Towards a Geographic Information System Facilitating Navigation of Visually Impaired Users

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Abstract. In this paper, we propose some adaptation to Geographical Information System (GIS) components used in GPS based navigation system. In our design process, we adopted a user-centered design approach in collaboration with final users and Orientation and Mobility (O&M) instructors. A database scheme is presented to integrate the principal classes proposed by users and O&M instructors. In addition, some analytical tools are also implemented and integrated in the GIS. This adapted GIS can improve the guidance process of existing and future EOAs. A first implementation of an adapted guidance process allowing a better representation of the surroundings is provided as an illustration of this adapted GIS. This work is part of the NAVIG system (Navigation Assisted by Artificial VIsion and GNSS), an assistive device, whose aim is to improve the Quality of Life of Visually Impaired (VI) persons via increased orientation and mobility capabilities.

Keywords: Geographical Information System, Electronic Orientation Aids, Participatory design, Assistive technology.

1 Introduction

GPS-based personal guidance systems are assistive devices designed to increase the autonomy of Visually Impaired (VI) travelers. In 1998, Golledge et al. [1] raised three main issues to be solved in order to render these devices readily usable. Firstly, the hardware was expensive, but it was also too cumbersome and heavy, and all these factors prevented the adoption of these devices by VI users. Secondly, because of software limitations in 1998, the designers were forced to exclude potential functionalities to comply with limitations on data storage and processing power. Finally, it was necessary to have a better understanding of spatial cognition in the absence of vision to design a usable guidance device.

Improvements in electronic hardware – including computer systems, GPS receivers, sensors, Inertial Measurement Units, etc. – associated to price reductions have contributed to address the first two issues. Regarding the last issue, several studies have been done in order to understand spatial cognition in the absence of vision. It has been shown that mental mapping of spaces and of the possible paths to navigate within these spaces is essential for the development of efficient orientation and mobility (O&M) skills [3]. These skills are taught during O&M training sessions in specialized

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centers. Mobility depends on skillfully coordinated actions in order to detect paths and avoid obstacles in the immediate environment. Spatial orientation requires locating oneself and the desired destination, as well as the path linking these two points, in a global mental representation of space. Therefore, whether they are mental, printed on paper, or in an electronic format, maps are essential in order to navigate. Jacobson and Kitchin [4] suggested that an adapted GIS could provide VI people with access to detailed spatial information that would promote spatial learning, orientation, and appropriate decision making. Then, one challenge for assistive technology research consists in improving the transfer of spatial information from an adapted Geographical Information System (GIS) to cognitive maps.

Many research projects addressed this challenge and lead to navigation systems tailored to the needs of visually impaired (see e.g. MoBIC [5] and Drishti [6]). However, evaluations have shown that such systems are primarily limited by the lack of details in the GIS database and the insufficiency of maps in relation to the specificity of navigation without sight. Even commercialized devices such as Trekker (Humanware, Inc) or Kapten (Kapsys, Inc) are based on commercial GIS that are designed for vehicles navigation and are not suitable for pedestrians.

In this context, we have designed and implemented the NAVIG assistive device, which relies on a GIS adapted to guidance and spatial cognition of VI users (see [7] [8] for details). The primary purpose of the current article is to present the GIS component used in NAVIG. Through a participatory design framework with the visually impaired and O&M instructors, we focused on the adaptation of the geographical database and the guidance to VI pedestrian in navigation tasks. We then suggest a set of GIS analytical tools to ensure the construction of a proper cognitive map when using an electronic orientation aid. Finally we propose a first guidance process based on the adapted GIS that will assist VI users in building a better mental representation of the environment.

2 GIS and Assisted Navigation for the Blind

The GIS is one of the major components in a GPS-based personal guidance system. It is composed of a database and software that selects routes, provides guidance and tracks the traveler's itinerary. However, the guidance system must rely on accurate positioning (around one meter precision in real time) to determine if the user is on the right or the left sidewalk, if he is in front of a pedestrian crossing or if he has already started to cross the street, etc. The GIS database may be used to improve positioning through map matching methods that align a sequence of estimated positions with the road or sidewalk networks on the digital map. The GIS database may also be a valuable source of information to indicate the location of close or remote environmental features (e.g. landmarks) that are useful for orientation and spatial learning of the surroundings. It is known that landmarks are essential in order to provide a better sense of the environment [9]. These different GIS functions are not available without improving the resolution of the map and adding appropriate information into the database (e.g. the presence of walking pathway such as sidewalks and pedestrian crossing).

2.1 Data Collection

When compared to car navigation, this is obvious that pedestrian navigation, especially with visually impaired travelers, imposes additional requirements upon geographical data collection. For visually impaired pedestrians, completeness and accuracy of geographical data are critical in order to safely reach destination. As it appears that systematic collection and update of geographical data is very expensive and difficult, interesting complementary approaches have been proposed. For example, social cooperation (crowdsourcing) is a promising approach based on collection, sharing and multimodal annotation of geographical data within a community of users [10]. Another interesting proposition by Elias [11] relies on the development of different methods to automatically derive maps adapted to the needs of pedestrians from available geographical databases.

2.2 Data Extraction

Data extraction is a very relevant issue in the context of VI pedestrian guidance. Indeed, the device tracks the displacement of the traveler, selects the optimal pathway, provides guidance along the selected route and may extract relevant information to be displayed through a non-visual interface. This information may be used by VI users to build a cognitive map of the surroundings; but it is important to determine what geographical information to extract, from which distance relative to the user location, when to present it and with which frequency. A proposition to answer the last two questions was presented in a previous work [12]. In response to “what” and “where”, [1] proposed a buffering method to select data from the GIS database of the space immediately around the traveler (the current position being estimated by the GPS). However, when selecting data corresponding to an area in a large database, all the stored features in this area are extracted. If these features are all instantaneously displayed to the user, this can hinder the process of cognitive mapping. Sub-selection and sorting must be performed, but these processes require time and resources that are scarce in a mobile device.

Another important functionality assumed by the GIS component is the route selection. It is the procedure of choosing an optimal pathway between an origin and a destination. Traditionally, path selection for pedestrians is assumed to be the result of minimizing procedures such as selecting the shortest or the quickest path. For the visually impaired, a longer route that avoid difficulties and includes known or preferred landmarks can be more convenient than a shorter route. When based on commercial GIS (with inadequate database and functions), route selection cannot be adapted to VI pedestrian guidance.

3 The NAVIG GIS Component

The NAVIG system [8] is an assistive device whose aim is to improve mobility and orientation of visually impaired pedestrians when navigating in unknown environments. The prototype architecture is divided into several functional elements structured around a multi-agent framework employing a communication protocol based on the IVY middleware. In this prototype, user position is estimated from fusion of artificial vision and GPS signals [13]. The GIS module, presented in this paper, consists of an adapted digital map including walking areas (e.g. sidewalks, zebra crossing) and environmental features (landmarks, points of interest, etc.). The user interface is based on speech and/or sound interaction using a 3D rendering engine (LSE from the LIMSI, see [8] for details).

3.1 Participant and Design Process

In the NAVIG project, we have adopted a long-term user-centered design approach in collaboration with the Institute of Young Blinds (CESDV-IJA, Toulouse). We interviewed 19 users to define more precisely their needs as well as their degree of autonomy and technological knowledge. The target population comprised 7 females and 12 males with a mean age of 37. For daily mobility, 5 of them use a guide dog and 10 use the white cane. The last 4 prefer to have a person to guide them. All of them are legally blind and expressed their motivation and agreement to participate in this project. We had three meeting with four different O&M instructors from the CESDV-IJA. They precisely described the different steps and techniques that they teach to VI persons during O&M training. We also analyzed (videos and a posterior interviews) the O&M behavior of two VI users (one with a white cane and one with a guide-dog). We finally performed three brainstorming sessions with at least 4 VI users in which we focused on issues related to GIS used in electronic orientation aids.

3.2 The NAVIG GIS Database Scheme

The guidance process relies on the estimate of the location of a pedestrian relative to the expected trajectory. Guidance then provides her/him with the appropriate direction instructions, and/or with pertinent information about the surroundings. This definition clarifies the role of the GIS component in the context of assisted navigation. Four classes of objects were added and properly tagged in the GIS database. 1/ Walking Areas (WA) represent all the possible pedestrian paths (e.g., sidewalks, and pedestrian crossings). 2/ Landmarks (LM) are places or objects that can be detected by the user in order to make a decision or confirm his own position along the itinerary (e.g. changes in texture of the ground, telephone poles, or traffic lights). 3/ Points of Interest (POI) are potential destinations for a pedestrian (e.g. public buildings, shops, metro station, etc.). 4/ Difficult Points (DP) are not tagged in the database but are dynamically extracted (e.g. street crossing with the number and layout of the different streets). In the NAVIG device, the different classes of objects are displayed with different sounds that are virtually localized on the real object via binaural synthesis (see [8] for details). In figure 1 we present the class diagram of the NAVIG database.

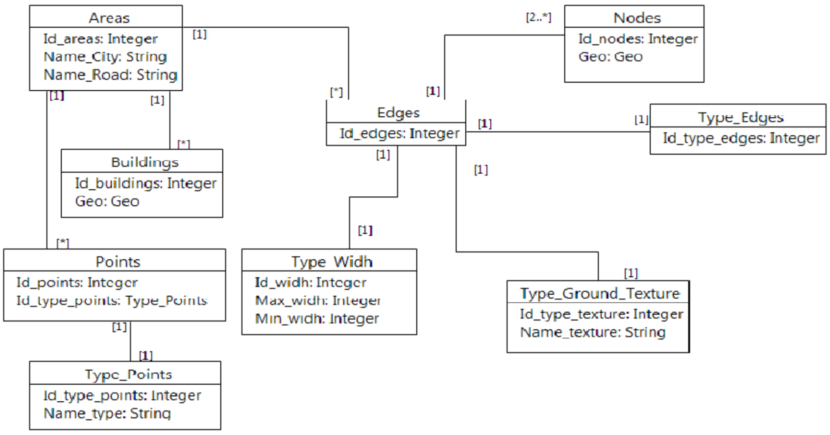

Fig. 1. Database scheme diagram

Each walking area is identified as an edge, having at least two nodes. Each edge has a specific type (sidewalk, crossing, staircase, pedestrian path) and width that can be used when selecting a path according to user preference. Five different widths have been considered: very narrow (less than 1m), narrow (between 1m and 2m), average (between 2m and 4m), wide (between 4m and 8m) and very wide (more than 8m). Each edge also includes a specific ground texture, which may be used as a landmark. In addition, the "Points" class defines specific points that are potential tactile (e.g. tactile guide paths), auditory (e.g. fountains) or olfactory (e.g. bakery) landmarks. The "Buildings" class is generally used to extract information about nearby services (office, post-office, etc.), which could be explicitly required by the user or used to map the environment.

3.3 The NAVIG GIS Software Design

In addition to the GIS database specification, several analytic functions have been proposed after brainstorming sessions. For pedestrian navigation and in the absence of vision, the GIS must integrate a set of functions similar to visual and cognitive (e.g. estimation of distance and direction) functions used by sighted travelers when they explore a new environment [1]. A list of the functions that we proposed in the GIS is presented here:

- List of Points in a Disc (LPD): this primitive extracts the list of tagged points around the user. The input is the distance of detection defined by the user or the system. The center of the disc is the current user location. This function is currently used when the user requests a survey of his surroundings.

- List of Points around a Line (LPL): this primitive extracts the list of tagged points around a segment (street, walking area, etc.). The input is the distance defined by the user or the system, and the name of the segment. It is generally used by the system to extract relevant points (Landmarks or Points of Interest) around a sec-tion. It may also be used by the user to get an overview of relevant points along a section.
- List of POlygons in a Disc (LPOD) is identical to LPD but extracts polygons (e.g. buildings) only. This primitive allows a general overview of the section and informs the user about the buildings in the surroundings.
- List of POlygons around a Line (LPOL) is identical to LPL, but extracts polygons only. As LPL, this function is generally used by the system to extract buildings information along a section.
- Position to address (P2A): this function converts the current GPS position into an address (i.e. number and street name). It also provides the user with his position when asking "where am I?"
- Route Selection (RS): The procedure of choosing an optimal itinerary, using the proposed classification. It computes the most suitable path according to user needs and preferences [7].

Additional functions to compute distance between different points were also added. These functions can be used by the system itself or by the user when asking for additional information such as the nearest bank for instance. To interact with the system, a vocal menu has been implemented.

3.4 Cognitive Mapping via Adapted GIS

When selecting a route between two points, a list of geolocalized Itinerary Points (IP) is generated. The selected path is composed of several sections; each section being defined by two successive IPs. For each section, lists of geolocalized landmarks, difficult points and points of interest are produced by the GIS component. Using IPs, the system then generates turn-by-turn instructions based on the traveler position and direction provided by the positioning component. Landmarks, difficult points and points of interest are displayed to provide the user with information about the travel and the surroundings. Verbosity can be adjusted according to ongoing task and/or user preference.

To track the user location, a simple algorithm based on activation fields was used. To trigger the display of information, a radius was defined according to each type of point (see Fig. 2). The radiuses of the different activation fields were determined during preliminary tests that were conducted with the positioning module. We chose a radius of five meters for both IPs, difficult points and landmarks, and a radius of 30 meters for POIs. When the user was closer than five meters from the current IP, the next one in the roadmap was displayed via a virtual 3D sound. TTS and 3D TTS were used to describe and/or localize landmarks, difficult points, and points of interest when the user reached the corresponding activation fields.

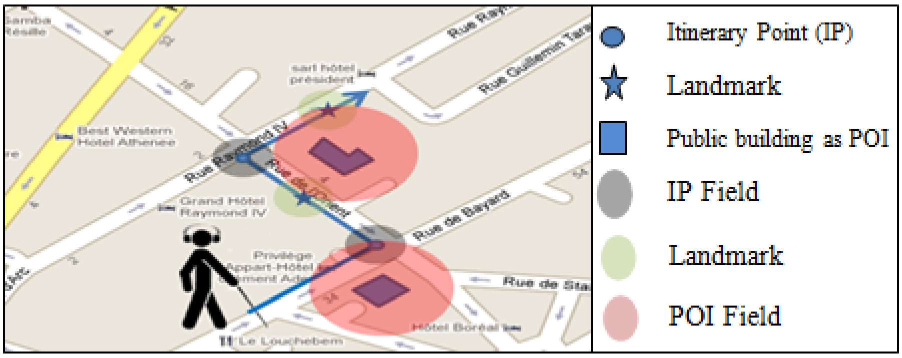

Fig. 2. Part of a selected route with Itinerary Points (IP - small circle), Points of Interest (POIs - squared shapes) and landmarks (stars) is represented. The activation field of IPs, POIs and landmarks are respectively figured in gray, red and green.

4 Conclusions and Discussion

In this paper, we examined how GIS technology may assist visually impaired persons during the different processes of a navigation task. Based on several brainstorming with VI users and O&M instructors, we designed a GIS adapted to VI needs and suitable for electronic orientation assistance. We proposed to improve both data collection (adding relevant information) and data extraction (defining new functions to extract and display spatial information). We specifically suggested that data collection should include environmental features especially useful for VI pedestrians such as pedestrian paths, difficult points, non-visual landmarks, and POIs. Of course, we implemented specific functions that extract and display these different types of points. We suggest that these functions may improve guidance as well as cognitive mapping. In addition to a putative enhancement of cognitive mapping, the GIS may be used to increase positioning accuracy. Indeed, when the estimated user location (GPS position) and the map are very accurate, map-matching techniques proved to be very efficient.

In the context of VI pedestrian navigation, it is critical to improve the display of spatial information to the traveler, especially with the objective of enhancing cognitive mapping. Using an adapted GIS, route selection and guidance may be greatly improved. However, the experimental testing of different guidance algorithms for VI users is really difficult and dangerous in real environments. Many research groups have shown that navigation in virtual environments may assist VI people in learning Orientation and Mobility skills (see e.g. [3]). Instead of representing abstract places, virtual environments may be based on the GIS of a city. We have designed a virtual environment based on a real – representing part of the Toulouse city – but adapted GIS [14]. In future work, we will systematically evaluate different algorithms according to usability of guidance and resultant cognitive mapping.

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