Wanderungen. Diploma Thesis, Institute for Geoinformation, Vienna University of Technology.

Davies, N.; Cheverst, K.; Mitchell, K.; Efrat, A., 2001: Using and Determining Location in a Context Sensitive Tour Guide. IEEE Computer Journal, 34 (8): 35-41.

Denis, M.; Pazzaglia, F.; Cornoldi, C.; Bertolo, L., 1999: Spatial Discourse and Navigation: An Analysis of Route Directions in the City of Venice. Applied Cognitive Psychology, 13: 145-174.

Downs, R.M.; Stea, D., 1982: Kognitive Karten - Die Welt in unseren Köpfen. UTB. Harper & Row, New York, 392 pp.

Drane, Ch., M. Macnaughtan, C. Scott, 1998: Positioning GSM Telephones. IEEE Communications Magazine, April 1998.

Ehrgott, M., 2000: Multicriteria Optimization. Lecture Notes in Economics and Mathematical Systems, 491. Springer, Berlin.

Ellum C., N. El-Sheimy, 2000: The Development of a Backpack Mobile Mapping System. in: Papers presented at ISPRS 2000, July 16-23, Amsterdam, Netherlands, International Archives of Photogrammetry and Remote Sensing, Vol. XXXIII, Part B2, pp. 184-191.

EML, 2001: http://www.eml.villa-bosch.de/english/research/deepmap/deepmap.html, Last access IX.2001.

Fonseca, F.T.; Egenhofer, M.J.; Davis, C.A.; Borges, K.A.V., 2000: Ontologies and Knowledge Sharing in Urban GIS. Computer, Environment and Urban Systems, 24 (3): 232-251.

Fontaine, S.; Denis, M., 1999: The production of route instructions in underground an urban environments. In: Freksa, C.; Mark, D.M. (Eds.), Spatial Information Theory. Lecture Notes in Computer Science, Vol. 1661. Springer-Verlag, Berlin, pp. 83-94.

Frank, A.U., 1997: Spatial Ontology: a Geographical Information Point of View. In: Stock, O. (Ed.), Spatial and Temporal Reasoning, Kluwer Academic Publishers, pp. 135-153.

Frank, A.U., 1999: One step up the abstraction ladder: Combining algebras - From functional pieces to a whole. In: Freksa, C.; Mark, D.M. (Eds.), Spatial Information Theory. Lecture Notes in Computer Science, Vol. 1661. Springer-Verlag, Berlin, pp. 95-107.

Frank, A.U., 2001: Pragmatic Information Content - How to Measure the Information in a Route Description. Technical Report, Institute for Geoinformation, Vienna University of Technology.

Freundschuh, S.M.; Mark, D.M.; Gopal, S.; Gould, M.D.; Couclelis, H., 1990: Verbal Directions for Wayfinding: Implications for Navigation and Geographic Information and Analysis Systems. In: Brassel, K.; Kishimoto, H. (Eds.), 4th International Symposium on Spatial Data Handling. Department of Geography, University of Zurich, Zurich, pp. 478-487.

Freundschuh, S.M.; Egenhofer, M.J., 1997: Human Conceptions of Spaces: Implications for Geographic Information Systems. Transactions in GIS, 2 (4): 361-375.

FTW, 2000: UMTS Service Development. Technischer Annex (unveröffentlicht).

FTW, 2001: http://www.ftw.at/projektC1_de.html, Last access X.2001.

Gartner, G., 2000c: Bedeutung der Interaktivität für die kartographische Informationsvermittlung. Habilschrift, Wien, TU.

Gartner, G. & S.Uhlirz, 2001: Cartographic Concepts for Realizing a Location Based UMTS Service. In: Proc. of the ICA Beijing 2001. S.3229-3238.

Geldof, S.; Dale, R., 2002: Improving route directions on mobile devices, Proceedings of the ISCA Workshop on Multi-Modal Dialogue in Mobile Environments, Kloster Irsee, Germany.

Golledge, R.G., 1995: Path Selection and Route Preference in Human Navigation: A Progress Report. In: Frank, A.U.; Kuhn, W. (Eds.), Spatial Information Theory - A Theoretical Basis for GIS. Lecture Notes in Computer Science, Vol. 988. Springer, Berlin, pp. 207-222.

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

Gruber, T.R., 1993: Toward Principles for the Design of Ontologies Used for Knowledge Sharing, Knowledge Systems Laboratory, Stanford University.

Guarino, N., 1995: Formal Ontology, Conceptual Analysis and Knowledge Representation. International Journal of Human and Computer Studies, 43 (5/6): 625-640.

Guarino, N., 1998: Formal Ontology and Information Systems. In: Guarino, N. (Ed.), 1st International Conference on Formal Ontology in Information Systems. IOS Press, Trento, Italy, pp. 3-15.

Habel, C., 1988: Prozedurale Aspekte der Wegplanung und Wegbeschreibung. In: Schnelle, H.; Rickheit, G. (Eds.), Sprache in Mensch und Computer, Westdeutscher Verlag, Opladen, pp. 107-133.

Hardy, P.G. et.al., 2001: Mobile Mapping on demand. In: Proc. of the ICA Beijing 2001. S.3239-3247.

Herrmann, T.; Schweizer, K., 1998: Sprechen über Raum. Huber, Bern.

Hein G., B. Eissfeller, V. Oehler, J. O. Winkel, 2000: Synergies Between Satellite Navigation and Location Services of Terrestrial Mobile Communication. in: Papers presented at ION GPS Meeting 2000, Salt Lake City, Utah, U.S.A., September 19-22, 2000.

Hightower J., G. Borriello, 2001: Location Systems for Ubiquitous Computing. Computer, Vol. 34, No. 8, IEEE Computer Society Press, August 2001, pp. 57-66.

Klinec D., S. Volz, 2000: NEXUS – Positioning and Communication Environment for Spatially Aware Applications. in: Papers presented at ISPRS 2000, Amsterdam, The Netherlands, Part B2, pp. 324-330, see also: http://www.nexus.uni-stuttgart.de/, Last access 12.2003.

Kuipers, B., 2001: The skeleton in the cognitive map: a computational hypothesis, Third International Symposium on Space Syntax, Atlanta.

Lehto, L. 2001: Multi-purpose Publishing of Geodata in the Web. In: Journal of South China Normal University, Guangzhou, 2001. S.105-111.

Lovelace, K.L.; Hegarty, M.; Montello, D.R., 1999: Elements of Good Route Directions in Familiar and Unfamiliar Environments. In: Freksa, C.; Mark, D.M. (Eds.), Spatial Information Theory. Lecture Notes in Computer Science, Vol. 1661. Springer, Berlin, pp. 65-82.

Maaß, W., 1996: Von visuellen Daten zu inkrementellen Wegbeschreibungen in dreidimensionalen Umgebungen. Dissertation, Saarbrücken.

Maaß, W.; Schmauks, D., 1998: MOSES: Ein Beispiel für die Modellierung räumlicher Leistungen durch ein Wegebeschreibungssystem. Zeitschrift für Semiotik, 20 (1-2): 105-118.

MacEachren, A.M., 1995: How maps work. Guilford Press, New York.

Martins, E.Q.V., 1984: On a multicriteria shortest path problem. European Journal of Operational Research, 16: 236-245.

Michon, P.-E.; Denis, M., 2001: When and Why are Visual Landmarks Used in Giving Directions? In: Montello, D.R. (Ed.), Spatial Information Theory. Lecture Notes in Computer Science, Vol. 2205. Springer, Berlin, pp. 292-305.

Mogid, 2000: http://www.mogid.com/, Last access XII.2000.

Mok E., G. Retscher, Y.-Q. Chen, 2000: Conceptual Design of an Intelligent GPS Vehicle Navigation System Suitable for Hong Kong. HKIS Journal, September.

Neumann, L. & A.Raposo, 1999: An Approach for an adaptive visualization in a mobile environment. In: Steinmetz,R.(Hrsg.): Interactive distributed multimedia systems and telecommunication services. Lecture Notes in Comp. Science, Vol. 1309. Berlin. S.272-281.

Nothegger, C., 2002 (in progress): Automatic Selection of Landmarks for Pedestrian Guidance. Diploma thesis, Institute for Geoinformation, Vienna University of Technology.

Pammer, A., 2001: Entwicklung kartenbasierter Routing-Applikationen im UMTS-Bereich mit GeoMedia WebEnterprise. In: Proc. of 16.Intergraph-GeoForum, Offenbach.

Raubal, M., 2001: Ontology and Epistemology for Agent-Based Wayfinding Simulation. International Journal of Geographical Information Science (7).

Raubal, M.; Winter, S., 2002 (in print): Enriching Wayfinding Instructions with Local Landmarks. In: Egenhofer, M. (Ed.), GIScience. Lecture Notes in Computer Science, Springer, Berlin.

Reichenbacher, T., 2001: The world in your pocket. In: Proc. of the ICA Beijing 2001. S.2514-2521.

Retscher G., E. Mok, 2001: Integration of Mobile Phone Location Services into Intelligent GPS Vehicle Navigation Systems. in: Papers presented at the 3rd Workshop on Mobile Mapping Technology, January 3-5, 2001, Cairo, Egypt.

Retscher, G., 2002: Diskussion der Leistungsmerkmale von Systemen zur Positions-bestimmung mit Mobiltelefonen als Basis für Location Based Services. in: Papers presented at the Symposium on Telekartographie, January 28-29, 2002, TU Wien, Austria, published as Geowissenschaftliche Mitteilungen, No. 58, Institute of Cartography, Vienna University of Technology, Austria, pp. 41-58 (German).

Retscher G.; G. Skolaut, 2003: Untersuchung von Messsensoren zum Einsatz in Navigationssystemen für Fußgänger. Zeitschrift für Geodäsie, Geoinformation und Landmanagement ZfV, No. 2, pp. 118-129 (German).

Retscher G., E. Mok, 2003: Sensor Fusion and Integration using an Adapted Kalman Filter Approach for Modern Navigation Systems. Paper submitted to Survey Review.

Siegel, A.W.; White, S.H., 1975: The development of spatial representations of large-scale environments. In: Reese, H.W. (Ed.), Advances in child development and behaviour, 10. Academic Press, New York, pp. 9-55.

Siegele E., 2001: Integration von Mobilkommunikationstechnologien zur Positionsbestimmung in Autonavigationssystemen. Diploma thesis, Vienna University of Technology (German).

Skolaut, G., 2002: Untersuchung von Messsensoren zum Einsatz in Navigationssystemen für Fußgänger. Diploma thesis, Vienna University of Technology (German).

Smith, B., 1999: An Introduction to Ontology. In: Peuquet, D.; Smith, B.; Brogaard, B. (Eds.), The Ontology of Fields. Report of a Specialist Meeting held under the auspices of the Varenius Project, NCGIA, Bar Harbour, Maine.

Sorrows, M.E.; Hirtle, S.C., 1999: The Nature of Landmarks for Real and Electronic Spaces. In: Freksa, C.; Mark, D.M. (Eds.), Spatial Information Theory. Lecture Notes in Computer Science, Vol. 1661. Springer, Berlin, pp. 37-50.

Stocky, T.: Conveying routes. Dipl. Thesis, MIT, Boston, 2002.

Sypniewski J., 2000: The DSP Algorithm for Locally Deployable RF Tracking System. in: Papers presented at International Conference on Signal Processing with Applications, Orlando, October 2000, http://www.syptech.com/publications/publications.html, Last access 12.2003.

Timpf, S., 2001: Ontologies of wayfinding: a traveler's perspective. ST1/01, Department of Geography, University of Zurich.

Timpf, S.; Volta, G.S.; Pollock, D.W.; Frank, A.U.; Egenhofer, M.J., 1992: A Conceptual Model of Wayfinding Using Multiple Levels of Abstraction. In: Frank, A.U.; Campari, I.; Formentini, U. (Eds.), Theories and Methods of Spatio-Temporal Reasoning in Geographic Space. Lecture Notes in Computer Science, Vol. 639. Springer, Berlin, pp. 348-367.

Uhlirz, S., 2001: Cartographic Concepts for UMTS-Location Based Services. In: Proc. of Symposium of Mobile Mapping Technology, Cairo (CD-ROM).

Wang, M. et.al., 2001: Research on Speech Recognition technology applied for Intelligent Mobile Navigation System. In: Proc. of the ICA Beijing 2001. S.3248-3252

Webraska, 2001: Webraska Wireless Navigation Worldwide. http://www.webraska.com. Last access: 8.8.2001.

Welch, G; G. Bishop, 1997: SCAAT: Incremental Tracking with Incomplete Information. in: Proc. of ACM SIGGRAPH 1997; see also http://www.cs.unc.edu/~welch/media/pdf/scaat.pdf, Last access 12.2003.

Werb J., C. Lanz, 2000: Designing a positioning system for finding things and people indoors. http://www.rftechnologies.com/pinpoint/index.htm, Last access 12.2003.

Werner, S.; Krieg-Brückner, B.; Herrmann, T., 2000: Modelling Navigational Knowledge by Route Graphs. In: Freksa, C. et al. (Eds.), Spatial Cognition II. Lecture Notes in Artificial Intelligence, Vol. 1849. Springer, Berlin, pp. 295-316.

WIGeoGIS, 2001: http://www.wigeogis.at, Last access 9.2001.

Winter, S., 2002a: Route Specifications with a Linear Dual Graph. In: Richardson, D.; van Oosterom, P. (Eds.), Advances in Spatial Data Handling, Springer, Berlin, pp. 329-338.