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MOBILE PEDESTRIAN NAVIGATION SYSTEMS *WAYFINDING BASED ON LOCALISATION TECHNOLOGIES*

INTRODUCTION

Increasing traffic volumes have led to the development of traffic telematics services with the objective of improving transport safety and avoiding capacity overloads. A central component of telematics services is navigation systems based on localisation technologies. For example, the Global Positioning System (GPS) is used to determine the location of a car and to assign its position to road-related datasets. The Geographic Data Files (GDF), a European standard that is used to describe and transfer road networks and road-related data, serves as a basic dataset for car navigation technologies. It provides information on distances, directions, street names and specific "points of interest" (POI).

While navigation systems have been mainly developed for vehicles, technological progress has led to the construction of small and cheap components, allowing the design of mobile devices for pedestrian navigation services. These make it possible to provide navigational aid to users at any unfamiliar place. Especially in surroundings of public buildings such as airports or train stations, people subject to time pressure often find it difficult to find their way without delay. Pedestrians would hence benefit from a system offering navigational information via mobile devices. An overview of existing pedestrian navigation systems and some of their advantages and disadvantages can be found in Retscher (2004) and Miyazaki and T. Kamiya (2006).

Existing concepts aiming to provide car drivers with wayfinding instructions are not adoptable for the navigational needs of pedestrians for several reasons. Firstly, as pedestrians are not bound to the road network, they have a greater degree of freedom of movement compared to car drivers (Corona and Winter, 2001). Secondly, GPS localisation accuracy of 5-30 meters is often not sufficient for pedestrians, and locating GPS devices in buildings would be virtually impossible (cf. chapter 3). Hence, the accurate localisation of walking individuals demands additional technologies, especially if a person must be located on the correct floor of a multi-storey building (Gartner et al., 2004). Thirdly, car navigation services usually provide geometric information such as directions and metric distances, whereas human wayfinding strategies naturally rather include landmark information. Salient objects which are easily recognised and remembered should therefore be included in wayfinding instructions for pedestrians (Millonig and Schechtner, 2007).

The first part of this paper gives a survey of the state of the art of research on human spatio-temporal behaviour in connection with the development of pedestrian navigation systems. The second part of the paper deals with the problem of pedestrian route choice behaviour. It is in particular concerned with localisation technologies and their adaptation to location-based information systems. The third part of the paper outlines three projects performed at *arsenal research* and the Vienna University of Technology in these areas. Firstly, it describes a research project on the requirements with regard to the development of ubiquitous cartography for pedestrians in indoor and outdoor environments. Secondly, it describes a self-learning travel guide for city tourists based on mobile phones and GPS. Lastly, it describes an audio-guide system which provides landmark-based navigation instruction.

RESEARCH ON HUMAN SPATIO-TEMPORAL BEHAVIOUR

Mobile guiding systems provide information for travellers, both during and after their actual trip. The systems inform them of possible paths and ways to their designated destination with the help of small, handy devices like mobile phones or PDAs (Personal Digital Assistant). Such services give users the possibility of changing their location whenever they wish, while providing them with information and interesting facts about their current environment.

Pedestrian Route Choice Behaviour

Common concepts used in car navigation systems have proved to be inappropriate for the development of mobile navigation systems for pedestrians, especially as the complexity of human spatio-temporal behaviour makes it necessary to provide other route qualities than shortness. Several findings in the study of human route decision behaviour indicate that there are significant differences in the way in which pedestrians choose a specific path to a desired destination, e.g. the "most attractive", the "most convenient", the "safest" path, or the path with the "fewest turns" (the simplest path) (Blivice, 1974; Thomas, 2003; Golledge, 1995). Although it is often assumed that people will generally choose the optimal path to a specific destination, it is conceded that this may merely be true in standard situations. Helbing (1991) states that that non-optimal behaviour, and therefore differences in spatio-temporal behaviour, may also occur either due to an individual not yet having learned the optimal strategy, or in connection with certain emotional or other reasons leading to suboptimal behaviour. Deviations from optimal behaviour (i.e. choosing the fastest path) may also be caused by the fact that an alternative path is more attractive (e.g. less noisy, more friendly environment, less waiting time at traffic lights) (Helbing et al., 2001; Millonig and Schechtner, 2007).

Research on human spatio-temporal behaviour has shown that there are two main categories of behaviour-influencing factors, namely internal factors (personal characteristics of individuals) and external factors (characteristics of the environment). Internal factors refer for example to socio-demographic attributes (gender, age, health, etc.) (Daamen and Hoogendoorn, 2003) as well as culture, lifestyle, level of education, beliefs, and attitudes (Holden, 2000). External factors include characteristics of the trip (familiarity, trip length), properties of the infrastructure (type, attractiveness, shelter), and environmental characteristics (ambient, weather conditions) (Daamen and Hoogendoorn, 2003). External factors can also be classified according to different dimensions of route qualities: physical (distance, acclivity), emotional (attractiveness, safety), and cognitive qualities (complexity, landmarks) (see **illustration 5.1**).

All these results support the assumption that the choice of a specific route and actual walking behaviour depend on a variety of different influence factors. Hence, the decision to take a particular route is strongly influenced by an individual's knowledge of various interacting kinds of route qualities as well as his or her personal preferences and habits.

Application of Localisation Technologies for the Development of Mobile Pedestrian Navigation Services

The possibilities of improving navigation services for pedestrians by the application of localisation technologies are twofold. On the one hand localisation technologies offer the possibility of studying human spatio-temporal behaviour in order to obtain comprehensive insights into human wayfinding strategies and route decision processes. On the other hand ubiquitously available location-based information can serve a multitude of purposes for different

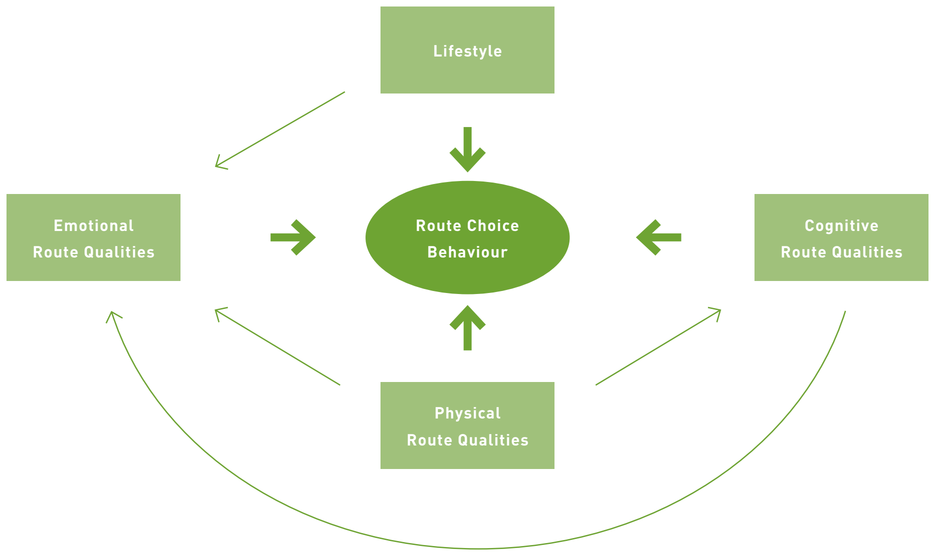


Illustration 5.1 Effects on route choice behaviour.

kinds of users. Route instructions and information concerning useful facilities in the vicinity can be tailored to individual needs and preferences.

As findings reveal that there is a great diversity of different navigation strategies and individual preferences concerning route qualities (see above), conventional navigation systems fail to respond to personal preferences and requirements with regard to spatial information. The development of future pedestrian navigation services and Location-Based Services will have to take individual preferences and wayfinding styles into consideration in order to provide efficient, personalised services to fulfil an individual's requirements. The investigation of human walking behaviour therefore calls for a combination of different empirical methods with a view to obtaining comprehensive information on pedestrian wayfinding and decision processes. While previous empirical studies on human walking behaviour usually had to rely on path following, inquiry techniques, and scene analysis, new technologies such as localisation systems and sensor networks offer innovative possibilities of collecting localisation data. The most commonly used methods are satellite-based technologies (Global Positioning System, GPS, cf. chapters 6 and 7), land-based technologies (cell identification, cf. chapter 8), sensor networks (e.g. RFID), or hybrid solutions (Bandini et al., 2007; Shoval and Issacson, 2007, cf. chapters 2, 9 and 10). The main advantages of using localisation technologies lie in the possibility of collecting data from a comparatively extensive environment. Furthermore, the employment of localisation systems does not require a great deal of effort on the part of the subjects under observation. Nevertheless, major limitations in the use of localisation technologies and sensor networks should be mentioned. At the present, localisation systems are still quite cost-intensive, as users have to be equipped with tracking devices. This also leads to the risk of observer effects, since participants are aware of the fact that they are being observed and might therefore change their behaviour. Still, the use of localisation technologies and sensor networks are expected to enhance the quality of human spatio-temporal behaviour research, especially when combined with complementary empirical methods (cf. chapter 10).

Current services offering navigational instructions for pedestrians still usually concentrate on physical route qualities, like shortness or accessibility for handicapped people (i.e. avoidance of stairs, use of elevators). However, the increasing amount of ubiquitously available information now offers the possibility to supply mobile users with efficient and practical location-based information. This enables the enhancement of wayfinding tasks with additional information on useful facilities in the vicinity.

PROJECTS AT VIENNA UNIVERSITY OF TECHNOLOGY AND 'ARSENAL RESEARCH'

This section outlines three projects related to pedestrian wayfinding based on localisation technologies performed at the Vienna University of Technology and *arsenal research*. The first section below describes a joint research effort with regard to requirements for developing ubiquitous cartography for pedestrians in indoor and outdoor environments. The subsequent section describes a self-learning travel guide for city tourists based on mobile phones and GPS. Finally, an audio-guide system providing landmark-based navigation instruction is described.

Ubiquitous Cartography for Pedestrian Navigation

This currently ongoing research project (UCPNavi) assumes that navigation in a ubiquitous environment with a combination of active and passive systems enables customised route guiding and therefore optimises the wayfinding process. Instead of passive systems that are installed on the user's device and frequently position the user as he moves along, new technologies originating in ubiquitous computing could enrich guiding systems by including information captured from an active environment. As recent developments in the field of mobile information and communication technologies have led to an increasing amount of ubiquitously available information, users can be offered a wide range of possibilities to be supplied with location-based information. Therefore, the wayfinding process could be enhanced with additional information and various presentation forms.

In addition to navigation support, it could be beneficial to supply the user with information adapted to the current task. This would mean that the user is perceived by a ubiquitous environment and receives location-based information that is suitable for the respective device or is supplied with helpful notes via a public display or similar presentation tools. Furthermore, these smart stations could substitute or complement traditional indoor positioning methods by sending coordinates of the station instead of locating the user. Based on the concept of Active Landmarks, which actively search for the user and build up a spontaneous "ad-hoc network" via an air-interface, a ubiquitous solution where an information exchange between different objects and devices is accomplished could be investigated for use in navigation.

As opposed to conventional navigation systems which are based on preinstalled software, ubiquitous cartography responds to an individual user at his present location in real-time. Interactivity is facilitated and wayfinding aid is more flexible, providing new opportunities and challenges in the field of cartography and offering new possibilities for research in positioning techniques with alternative sensors.

Due to the above mentioned reasons, the research topics in this project aim at the investigation of efficient positioning methods in a smart environment in combination with conventional positioning techniques, as well as the development of pedestrian typologies by observing the pedestrians' mobility behaviour at certain highly frequented environments using different tracking methods, and the determination of suitable route presentation forms, which could be provided either by the ubiquitous environment or by a passive system on the client of the user. **Illustration 5.2** depicts the project design. The empirical techniques used in the investigation of mobility behaviour include unobtrusive observations, tracking (using localisation technologies such as GPS and Bluetooth), and standardised interviews. The combination of multiple empirical techniques ("across-method triangulation") will allow a detailed investigation of the complexity of human route decision processes, individual habits and preferences, and discriminative features for different classes of spatio-temporal behaviour (Millonig and Gartner, 2007).

Preliminary experimental results concerning the investigation of human spatio-temporal behaviour prove that pedestrians show specific walking patterns which can be categorised. During a heuristic phase of unobtrusive observations in an outdoor and an indoor environment (a major shopping street and a shopping centre) a data set of over 100 trajectories of people observed by path-following methods has been collected.

First analyses using agglomerative hierarchical clustering algorithms provide three homogenous clusters for the indoor data. The outdoor dataset analysis produces eight clusters, with 86% of observations belonging to four classes, and only several observations related to the other four classes. This difference in behaviour could be the result of differing context influences; as the outside investigation area concerns an urban street, observed individuals may have other objectives than shopping. Persons who enter a shopping centre seldom pursue other goals than shopping, and their behaviour appears to be able to be categorised into several classes.

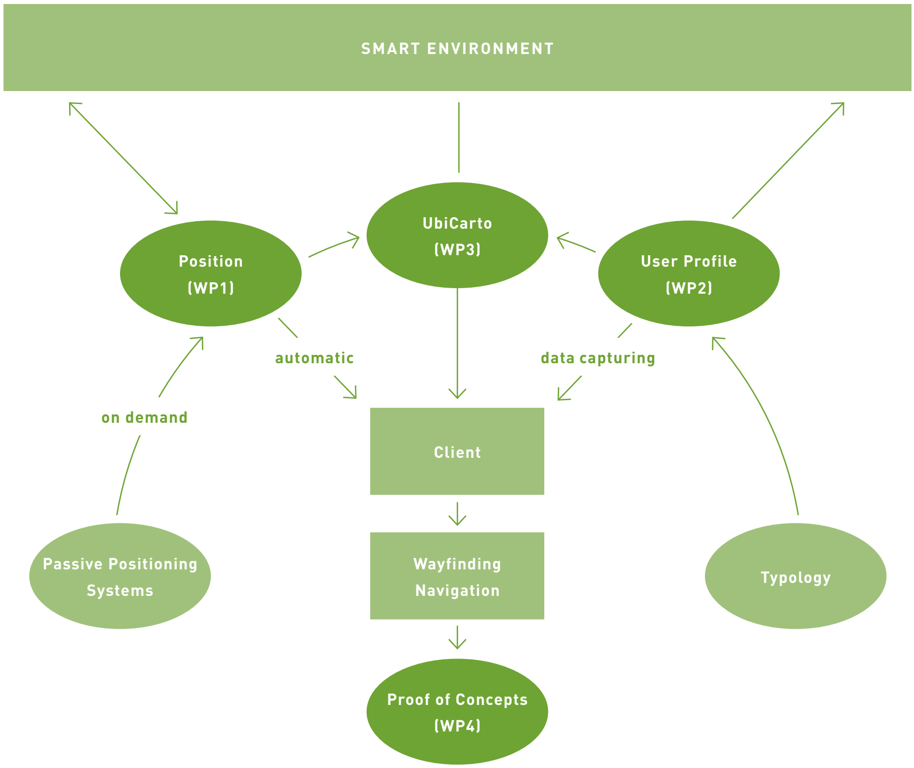
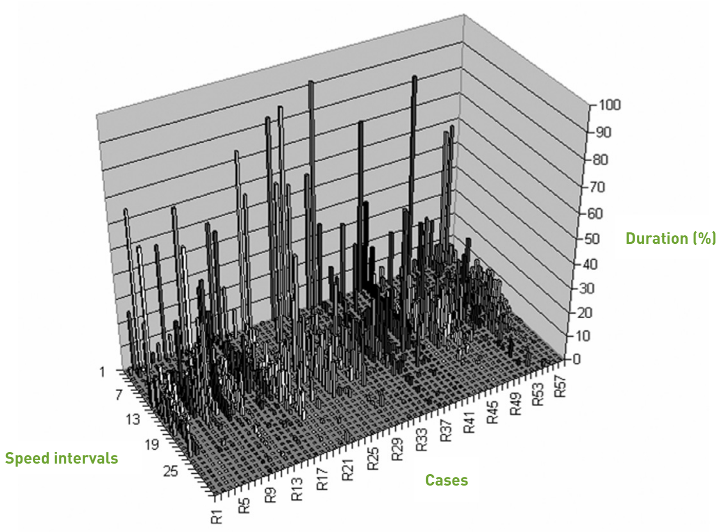


Illustration 5.2
The project work packages and their interaction.

55.6% of the observed individuals in the shopping centre can be related to a cluster showing a high percentage of time spent in front of or inside a shop (77.8%). Individuals falling in this category also walk at a lower speed than persons related to the other classes (mainly within a speed interval of between 1 and 1.1 m/s). Outside observations show a wider range of classes of behaviour. Although many individuals still spend some time inside a shop or standing in front of it, more time is spent walking around at a variety of different speed levels than in the indoor observation field. **Illustration 5.3** shows the main differences in the observable walking behaviour of pedestrians demonstrated by speed histograms of outdoor and indoor observations.

The results lead to the definition of an initial typology of pedestrian spatio-temporal behaviour in a specific consistent situation. The aim of the deductive phase of the study currently starting is to verify the provisional types defined in the first survey. The actual walking and route choice behaviour is observed using technological localisation methods (outdoor: GPS; indoor: Bluetooth) and will subsequently be compared with the formerly identified hypothetical typology. The analysis of the tracking results focuses on routes, velocities and breaks. After the tracking process, detailed standardised interviews are conducted with the participants who have been previously tracked to obtain information on their actual intentions, attitudes, lifestyle and socio-structural attributes. The obtained data is related to defined specific mobility types, allowing their validation with regard to internal homogeneity and external heterogeneity.



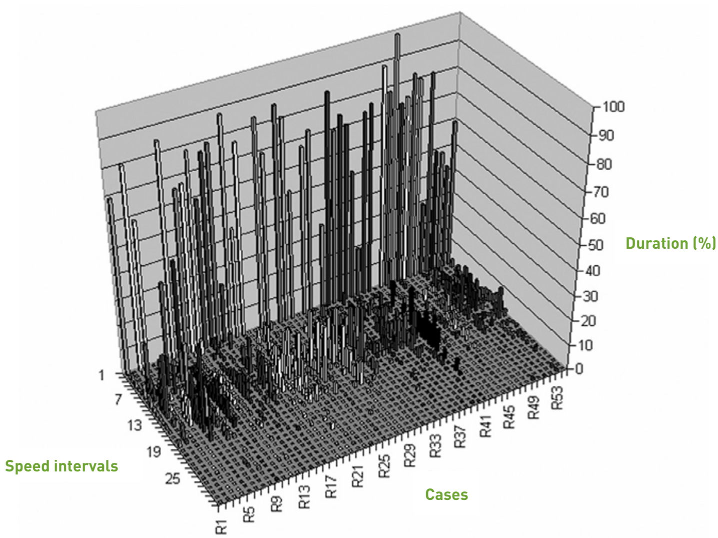


Illustration 5.3a and 5.3b Histograms of all outdoor (above) and indoor (below) observations.

Based on the results of both empirical phases a model of pedestrian mobility styles is developed, including multiple aspects of each detected type (basic parameters of velocities, stops, and turns; behavioural characteristics; preferences; socio-demographic and lifestyle attributes). Discriminative features are determined and extracted, which can be used to provide customised information to specific types of pedestrians using an implemented wayfinding system.

Mobile City Explorer

The Mobile City Explorer (MCE) is a prototype for a location-aware travel assistant based on a combination of widespread conventional mobile phones with built-in cameras and GPS/GALILEO receivers (Wiesenhofer et al., 2006). Its aim was to provide city tourists with suggestions for a sightseeing tour based on their interest profiles which are adapted following their actual movement in the city on a client-server basis. Additionally, MCE provides tourists the possibility of capturing digital images, the contents of which are analysed by server-based object classification algorithms. Moreover, the route, the captured images, videos, text comments and acoustic impressions can be saved in an automated travel diary, which is accessible via WWW.

This concept allows the exploration of a city according to the individual interest profile, adapting real time according to the movement of the user. By combining the data of all tourists, it also allows the investigation of the movement of a specific group in the city, its main interests, etc.

The smart guide (mobile camera phone with GPS receiver and software for "High Level Routing") determines an initial sequence of Points of Interest (POIs). The suggested sequence of POIs takes into account user interests, current position and time constraints. This allows an individual trip to be provided best matching a tourist's interests. The service predicts interests and preferences for each individual user; deviations from the suggested route will result in updates in the High Level Routing model and lead to the reselection of POIs and tour recalculation.

Major research questions concern the accuracy of matching the position supplied by the GPS device with the actual city map (map-matching, and the problem of urban canyons (Ray, 2005, cf. chapter 12), the definition of deviation parameters (time and space) triggering an update of the initial route, and the visual information displayed on the camera display.

Results from the pilot tests show that initially suggested routes were abandoned quite frequently and that interest profiles given at the beginning of the tour were altered considerably. **Illustration 5.5** provides an example of five different interest groups defined by a tourist at the

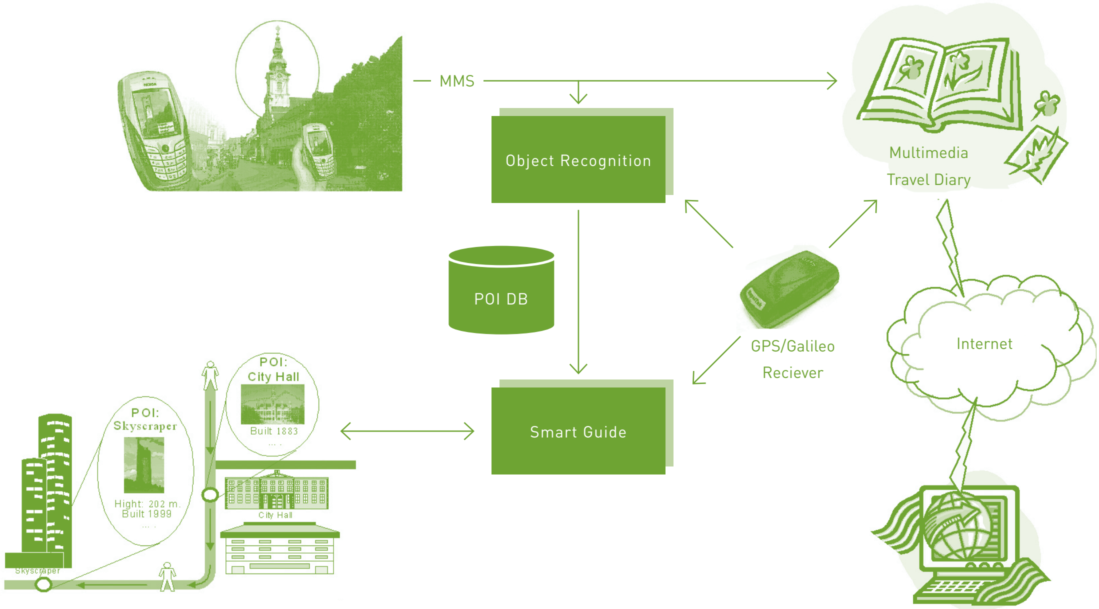


Illustration 5.4
Schematic View
of the MCE
Functionality.

beginning (front of the figure). In the course of the day, the change of route and the time spent at specific places indicates that his interests changed to subjects not listed at all at the beginning, while subjects listed at the beginning seem to be not at all interesting by the end (actual user interest probabilities at the back of the figure). More detailed information on learning interests based on motion behaviour can be found in Schrom-Feiertag and Ray (2007).

Similar results from other test users suggest that the motion behaviour of tourists in a city deviates considerably from suggested routes and that the actual interest profile of a tourist is less specific than the tourist might himself believe.

Aggregated data of the test users resulted in a clear picture of favourite locations for spending time in the test city. **Illustration 5.6** depicts as contour plots several spots where test users tended to have long dwell times, thus indicating sites of major tourist interest.

In order to learn tourist behaviour within a city on a large scale, a large set of real life data is required. Moreover, data interpretation has to take into account the current shortcomings of GPS technology in urban areas; registration times into the GPS service are long and position information is sometimes lost and/or may not be accurate enough for the pedestrian context.

Landmark and Speech-based Guiding System

The landmark and speech-based guiding system is based on a mobile phone-based audio system guiding users between landmarks. The landmarks have to be easily detectable and uniquely named and it must be certain that the object can be seen and clearly described (Sefelin et al., 2005).

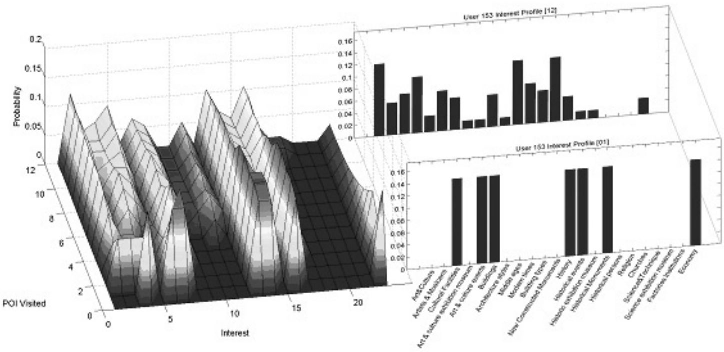


Illustration 5.5
Change of interest profile.

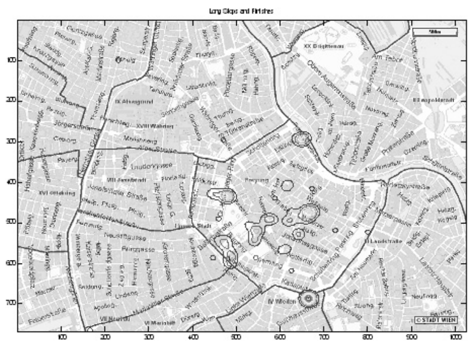


Illustration 5.6
Long time stops according to test data.

Illustration 5.7 sketches the general sequence of such mobile audio guidance. The person seeking help calls a specific number via his mobile phone and informs the system of the desired target. The system aims to determine a user's current position through a question-and-answer process and guides him to the desired destination using significant landmarks. The system

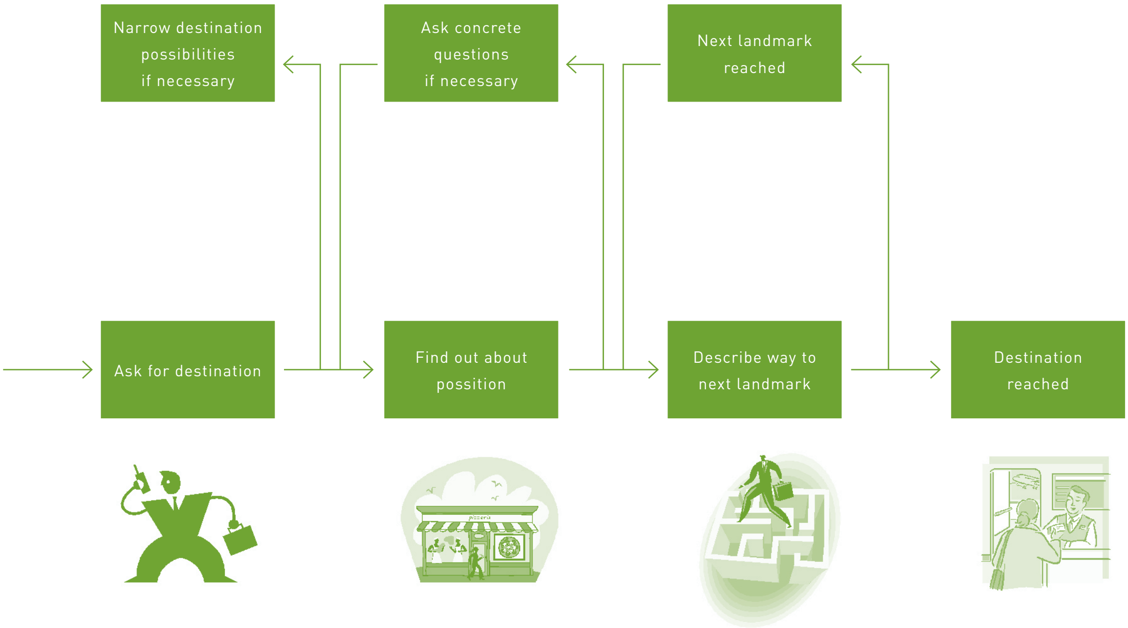


Illustration 5.7 Schematic Overview of a Guiding Dialogue.

therefore combines speech recognition, a text-to-speech module and efficient and clear routing via pre-defined paths between all landmarks.

The success of the guiding system depends on two key factors: 1) the identification of clear landmarks and the routes between them, and 2) the quality of the automatic speech recognition system. Landmark-based orientation is a natural wayfinding method for pedestrians (Millonig and Schechtner, 2007).

Two methods of identifying landmarks and routes were employed in the train station that we used as a test area, with cameras recording the daily movements of the people. By employing computer vision technologies, individual tracks were automatically collected. Based on the tracking data major routes and areas where many people stopped were identified. More detailed descriptions can be found in Bauer et al. (2006) and Brändle et al. (2006).

After having analysed major routes and main stopping areas, a study to identify the landmarks visible along these routes or from the stopping point led to the definition of reliable landmarks (e.g. particular shops, staircases, clocks).

Test users reported that the method of orienting themselves via landmarks was an efficient and successful method of wayfinding. Oral descriptions of the routes and landmarks also proved to be a mode people were used to. It has to be added, however, that one of the major challenges of automatic speech recognition is the presence of noise. This is moreover one of the key challenges in making speech recognition a reality for everyday and practical environments.

CONCLUSION

Illustration 5.8 Examples of landmarks: situated either along (e.g. statues, also signposts) or at a distance from the route (wall clock), or a unique part of the route itself (escalator).

Research on pedestrian spatial orientation behaviour and the subsequent development of navigation systems for pedestrians have to deal with the problem of obtaining sufficient reliable data to analyse real pedestrian movement and feeding these results back into efficient navigation systems. Without the widespread use of navigation systems, not enough data can be collected, and without enough data the navigation systems only offer poor services to the user, therefore preventing widespread use.

Localisation technologies currently offer the possibility of investigating human spatio-temporal behaviour and route decision processes in more detail, in order to develop navigation services which offer personalised route instructions and individually interesting location-based information. The employment of various localisation technologies is expected to increase the quality of human spatio-temporal behaviour research and to improve the possibilities of supporting pedestrian wayfinding by means of mobile navigation services. Localisation technologies and sensor networks are especially essential for the development of navigation systems for indoor environments. This contribution introduces several research projects employing different localisation and tracking methods either for the investigation of human walking behaviour or for the localisation of users in order to provide efficient localisation-based information and navigational instructions. The research projects refer to different kinds of specific target groups (e.g. tourists, passengers at railway stations, or pedestrians navigating through both indoor and outdoor environments) and employ several different localisation and tracking technologies for the assessment and analysis of human walking behaviour. Results indicate that there are multiple influence factors determining human route decision processes. The design of the physical environment (e.g. indoor or outdoor environment) leads to significant differences in wayfinding and route choice behaviour.

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