Chapter X

Designing a Virtual Environment Framework for Improving Guidance for the Visually Impaired

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X.1 Introduction

Electronic Orientation Aids are dedicated to orientation assistance for the visually impaired. They are made at least 3 essential components: 1) A positioning system (*e.g.* GPS); 2) A Geographical Information System (GIS) that includes both a digitised map, and a software designed to select routes, track the traveller's path, and provide him with navigation information; 3) A User Interface (UI) that relies on non-visual (usually auditory or tactile) interaction.

These three components could all be at the origin of usability issues. The first major issue is error in GPS positioning that is frequently superior to 20 metres (especially in cities), which is really not compatible with VI pedestrian guidance. Secondly, GIS usually exclusively contain road networks, and hence lack pedestrian-related information. Finally, the interaction with an EOA is a key element, and it must be designed from the beginning for visually impaired users in mobility. Virtual interactive environments may represent a valuable platform to selectively isolate GIS or UI-related issues for being safely and systematically tested in laboratory before on-site evaluations.

With the rise of the number of EOAs, research groups were interested in virtual environments (VE) to assist visually impaired people in learning Orientation and Mobility skills (Sanchez and Tadres, 2010). Those systems have been developed to help constructing a mental representation of space from tactile or auditory cues, to increase spatial cognitive abilities (Mereu and Kazman, 1996), and to provide visually impaired people with a tool for safely exploring and learning about new spaces on their own (Schloerb *et al*., 2010). Generally, these systems are designed to allow VI users to explore virtual representations of real or abstract (*e.g.* a labyrinth) spaces, as well as to interact with objects within these spaces (Sanchez and Hassler, 2006). However they never rely on defective positioning, nor on GIS adapted to visually impaired pedestrian.

With the purpose of improving autonomy in the mobility of the visually impaired, this study proposes the exploration of a virtual environment (VE), through auditory and haptic interaction. This platform allows the user to navigate in a virtual environment representing an existing space (based on the GIS of a city for instance). The aim of this platform is to systematically test several guidance processes before implementation in an EOA. These tests will help to determine which guidance process is the most efficient to compensate for inaccurate GPS positioning, while improving mobility and orientation at the same time.

In the following section, we describe the guidance process generally used in EOAs. In section X.3 we present the proposed virtual environment framework. We focus on the GIS component, users' interfaces and mobility within the VE, and technical issues during design and implementation steps. Finally we discuss how this system will help to benchmark different guidance processes used in EOAs, and evaluate resultant navigation performance and cognitive mapping.

X.2 Guidance in Electronic Orientation Aids

When compared to car navigation, this is obvious that pedestrian navigation, especially with visually impaired travellers, imposes additional requirements upon the electronic aids. Studies on human navigation (see *e.g.* Loomis *et al.*, 2001) report that there are two distinct methods for keeping track of position and orientation during travel. The first mode is called landmark-based navigation. In this mode, visual landmarks provide the traveller with direct feedback regarding current position and orientation. When considering navigation of visually impaired pedestrians, visual landmarks are inoperative, but are replaced by auditory, somatosensory or olfactory landmarks. In the second mode, called path integration, the traveller uses the sense of body motion (kinaesthetic feedback) to update his current position and orientation relative to the starting point. This mode is operative in visually impaired pedestrian navigation, but estimated position rapidly drifts if landmarks for position correction are too sparse. Then an efficient EOA should provide the visually impaired traveller with mobility instructions, but also with frequent and usable landmarks that allow both landmark-based navigation and path integration.

In EOAs, the guidance process consists first in identifying the location of a visually impaired user relative to the expected trajectory and then providing her/him with the appropriate direction instructions, or with pertinent information about the surroundings. Hence we can define guidance process according to three main steps: 1) Route selection procedure for computing the optimal itinerary; 2) User tracking for estimating his current position; 3) Display of navigation instructions and spatial descriptions to orientate the traveller and improve his mental representation of the environment (Kammoun *et al.*, 2011). In order to systematically and efficiently test different guidance processes, these three modules should be operating at once, which is very challenging with visually impaired users moving in a real environment. To palliate this difficulty, we designed a controlled virtual environment for testing different guidance processes potentially used in EOAs.

X.3 A Platform for Improving Visually Impaired Guidance

The system described here is a research tool aimed at designing and evaluating improved guidance for the visually impaired. Our objective is to use this platform to evaluate different guidance processes to be implemented in an EOA. In a second step, the platform will also serve to study the enhancement of cognitive mapping of the visually impaired during guidance. Improved guidance is based on the presence of numerous geolocated pedestrian-related data (pedestrian paths, non-visual landmarks and points of interest) that are annotated in the GIS database and displayed during navigation. In the following sub-sections, we focus on the technical development of the platform.

X.3.1 Adapting GIS Components to Visually Impaired Needs

Most spatial databases used in GIS have been developed without considering the needs of the Visually Impaired. Very few studies aimed to identify the needs of the visually impaired and proposed an annotation of geographical objects that should be included in specialised GIS databases. An interesting classification has been proposed (Golledge *et al*., 1998). They divided pedestrian features into four classes: (1) transportation (*e.g.* roads, bike paths, walkways, car parking areas, bike parking), (2) buildings, (3) land use (*e.g.* open space, recreation, vegetation), and (4) other objects (*e.g.* light poles, telephones, and stairs). This classification is interesting but still misses important data to select the most adapted route for the VI. In our research group, we have adopted a long-term user-centered design approach in collaboration with the Institute of Young Blinds (CESDV-IJA, Toulouse) (see Brock *et al.,* 2010). For this specific project, 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 4 remaining 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 blind persons during O&M training. We also analysed (video and a posterior interview) the O&M behaviour of two blind users (one with a white cane and one with a dog). We finally performed three brainstorming sessions with at least 4 blind users in which we got into issues related to VI navigation. Taking in consideration these different data, we finally proposed an annotation of geographical data including three main classes: (1) Walking areas that compose the pedestrian network (sidewalks, pedestrian crossing, *etc.*); (2) Non-visual landmarks corresponding to locations that can be detected by a VI pedestrian on his/her own (*e.g.* change in the pavement texture or inclination, street furniture, potential odours or sounds, *etc.*). These landmarks are either decision (*e.g.* when to turn) or confirmation (*e.g.* a good choice was operated) points; (3) Points of Interest (POIs) such as places or objects that are potential destinations (*e.g.* public building, shop, street furniture like mailbox or bus station, *etc.*). When POIs are not a destination per se but in the vicinity of the itinerary, they may be useful to figure out how the different elements in a city are spatially organised. In addition, both landmarks and POIs may subserve landmark-based navigation as well as path integration.

We used data from Open Street Map (OSM) to construct the GIS database. OSM is an open source project used by a large and dynamic community. The main advantage is that OSM is an open resource, and it is easy to add data and features to the database via a simple editor (JOSM). In addition, the data can be shared online. This is hence easy to annotate OSM database according to the proposed classification by editing nodes, ways, metadata tags and relations.

X.3.2 Avatar Mobility

We chose to rely on a force feedback joystick to control the exploration, because it is a convenient device to manipulate several dimensions at once (heading, translations and rotations), and its sensitivity and gain can be adjusted to fit real human walking speed. Forward/backward movements of the joystick allowed displacement respectively forward and backward in the VE. Left/right joystick movements controlled body rotation angle. In order to minimise the complexity of input interaction, translation and combination of two movements were not allowed. As the user moved the joystick, the system tracked the direction of the movement and continuously updated the position of a corresponding avatar in the VE while providing at the same time auditory feedback in relation to the displacement (step sounds).

X.3.3 Output User Interface

In order to design the output interface, we organized two separate brainstorming sessions with expert and novice users of EOAs. Our goal was to define the type and quantity of information required during a guided travel, as well as appropriate modalities that don't interfere with the learned O&M techniques and abilities. These two sessions made clear that, during a navigation task, an EOA should provide two classes of information: (1) Direction instructions, i.e. turn-by-turn instructions, and (2) Space-related information (landmarks for navigation, but also information about the surroundings, description of difficult points, *etc.*). To display both of them, an adapted interface is required, which must rely on non-visual (*e.g.*

auditory or somatosensory) modalities. Text To Speech (TTS) as well as binaural synthesis - which provides virtual 3D sounds at any desired location in the listener's space - have been evaluated in real navigation context (Loomis *et al*., 1998; Gaunet, 2006) and within virtual environment for orientation and mobility training (Sanchez *et al*., 2009; Schloerb *et al*., 2010).

In real navigation task, the somatosensory modality is another efficient output modality in different situations, *e.g.* when natural sounds are critical and should not be masked, when ambient noise level is too high, or when user impairment prevents auditory-based interaction (visual impairment is sometimes associated with auditory impairment). Different studies have shown the usability of tactile displays for presenting directions by mapping them onto body locations. Information regarding the expected direction was provided through the activation of a given vibrator mounted in a belt (Pielot *et al*., 2008), or within a backpack (Ross and Blasch 2000). Haptic feedback has also been used within virtual environments designed for supporting orientation and mobility training (Schloerb *et al*., 2010).

In the platform, we implemented a feedback editor that allows adding single or combined feedback on objects (TTS and/or 2D/3D sound on the audio channel; vibration and/or force on the joystick). We first implemented a footstep feedback that was related to walking speed. Additional feedbacks allowed displaying both direction instructions, obstacles encountered, and spatial configuration information (landmarks, POIs). We suggest that combination of TTS and binaural synthesis is an interesting solution for guidance as the two kinds of information are easily discriminated. Spatialised audio was mainly used for directional information. Indeed it allowed the user to hear the direction (Right/Left) of sounds in the VE as if he were standing at the location of the avatar. Spatialised TTS was also used to render location of environmental features (landmarks and POIs). As binaural estimation of distance is rather limited in humans (Middlebrooks and Green, 1991), TTS or spatialised TTS seemed advantageous to render this cue. We also designed force-feedback effects that we can attach to different textures or obstacles in the VE. Hence the user felt the variations in ground texture and presence of steps (*e.g.* sidewalk) or obstacles (*e.g.* wall) as in a real navigation task using the white cane. These somatosensory cues may also serve as landmarks.

X.3.4 Virtual Environment Implementation

As mentioned above, we used OSM database as the original source of geographical information in the GIS database. In order to extract information from the OSM database, we generated an XML file from a selected area. This XML file was then parsed to get the geometry and attributes of roads, walking areas, buildings, landmarks and POIs. We finally converted the Word Geodetic System coordinates (WGS84) used in OSM database to a Cartesian coordinate system in order to build the virtual environment. Three important classes of objects were included: 1) Polygons that represent the different buildings, walls and car park areas. Each building was defined by its name or function, extracted from the OSM data. 2) Lines that represent different types of roads, walking areas, sidewalks, zebra crossings. Each line was defined by its name (for the streets), or its direction compared to North for differentiating road sidewalks. 3) Points that represent Landmarks and POIs.

The platform presented two distinct modes: *Control* mode that is used by VE developers, researchers, and Orientation & Mobility instructors. The Control mode allows developers to create and modify VEs. A key feature of the Control mode is the program's ability to import an XML file from Open Street Map to create a new 3D virtual map and to manually or automatically (via the route selection algorithm from Kammoun *et al*., 2010) select a path between two points. This makes it possible to easily import maps of different campus or cities. The control mode includes the feedback editor (tactile & auditory feedbacks). The second mode is an *Evaluation* mode that allows researchers and Orientation & Mobility instructors to record and review the user behaviour in the VE. During an experimental session, the system recorded in a text file the avatar's (user) position, orientation and speed within the VE, along with any interaction between the user and the system.

For the experimenter display, different textures were applied according to the type of surface (building, walls, *etc.*) or the type of line (*e.g.* tar texture is chosen for roads, and zebra texture for pedestrian crossing). Figure 1a shows an example of the University of Toulouse environment including the global map in the lower right hand corner. Figure 1b shows a close-up view of the global map with the actual position of the user (red spot) in the virtual space. The platform was implemented in C++ code running under Windows 7. It uses an open-source graphic rendering engine (OGRE 3D), and a cross-platform 3D audio API (OpenAL) appropriate to display 3D spatialised sounds via the headphones. A collision detection algorithm based on ray tracing was integrated into the framework so as to allow real time collision detection in complex environments.

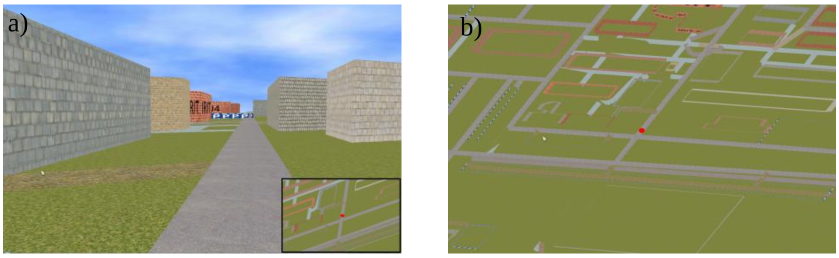

Figure X.1. a) A screenshot from the graphic interface of the virtual environment. The global map is on the lower right hand corner. One can observe different buildings, walking areas and car park areas. b) Close-up view of the global map, the red point represents the position of the traveller in the virtual space. Each type of walking area (sidewalk, pedestrian crossing, car park area, and road) is represented with a distinct colour.

X.4 Navigation and Guidance Process

Before beginning guidance, whether in real or virtual conditions, route selection is necessary and is usually included in the GIS component. It is defined as the procedure of choosing an optimal pathway between origin and destination. When considering pedestrian navigation, the shortest path might be appropriate but should rely on a GIS database including essential information for pedestrian mobility (*e.g.* sidewalks and pedestrian crossings). In addition, brainstorming sessions revealed that excluding difficult points (*e.g.* complicated crossroads) as well as including non-visual landmarks on the itinerary is important when route selection is made for the Visually Impaired. Using the database described in section X.3.1 we were able to select an adapted path for VI pedestrian by using the algorithm indicated in (Kammoun *et al.*, 2010). When a route was selected, several sections defined by two successive Itinerary Points (IPs) were generated. Each section contained a list of Landmarks and POIs extracted from the GIS.

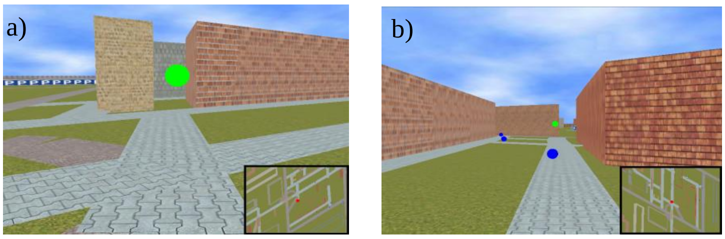

Figure X.2. a) The green point represents an intermediary itinerary point (IP) (a virtual spatialised sound is placed at this location). When the point is reached, feedback is given to the subject and the next IP is activated. This guidance process allowed the user to reach his/her destination by small, easily reachable steps. b) Blue points represent landmarks or POIs selected on this path, and extracted from the GIS**.**

As mentioned in the previous section, virtual 3D sounds, TTS and Spatialised TTS were used to display instructions and environmental information (see Figure X.2). Based on simple interaction properties attached to the different scene elements it will be possible to design and evaluate many guidance processes. A first instance of direction instruction process was designed by displaying a spatialised sound on the next IP position according to the traveller position and orientation.

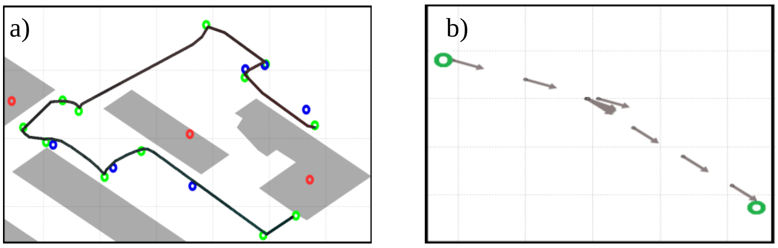

Figure X.3. a) Representation of a recorded journey around two virtual buildings in the University campus during an evaluation session with a VI user. Green, blue and red points represent, respectively, IPs, landmarks, and POIs that were displayed. The dark line represents the trajectory of the avatar. b) During the evaluation session, navigation speed and orientation of the avatar were also recorded; each arrow represents speed and orientation during navigation within the VE.

Landmarks and POIs that were on the vicinity of the path were displayed, which provide the user with spatial indications about his surroundings. In this case, a circular activation field (with an adjustable diameter) was attached to each type of element to trigger information display. Figure X.3 shows the representation of recorded displacements during two preliminary evaluation sessions.

X.5 Discussion and Future Work

This paper presents the design and implementation of a virtual environment framework in order to evaluate tracking and guidance strategies before their implementation in an EOA. Based on a geographical database including specific - and essential- information for pedestrian mobility as well as important Landmarks and POIs for the VI users, we built a virtual environment in which several user tracking and guidance strategies will be evaluated safely and systematically in the laboratory. The most promising strategies will then be tested in the real world with a prototype of an EOA sharing a large set of components with the VE (GIS database; route selection, tracking and guidance software; TTS and binaural synthesis output, see Katz *et al*., 2010).

X.5.1 User Tracking and Guidance Process

Tracking user location is essential for an efficient guidance process in visually impaired navigation. For EOAs, geolocation based on GPS is the most common technique. However, positioning precision with GPS alone is rarely better than 20 metres in many environments. This is particularly the case in cities where urban canyons between buildings prevent direct line of sight with the satellites. Several approaches have been developed to improve the GPS precision in such environments. Dead-reckoning algorithms combine GPS with inertial sensors to improve estimated users' positioning. Differential GPS (see *e.g*. Loomis *et al*., 1994) can provide an accurate positioning, and hence better guidance, but rely on a network of stations that is not available everywhere. Electronic location identifiers, such as RFID tags, WLAN networks or Bluetooth beacons have also been used in indoor environments such as museums, hospitals, and so on. However, they entail a large scale infrastructure with a specific deployment phase and important maintenance costs, which is very rarely available in cities. In this context, the use of a platform simulating real environment and positioning (with added inaccuracy) seems a promising approach when designing an EOA. Indeed, in this experimental platform, it is very easy to add systematic and random noise on the positioning of the avatar. The resulting positioning will mimic the positioning observed with real GPS in different environments. The platform will then be used for testing the robustness and usability of the different tracking and guidance process implemented.

X.5.2 Sound Localisation and Haptic Feedbacks

In the platform that we describe, guidance instructions and environmental description are displayed using a combination of TTS, binaural synthesis and haptic feedback. There is a well-known issue related to the use of binaural sounds: the spatialisation must be defined in the head-centred reference frame of the user, not in that of the external world. However (Katz and Picinali, 2011) showed that head-tracking was not necessary for 3D sound-based navigation in VE; 3D sound synthesis based on the movements of the joystick (and hence on the displacement of the avatar) were sufficient for users to succeed in non-visual navigation tasks.

A rich haptic interaction is provided through the use of a force feedback joystick device. Many scene elements can generate vibration and force feedback when they are encountered. This haptic interaction was designed to reproduce the information that a visually impaired person gathers - including ground texture, step and obstacle detection - when moving with a white cane or a dog.

X.5.3 Spatial Cognition in the Visually Impaired

Virtual environments appeared to be effective in the transfer of cognitive mapping to real environments, even for visually impaired users (see *e.g.* Lahav and Mioduser, 2003). Our aim was different in that the platform is designed for evaluating robustness of tracking and improved guidance for the visually impaired (including map adaptation, route selection, direction instruction and space description). Indeed, as we previously stated, this platform will ease the tests of route selection - comparing for instance the automatically selected route with the users' preference - or robustness of tracking algorithms by adding systematic and/or random noise on the position of the avatar. But, importantly, we will also modify the quality and the quantity of direction instructions, landmarks and POIs mentioned during the journey. We will use different experimental designs to test the efficiency of the guidance itself (number of errors and time to succeed), but also the mental maps acquired during the journey. These maps will be compared to maps acquired during mobility in real environments, as well as to topographic maps (see Lahav and Mioduser, 2008 for indoor real vs. virtual exploration).Our aim is to finally select the strategies that enhance not only the egocentric representations related to turn-by-turn instructions but also the global spatial knowledge of the explored environment.

X.6 References

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