A Navigation Concept for Visually Impaired Pedestrians in an Urban Environment




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Abstract

An overall concept of navigation is adapted to the special needs of blind and visually impaired pedestrians and is being developed in national R&D-projects. The development aims at prototypes of navigation systems which cover the total spectrum of navigational components. This comprises an appropriate modeling of the navigational environment, fast routing algorithms generating lists of maneuvers, suitable positioning tools based on sensor fusion and Kalman filtering, reliable map matching algorithms for route checking, and, finally, efficient guidance instructions communicated via an adequate man-machine interface.

Kurzfassung

In zwei F&E-Projekten des Instituts für Navigation und Satellitengeodäsie wird ein allumfassendes Konzept eines Navigationssystems entwickelt, welches den speziellen Bedürfnissen blinder und sehbehinderter Fußgänger angepasst wird. Das Vorhaben zielt jeweils auf einen Prototyp ab, welcher das gesamte Spektrum von Navigationskomponenten abdeckt. Dazu gehören eine entsprechende Modellierung des Umfeldes, in dem navigiert wird, schnelle Routingalgorithmen zur Generierung von Manöverlisten, geeignete Positionierungsmethoden basierend auf Sensorfusion und Kalmanfilterung, zuverlässige Map-Matching-Algorithmen zur Routenverfolgung und schließlich eine effiziente Zielführung mittels eines dem Zweck entsprechenden Man-Machine-Interfaces.

1. Introduction

1.1. The projects

The research projects at the Institute of Navigation and Satellite Geodesy (INAS) of the Graz University of Technology dealing with navigation systems for blind people are called PONTES (“positioning and navigation of visually impaired pedestrians in an urban environment“) and ODILIA (“mobility of blind people through user-oriented information and satellite-based navigation“). Both the term PONTES (Latin word for bridges) and the term ODILIA (patron of the blind) underline the benefit of technological development for physically disabled people. Financial support is granted by the Austrian Federal Ministry of Transportation, Innovation, and Technology. The ministry is represented by the Austrian Research Association (FFG) and by its aerospace agency, respectively. The R&D-program in which PONTES and ODILIA are embedded is the Austrian Radionavigation Technology and Integrated Satnav Services and Products Testbed (ARTIST). PONTES has started in May 2005 and ODILIA in September 2006 with a duration of sixteen months per project.

From the very beginning, potential users of a future navigation system for the blind people are involved in the projects. There is a close cooperation between INAS and the Styrian Association of the Blind and Visually Impaired People.

Further cooperations are initiated with Vectronix AG (Heerbrugg) which distributes pedestrian navigation modules and the company AFN (Vienna) which develops user interfaces for the blind and visually impaired.

1.2. The intention

The first essential aspect is to find an application for a pedestrian navigation system with social relevance. The second issue is to develop an overall outdoor-navigation concept, i.e., covering the whole spectrum of navigation from positioning to guidance.

The specific user group requires a tailored system architecture and a user-oriented development. Therefore, blind and visually disabled people are defining their needs and requirements with respect to an appropriate navigation tool and its components, are contributing during the conceptual phase, and are then testing the prototype system.

The underlying issues of the projects mainly are:

- a two-phase development of demonstrator prototypes where the first phase is covered by PONTES and represents the system's main functionality and where the second phase is performed by ODILIA and includes innovative aspects and sophisticated add-ons;
- the use of existing hardware components, especially for positioning and the man-machine interface;
- a proprietary software development for routing, map matching, and guidance;
- a technical feasibility and acceptance study rather than commercially oriented exploitation and dissemination;
- supplementing common aids for the blind people, e.g., the blindman's stick, and medium-term replacing the guide dog or a coach person (visually enabled).

2. The Concept

The system is self-contained, apart from received positioning signals (e.g., from GPS), and is therefore autonomous, i.e., independent of any control center. The system's architecture is similar to the concept of an in-vehicle navigation system but is tailored to the special needs of the visually impaired pedestrian [1]. The components shown in Fig. 1 appear in three (colored) pairs:

- The navigable map describes the geographic space in terms of the path network and the navigational environment and is the primary source for route planning which computes an optimal path from a starting point to a given destination.
- The positioning module has to forward the position of the pedestrian to the map-matching module which transforms the absolute position to a location relative to a close-by object or a decision point.
- Route guidance directly profits from route planning as well as from map matching. The guidance instructions are mainly transmitted acoustically via the man-machine interface at the correct time.

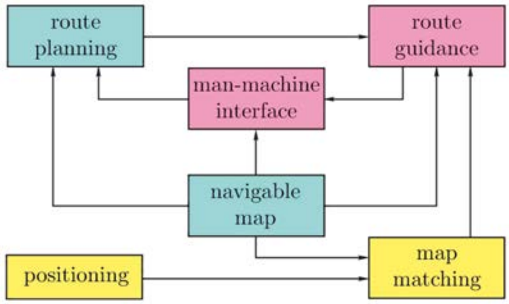

Figure 1: Components of a pedestrian navigation system.

In the following, the components are described in more detail except of the man-machine interface. Although it is of great importance in the case of a blind user and puts big requirements on the information exchange by voice between the navigation device and the person using it, it is not a typical navigation component and is skipped for that reason.

3. The System's Components

3.1. Navigable Map

A navigable map tailored to the needs of a visually impaired person is the digital answer to tactile maps which are normally used by blind people to get acquainted with the surrounding in which they move. In order to become navigable, a digital map must be able to support routing in the sense of route planning, positioning by map-based "artificial" observations (map aiding), map matching as the projection of a position onto the map, and finally guidance on the basis of a maneuver list.

A careful modeling of the urban environment plays a key role for the navigation system's reliability. A visually impaired person must count on the guidance instructions generated by the system, since the person is unable to compensate any misinformation by visual faculty. As a consequence, the navigable map must be geometrically accurate, topologically consistent, and thematically correct, up-to-date, and complete on a topmost level. Furthermore, the map and the corresponding database have to fulfill efficient data storage and modeling rules of national standards or, preferably, those of the Comité Européen de Normalisation (CEN) and the International Organization for Standardization (ISO), respectively.

The modeling of the navigational environment and the generation of the navigable map are achieved by a geographical information system

(GIS) and are based, e.g., on a digital map for an urban area (Fig. 2). The first step is to create an application layer for the special navigation purpose in case of a visually impaired person. This is done by eliminating unnecessary features and attributes (e.g., road markings) and adding those of specific importance (e.g., "acoustic" traffic lights). The second step is to establish a path network for the blind people and the respective database containing all the geometric, topological and thematic information [2].

Figure 2: Extract of the digital city map of Graz.

The data structure of the vector-type path network consists of nodes (e.g., intersection of pavements) and edges (e.g., promenade, zebra crossing) relevant for route planning and of polygon points relevant for guidance. The latter represent obstacles, pre-defined guidance instructions, and points of interest (POIs). Fig. 3 shows an example of a path network (area extracted from Fig. 2) where nodes and edges are colored in orange and polygon points are colored in blue.

Figure 3: Example of a path network for the blind.

3.2. Routing

Planning the optimal route from a start site to a destination site equals finding the shortest path between the two corresponding nodes in the path network. Note that the terms "optimal" and "shortest" represent the safest route in case of the visually impaired pedestrian. In addition, the result of the routing procedure defines a line-based (i.e., one-dimensional) motion. This strongly facilitates subsequent computations, e.g., map matching. In comparison, the trajectory of a sighted pedestrian in general has a degree of freedom which equals two. Mathematically speaking, the node-edge structure of a path network is represented by a valuated graph. A cost function c(e(i,j)) assigns a real valuation number c(i,j) to an edge e(i,j) from node v(i) to node v(j). The cost number c(i,j) is influenced by the geometric length of the edge and by safety aspects along the edge, e.g., occurrence of obstacles or dangerousness of road crossings. The shortest-path algorithm then tries to find the path with the minimal sum of cost numbers along the path. Because of the characteristic behavior of the valuation function it may of course happen that a path from v(i) over v(j) to v(k) is shorter in terms of the cost numbers than the direct path from v(i) to v(k).

One of the basic ideas of shortest-path algorithms is to generate a search tree which branches out radially with the start node as a root and grows iteratively till the destination node is reached. The result provides all shortest paths from the start node to all nodes within the tree (Fig. 4).

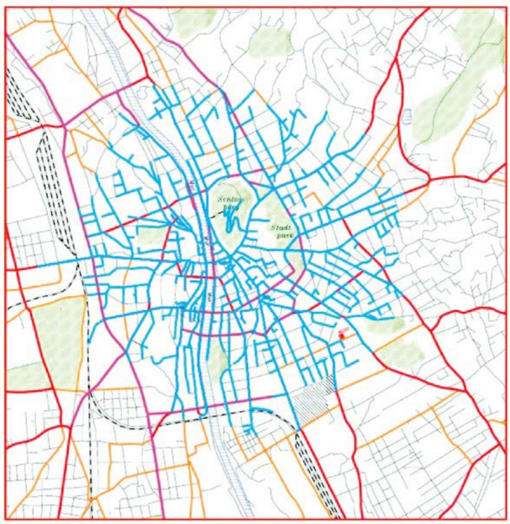

Figure 4: Search tree.

One of the most frequently tree algorithms used is the one by Dijkstra. In any case, the path network has to be efficiently stored by an indexed adjacency list, so that a direct access to all neighbors of a node can be guaranteed. This is needed to keep the algorithm's computation time as low as possible. Another strategy to achieve this is to apply heuristic concepts. Contrary to Dijkstra's algorithm, the A*-algorithm (pronounced as "A star") extends the search tree predominantly towards the destination and much closer to the shortest-path result. A second heuristic approach is the task of spatial reasoning. The cognitive map as the mental representation of the environment and the way how visually impaired human beings reason about space helps to understand whether they use the same criteria as the network algorithms [3, Sect. 14.2].

3.3. Positioning

Compared with conventional pedestrian navigation, the quality requirements on position determination are much higher in the case of blind pedestrians. Accuracy should be at the one-meter level and below. The position must be accurate enough so that objects and locations relevant for guidance instructions are reliably situated within the tactile range of the blindman's stick. Of course, availability must be ensured anytime and anywhere with a top-level integrity.

To achieve the above quality requirements, an integrated concept of position determination is indispensable. On the hardware side this is realized by a multisensor system where the determination of the pedestrian's state vector (position and velocity, and to a certain extent even attitude) has to follow the principles of sensor fusion. Hence, appropriate methods of signal processing, i.e., methods of computing and updating (or filtering) the actual state vector are required. In kinematic mode, optimal filtering is achieved via Kalman filtering based on measurements from the multisensor equipment and on dynamic modeling of the motion.

Typically, the integrated concept for pedestrian navigation is the combination of satellite-based positioning, e.g., GPS using code pseudoranges, and dead reckoning (DR). In the sense of relative positioning, the DR vector is calculated from an oriented direction (course angle) and a range (covered distance). In case of a pedestrian, the range is derived from step detection.

Integrated positioning techniques profit from redundant information. The combination of GPS and DR is a typical example for a complementary redundancy. The sensors are based on different physical principles; and, to some extent, they complement each other: GPS, e.g., is affected by outages due to shadowing effects in urban areas, which can be overcome by DR. In contrast, DR may keep sufficient accuracy only over a short distance traveled.

Although INAS and its cooperative partners have been already involved in the research and development phase for a commercial prototype of pedestrian positioning devices [4], the decision in PONTES and ODILIA was "not to reinvent the wheel" and to use therefore existing pedestrian navigation modules, e.g., the PNM kindly offered by the Swiss Vectronix AG for the duration of the projects. The conceptual design and the technical implementation of the device should ensure that the PNM will fulfill its purpose [5].

The PNM in use has a size of 85 × 135 × 35 mm, is mounted on a belt and should be carried at the back (Fig. 5). The GPS antenna can be fixed on a cap and the RS232 cable for bidirectional data exchange is connected to a PDA or subnotebook. According to the above multisensor concept, the PNM includes a GPS receiver for absolute single point positioning, a magnetometer triad and a gyrocompass for course determination, an accelerometer triad for step detection (derived from frequency analysis mainly in the vertical component), and a barometric altimeter for height determination. The associated firmware calculates the DR position and integrates it with the GPS position using filtering techniques.

Figure 5: PNM, Vectronix AG.

Future improvements of the positioning performance may be achieved for instance by:

- image-based positioning using a head set of two micro-cameras: in principle, the position is derived after feature extraction from the images and object matching in a city model;
- the integration of differential GPS: especially, if the accuracy of the map-matched GPS position is not sufficient (cf. Sect. 3.4);
- applying map aiding: suitable contents (e.g., direction or height information) of the navigable map is used as a kind of pseudoobservation;
- a centralized filter architecture: the sensors are integrated on the measurement level and the data are not preprocessed within the individual sensor.

3.4. Map matching

The process of map matching (MM) "projects" the pedestrian's trajectory onto an edge sequence in the digital map (Fig. 6). The current position is matched to a map point which is directly situated on an edge of the model graph. In other terms, the real position, absolutely defined in a coordinate reference frame, is transformed to a location relative to the nodes of an edge in the graph. This makes sense, since the guidance instructions which have to be communicated according to a current position are unexceptionally stuck to topological relations in the map: e.g., an obstacle warning is announced a few meters prior to the occurrence of the hindrance, certain maneuver instructions (e.g., "turn left") are announced immediately before the direction of the path changes, etc.

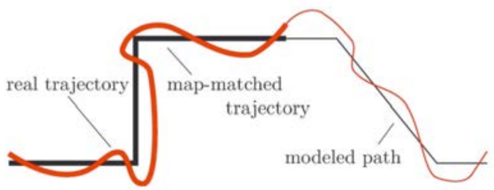

Figure 6: Principle of map matching.

MM directly follows Kalman filtering where the observed trajectory is updated. The resultant filtered trajectory is then blended with the navigable map in the subsequent MM step what finally leads to a map-matched trajectory (Fig. 7). Thus, MM also serves as a kind of filter-based updating. In this respect it must be mentioned that it is mathematically controversial to combine Kalman filtering and MM in a common central filter.

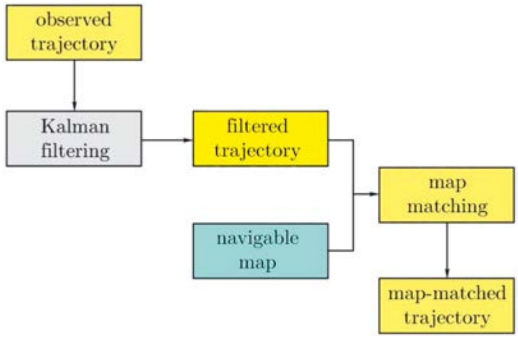

Figure 7: Process of trajectory computation.

MM calculations are complex and time-consuming, since sophisticated MM algorithms perform an edge-to-edge and not a point-to-point matching. Not only the current position is taken into account but also a (partial) "history" of the trajectory. Especially, in the neighborhood of nodes representing a junction with at least three roads, edge-to-edge matching helps to decide which of the branching roads has to be taken when leaving the node [6]. The two elementary edge-based MM strategies use either correlation tests or affine transformations. Both methods measure the similarity between the trajectory and its potential map representatives, and the final trajectory matching corresponds to the nature of a least-squares alignment. MM algorithms must also be able to warn of off-route or even off-road situations. In the first case, the pedestrian is still moving on a path within the network but not on the precomputed one, in the second case, he has totally left the path network [3, Sect. 14.3.1].

3.5. Guidance

As in vehicle navigation, the guidance concept is the one for en route guidance along a line-based trajectory following a precomputed route. As shown in Fig. 8, the main components of this concept are the generation of a maneuver list and the permanent route checking. Including warnings of obstacles and information on POIs, the maneuver list contains all turn-by-turn instructions which strictly rely on the prior map-based route computation. The route checking task is permanently monitoring the pedestrian's map-matched position relative to the points where guidance instructions are to be reported. As the maneuver list tells how to guide, route checking decides when to guide. The appropriate guidance instructions are then communicated acoustically via a head set to the visually impaired pedestrian [3, Sect. 14.3.2].

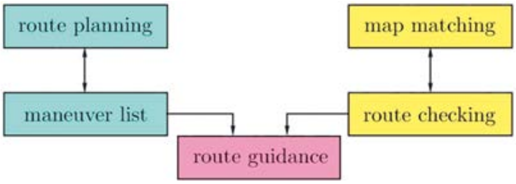

Figure 8: *Concept of guidance.*

The "vision" for the future is that the above guidance concept supplements usual tactile aids like blister paving and acoustic traffic lights (Fig. 9, upper left image). A further important issue is the capability of warnings with respect to permanent and temporary obstacles. In the permanent case, the information should be available in the database even if the hindrance can be detected by the blindman's stick (Fig. 9, lower right image). Warnings of a temporary obstacle, like the scaffold in Fig. 9 (upper right image), can be performed, if the database is updated continuously ("dynamic" database) or if the blind carries a camera head set. The digital data outcome of the camera is analyzed by digital image processing. Within the scope of ODILIA, further developments of the system may consider indoor guidance and the use of public means of transport like busses or trams. A desired system miniaturization including an appropriate design of the device should be enabled according to the principles of wearable computing and should be tailored to guidance purposes. Finally, effective on-trip guidance can be prepared by pre-trip training on a desktop computer under virtual reality conditions.

Figure 9: *Tactile aids and obstacles.*

4. Conclusions

The system concept introduced in PONTES and ODILIA should be understood as a navigation system tailored to the needs of visually impaired pedestrians in an urban environment. As the information distribution plays a dominant role in any location-based service [7], an efficient guidance to guarantee save mobility is aimed at in both projects. In the process, the blind pedestrian's location is gained by integrated positioning followed by map matching onto a highly accurate, digital map.

Nevertheless, some questions remain: Is the above approach the right one? Is the undertaking commercially feasible? Are there alternatives? E.g., especially in ODILIA, data acquisition and modeling of the path network are considered: the modeling of the navigational environment is an annoying and time-consuming task which can be accelerated by semi-automatic procedures. Or, instead of data acquisition done in advance, the potential user, guided by a sighted coach, moves along the path network and records his own data.

Whether data acquisition or one of the other components is considered, future developments will probably cast some light on the shadow.

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