Mobile Audio Navigation Interfaces for the Blind

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Abstract. In this paper we present a set of mobile, audio-based applications to assist with the navigation of blind users through real environments. These applications are used with handheld PocketPC devices and are developed for different contexts such as the neighborhood, bus transportation, the Metro network and the school. The interfaces were developed with the use of verbalized and sound-based environments. The usability of the hardware and the software was evaluated, obtaining a high degree of acceptance of the sound and user control, as well as a high level of satisfaction and motivation expressed by the blind users.

Keywords: blind navigation, orientation and mobility, mobile audio interfaces.

1 Introduction

The problems faced by blind users in mobile contexts are diverse and non-deterministic. This makes it difficult for such users to make decisions on what routes to follow, resulting in movement with very little autonomy.

Furthermore, blind users orient themselves in space by using straight angles, which does not allow them to develop a full representation of the real environment. One way to resolve this problem is by navigating through the use of a clock system 10. A clock system in combination with mobile technology can be a valuable alternative to help with the mobility and orientation of blind users.

Having a mental map of the space in which we travel is essential for the efficient development of orientation and mobility techniques. As is well known, the majority of the information needed for the mental representation of space is obtained through the visual channel [5, 12]. For blind people, key environmental information is received through the spatial relations constructed by the remaining senses. Despite this limitation, the cognitive mapping skills of blind people are flexible enough to adapt to this sensory loss. Even the congenitally blind are able to manage spatial concepts and are competent navigators [3].

Some generic problems blind people have when moving about have to do with localization and their perception of the environment, as well as choosing and maintaining a correct orientation, and detecting possible obstacles [14]. Jacobson & Kitchin 4 point out that the most important problem for the blind has to do with their incapacity for independent navigation and interacting with the rest of the world. Also, exploration can lead to disorientation, which is accompanied by the fear, stress and panic associated with the feeling of being lost. There is also a risk associated with obstacles

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that cannot be detected by the body or with mobile aids such as the cane [13]. Ran et al. [8] propose that the main difficulty for the blind in the context of orientation and mobility is knowing where they are at any given time and which way they are going, and that reorienting themselves is especially complicated if they get lost.

2 Related Work

There are several ways to help blind users achieve autonomous movement with the aid of mobile technology. One way is helping them with *in situ* assistive technologies in order to provide them with additional contextual information while they are moving; this is known as location technology. Such technology uses a variety of means such as RFID, IrDA, Bluetooth or WIFI, with which several solutions have been designed and developed to assist with the movement of blind users [2,6,7,8,15]. Some studies propose different modes of interaction for blind users who use mobile devices, which implies the implementation of entry modes that use tactile or voice commands, and outputs provided through verbal and/or iconic sounds [10,1].

Loomis et al. [6] has presented a study on the use of a GPS device that can guide a blind user in an outdoor environment. The synthesized voice-based system helped users to be able to identify the shortest route between two points. GPS does not work in indoor spaces, and in such contexts it is necessary to recur to other methods. Gill [2] presents a solution by using infrared technology standards (IrDa) that work as sensors to determine the user's indoor location.

The Drishti system, developed by Ran et al. [8], uses a combination of GPS for outdoor navigation and ultrasonic sensors for indoor navigation. One problem concerning GPS is the error associated with the measurements taken, more so when associated with a cloudy climate or if there are very tall buildings in the area. For the indoor environment, the blind user must carry two ultrasonic sensors that receive signals that are transmitted from different points in the rooms. With these signals it is possible to detect the location of the users by processing and analyzing the data.

A grid with RFID technology (Radio Frequency Identification) informs us on the location and proximity of a user in a certain environment [15]. Combined with Bluetooth technology the reading apparatus sends data to the user's handheld device or a cellular phone, which analyzes the information and indicates the user's position.

Finally, Na [7] proposes BIGS (Blind Interactive Guide System), a grid system that contains a group of RFID tags that are placed on the floor of a room, and an RFID reader carried by the user. In addition, this system is capable of constantly monitoring the movements of and the route taken by the user, thanks to communication via WIFI.

3 Methodology

3.1 Mobile Audio Interfaces

The 4 software programs presented in this paper are oriented towards developing navigation (orientation & mobility) abilities and strategies in blind users through the use of a mobile PocketPC device: 1. aGPS is used to navigate a neighborhood, which is a space that they travel daily, but deficiently and not in all its magnitude. Also, throughout their lives they may need to visit and navigate various unknown neighborhoods; 2. AudioTransantiago is a mobile application that provides assistance for using public transportation, particularly a bus; 3. mBN is mobile software that helps to move through and use the Metro network; and 4. MOSS is a system that provides necessary assistance for moving about without problems in an indoor environment such as a school or a specific building.

aGPS. In the aGPS software the entry interface consists of 3 buttons on the PocketPC. The first button is used to enter the starting point of a path, which could be the first position entered when starting the software, or a location entered after having changed directions. The second button is used to ask the system for information. When the user presses this button, the Text-to-Speech engine (TTS) replies with the distance to and direction of the destination (using the clock system to express the direction). The third button is used to change the destination point. When the user presses this button, he/she navigates a circular list 11 with different destinations read by the TTS.

The output interface is made up mostly of the TTS. As previously mentioned the TTS responds to the user's requests when he/she presses a certain button. The only output provided to the user consists of the distance to and direction of the destination point, and the names of the destination points. The user is not provided with the routes to be taken. The user must decide the paths to follow in order to arrive at the destination. There is also a visual interface that provides information regarding the destination point, the distance to and the direction of the destination point at any given time. This interface is used to help the facilitators to be able to support blind users in their learning for navigation purposes.

AudioTransantiago. *AudioTransantiago* stores contextual information on each stop of the *Transantiago* routes, from which the user chooses in order to plan his/her trips in advance. In addition, this software navigates the stops of a previously planned trip in order to strengthen orientation and facilitate the blind user's journey.

AudioTransantiago uses an audio-based interface consisting of a TTS engine and non-verbal sounds that help to identify the navigational flow within the application menus and through which it conveys information to the user. The interface is made even better by a minimalist graphic interface that includes only the name of the selection that is being used and the option that has been selected, including a strong color contrast (yellow letters over a blue background) that is useful for users with partial vision, but legally blind, who can only distinguish shapes when displayed as highly contrasting colors.

Navigation through the software application's different functions is performed through circular menus 11 and the use of the lower buttons on the PocketPC. The advantage of these menus is that they facilitate searches within the lists, which have a large number of different elements. The software application's two operational functions can be accessed through this structure (planning a trip and making a trip), as well as their respective submenus, which are explained in the next section.

mBN. The mBN, or mobile Blind Navigation, is a navigational system for use in a Metro network. The mBN software contents are presented in a hierarchy of menus displayed on the screen and also as audio cues. A menu has a heading and a set of items; the number of elements in each set has to meet the cognitive usability load restriction of 7 ± 2 chunks of information. Menus can be defined as circular 11 or normal according to the way in which they are explored.

When using mBN software, users have to execute commands through the touch screen of a PocketPC. The interface was designed and developed “with” and “for” users with visual impairments. The interaction is achieved with the corners of the PocketPC screen by joining adjacent corners. Thus the software registers, analyzes, and interprets the movements and jumps of the pointer. With this information, the software knows whether a command was executed. A blind user’s interaction with the touch screen is performed without the need for the pointer pen (stylus) by using touch to map the relief of the four corners needed to construct and execute a command.

The information managed by mBN is represented internally by strings transmitted to the user via spoken audio texts and high contrast color text on the screen. A TTS engine performs the translation of the written information to audio speech messages. These messages are complemented by earcons for a higher degree of attention and motivation when interacting with the software.

MOSS. This interface is mainly audio-based, in which information is provided through sound in two different ways. On one hand, iconic sounds (sound effects) associated with the different actions that the user performs (walk, navigate the menu, etc.) were used, which also provide contextual information (pass through a door, walk down a hall, bump into a wall, etc.). On the other hand, a TTS engine was used to provide information verbally (for the description of an element, or current position, etc.).

One of the main actions that the user can perform is *SoundTracing (ST)*. ST follows the metaphor that the individual emits a ray that detects all the objects that are in a certain direction, even if there are solid objects in the way. To generate an ST, the user must make a gesture on the touch screen of the PocketPC device that represents a line in the direction that he/she wants the ray to go.

3.2 Evaluation

For each one of the mobile audio interfaces a usability evaluation was made in order to detect the level of acceptance for the applications and their potential for use. This was done to determine whether the users were able to interact with the PocketPC device by using the sound-based interfaces. It was expected that users would be able to recognize both entry and output means of interaction (buttons, screen and audio).

Sample. The participants in the usability test for the *aGPS* software consisted of 4 users (two boys and two girls) with ages ranging from 11 to 13 years old, and all of who attended the Santa Lucia School for the Blind in Santiago, Chile. They had a variety of ophthalmic diagnoses and degrees of vision.

The sample for the evaluation of the *AudioTransantiago* prototype consisted of 6 legally blind participants between the ages of 27 and 50 years old, all of who were residents of Santiago, Chile. They had a variety of ophthalmic diagnoses, 3 of them had partial vision and all were men.

The sample for the usability evaluation of *mBN* consisted of 5 people, aged 19 to 28 years old, from the Santa Lucia School for the Blind in Santiago, Chile. Four of them had partial vision and one was blind. It is important to mention that none of these users had any previous experience interacting with PDA devices.

The sample to evaluate MOSS consisted of five children aged 8 to 11 years old, including three girls and two boys. Two of them attended a segregated school (fifth grade), while the rest attended integrated schools (3rd, 4th and 6th grade) and were held to the same standards as their sighted classmates. Of all the participating users, only one had partial vision (non-functional). On the other hand, the users did not present any additional deficit other than their visual disability.

All of users were legally blind (totally blind and partial vision). For all the usability evaluation sessions, two special education teachers specializing in visual disabilities and one usability evaluation engineer participated.

Instruments. For the usability evaluation of the aGPS, an End-User Usability Questionnaire was used that consisted of two parts: (1) A set of 24 closed questions with a scale of appreciation from 1 to 5; 12 questions regarding the software and 12 on the hardware, and (2) A set of 7 open questions that were extracted from Sanchez's Software Usability Questionnaire 9. The questionnaires were read and explained by facilitators and answered by users.

The usability evaluation of AudioTransantiago was performed by means of a Software Usability Questionnaire 9 adapted for adult users in the context of this study. This questionnaire includes 18 closed questions on specific aspects of the software's interface, together with 5 more general, open-ended questions regarding trust in the system, the way the system is used, and the perceived sense of utilizing these devices as a way to help users travel on a bus system. The results obtained can be grouped into four categories: (1) Satisfaction, (2) Control and Use, (3) Sound, and (4) Image.

To evaluate the usability of the mBN software, automatic data recording was used. This consisted of data structured in XML format that is internally stored by the software during the user's interaction, registering data on every key used, the Metro stations taken, and the time used to perform each action. To support the data collection process for usability testing, complementary software was created (AnalisisSesion). This software checks the data recorded during mBN sessions (automatic data recording).

The end user usability evaluation of MOSS focused on user acceptance, with questions on whether the user liked the software, which things he/she would change or add to the software, what use the software had for him/her, and other similar questions. These questions were based on Sanchez's Software Usability Questionnaire 9. Each statement on the software was evaluated with a score from 1 (strongly disagree) to 10 (strongly agree).

Procedure. Each usability evaluation was completed during two 60-minute sessions. In each session, the users interacted with the software for 25-30 minutes in order to evaluate the effectiveness of their interaction with the buttons and the PocketPC screen, control and use, and the clarity of the audio support.

Each session involved the following steps: (1) *Introduction to the software.* The functions of the software application and its use through the PocketPC buttons were explained to the participants. (2) *Interaction with the software.* The users tried out the software's functions and the use of its buttons. At this point they also planned a trip as their final task. This trip was arbitrarily defined so as to be used in a later cognitive impact evaluation. (3) *Documentation.* Sessions were documented in detail through the use of digital photographs. (4) *Evaluation.* The Software Usability Questionnaire was administered. Based on the comments and recommendations the participants provided, the software was modified and redesigned in order to improve its usability.

3.3 Results

Figure 1 shows the average scores obtained for the software and the hardware used. All scores are over 4.2 points, on a range that varies from 1 to 5 points. This means that the users' evaluation of the software and hardware's usability was quite satisfactory. These results are the same for the four dimensions of the software that were analyzed, in that all average scores are 4 or above, which indicates a high degree of user acceptance regarding each of the dimensions analyzed.

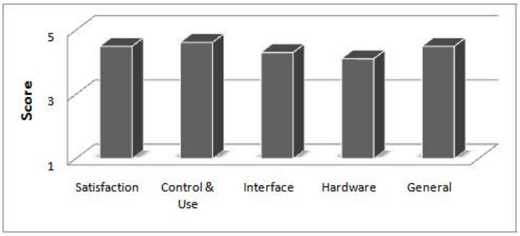

Fig. 1. Usability results of the software aGPS

The dispersion of the data is similar for both the software and hardware variables and the satisfaction and control & use variables. For software and hardware the standard deviation is between 0.348 (software) and 0.357 (hardware), with a kurtosis of 2.980 (software); 3.210 (hardware) and skew of 1.673 (software); 1.725 (hardware), which means that the evaluations of the software and hardware received very similar opinions, with a slight deviation towards higher scores. For control & use, the standard deviation is slightly lower than that for satisfaction (SD = 0.479 and 0.5 points respectively). The case of the image dimension is distinct, in that the degree of dispersion is far greater than that observed in the other dimensions (SD = 0.816). A kurtosis of -1.289 for control & use and of -3.901 for satisfaction was obtained, with skew of - 0.855 for control & use and skew of -0.37 for satisfaction.

Users were able to construct a correct map of the software. Their mental models easily grasped the application. The usability data showed that the proposed interface was easy to use and easily understood by blind users.

The usability questions for AudioTransantiago were evaluated on a scale ranging from 1 to 10 points, 10 being the highest. On average, the values obtained for all the items were quite satisfactory, obtaining an average of over 9 points for each item. The totally blind users assigned a score of 10 points for all the questions, while those users with partial vision assigned slightly lower scores (average of 9.02 points) (Fig. 2). As can be seen in table 1, users assigned high scores to all 4 dimensions. The scores are higher than 9.2 points for all dimensions. The most highly evaluated dimension is image, although this dimension was only analyzed by three users who were not total blind. This dimension also has the lowest degree of dispersion among the answers, with a standard deviation of 0.577. The degree of dispersion increased slightly for control & use (SD=0.698), satisfaction (SD=0.816) and sound (SD=1.123). The control & use and sound dimensions obtained a kurtosis of -0.053 and – 1.646 points respectively. Satisfaction obtained a Kutosis of 2.774. The skews for all the dimensions were the following: -1.732 (images); -1.276 (control & use); -1.783 (satisfaction); -1.006 (sound). This means that the highest degree of agreement is reached in the satisfaction dimension, and a comparatively lower degree of agreement is reached for control & use and sound.

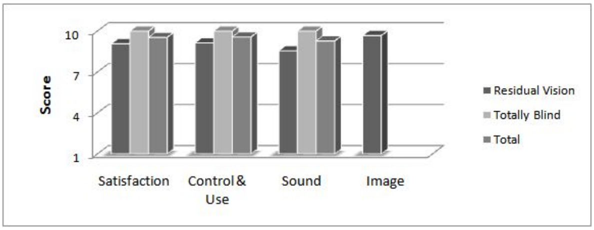

Fig. 2. Usability results of AudioTransantiago software

In the case of mBN software the usability evaluation sessions provided information that validated the event and sound feedback, the logic of the interface, the design, and the programming strategy. It also favored the improvement of the design and coding for the following milestones. Information was gathered on the time that a user needed to use the functions through the proposed input interface by dragging the pointer from one corner to another. The average time taken by the users for the different tasks assigned was 0.693 seconds, with a standard deviation that reaches 172.48 points. The distribution of the users' times shows a kurtosis of 2.358 and a skew of -1.225. With this information, a 2.5-second limit was established for entering a command. After this time, the action is timed out (Table 1).

Table 1. Action spent time

	Seconds
Minimum	**0,325**
Average	**0,69625**
Maximum	**1,35**
Timed Out	**2,5**

The device's screen can be used as support for the audio interface in the case of users with partial vision and for teachers involved in the testing. The same restrictions were obtained as those observed for the mBN software, with functions that should be implemented in the logic for menus, requirements, organization, and the debugging of contents presented in the software, such as including a menu with the value of a ticket over time, and including relevant information about the station's surroundings.

The proposal to present information on the stations' surroundings is related to the orientation and mobility cues that blind people use when navigating urban environments. These cues are: street numbers, cardinal points regarding traffic direction, cardinal points regarding street curbs, street intersections and other urban landmarks (sidewalks, stairs, rails and traffic lights).

Figure 3 displays the users' satisfaction with the MOSS software. This dimension obtained 9.5 points of a total of 10, and is followed by control & use with 9.17 points, and interface with 8.20 points. The standard deviation for the first two dimensions was 0.16, reaching 0.60 for interface. A kurtosis of 0 and a skew of 0 for all three dimensions show that the distribution for the three dimensions is symmetrical. On average a score of 8.88 points was obtained, which is an extremely relevant result that assures the usability and acceptance of the software. Some of the most highly evaluated statements were: "I like the software's sounds (9.8 points), "I learned with this software" (9.6 points), and "I like the software" (9.4 points). The lowest scores were obtained for the statements, "The software adapts to my rhythm" (8.0 points) and "I felt in control of the software's situations" (8.2 points), which reveals the existence of a certain learning and appropriation curve. In general, however, a high degree of appreciation was obtained from the end users.

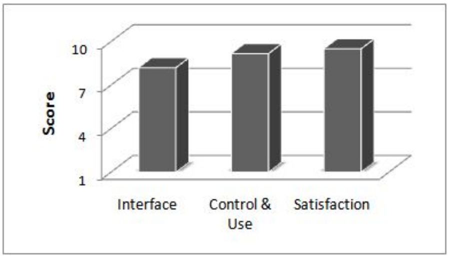

Fig. 3. Results of the end user evaluation of the MOSS software

4 Conclusions

Four prototype software applications were evaluated that seek to support the navigation of blind users in real environments such as a neighborhood, public bus transportation, the Metro network and the school or a closed building.

The interfaces of all prototypes evaluated are adequate for use by blind users. During the interaction it was possible to observe that users easily learned and recognized the audio cues and the functions used in the software, as well as their meaning. Through the evaluation of all the software applications we could determine that the use of a PocketPC was appropriate for the end goals of this study, in that the participants learned to use the device without any major difficulties, demonstrating a high level of skill in using the buttons on the PocketPC. Users were highly receptive to the 4 software applications, and were motivated by their use of the system.

Also, the use of both the synthesized voice and the non-verbal sounds in the audio system were highly accepted by the users. In this case, the natural sound of the TTS and the clarity of the sounds in general were highlighted.

In particular, the clock system that the software used to transmit information regarding directions was easily assimilated by users with visual disabilities.

The use of all the software applications allowed for relevant navigation by the users because it provided specific information to guide them during their travel. Because the handheld apparatus was a new device for them, there were some difficulties in the very beginning, but users slowly began to adjust to using the device. They discovered solutions such as using it from their pockets with earphones in order to avoid losing the auditory references in their surroundings, and choosing a safe and comfortable place in which to handle them.

5 Discussion

The interfaces of the software applications developed were evaluated by using a sample made up of participants with different ages and degrees of blindness, verifying in all cases that the users were able to interact with all the mobile software applications independently. At the same time they demonstrated that the handheld device, the interfaces designed and the model of interaction were all appropriate for users with visually disabilities. Although the samples used for this evaluation were limited, the different contexts of use and the various users' backgrounds allowed us to detect several usability problems (real and potential), as well as to measure the level of understanding the objective of the software, embedded representation and the ways to navigate and interact with it. During the interaction it was possible to observe that the users quickly learned and recognized the audio cues used in the software and their meanings. They were able to understand the model of interaction and the metaphor used. As far as the use of the device, none of the users had a hard time finding and identifying the buttons, the joystick or the screen. Besides these significant usability results, the evaluation became a useful opportunity to detect problems and opportunities to improve the design, as well as to correct the software's programming and modeling errors.

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