Augmented reality application for the navigation of people who are blind

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ABSTRACT

A person who is blind can be capable of locating objects and also other people, such as a sighted person, by just using audio cues. In this research we present the design, development and evaluation of ARTAB, a technological assistant for people who are blind that uses Augmented Reality to identify a set of objects in an indoor environment. As a result, we generated audio-based representations that allow a user to determine the position of an object relative to the angle of vision of the video capture device for navigation purposes. The usability testing performed allowed us to detect that it is not trivial to assign sound effects so that the variation of such effects would imply changes in the position of an object. The continual variation of the sound pitch does not generate the contrast necessary for the blind user to be able to obtain a certain kind of information. However, users generally perceive ARTAB as a useful tool for assisting orientation and mobility tasks.

1. INTRODUCTION

Computer science is part of our daily lives and is often invisible to mobile users. One of the new computing applications is directly related to supporting the development of orientation and mobility (O&M) skills in people who are blind.

A person who has a visual disability is clearly at a disadvantage compared to a sighted person, due to the fact that he must cope with a world that has been designed and constructed for by people who can see (Sáenz and Sánchez, 2010). There are several activities in daily life that require the use of vision as the main sense, and that are very difficult to perform through the use of other senses, unless there is some form of external assistance (Lahav and Mioduser, 2008). Such a disadvantage is clear for someone who cannot see.

One activity that may seem simple for many sighted people is navigating throughout the space, in that it is necessary to be constantly collecting information in order to know the place in which one is located and the location of the point to which one wants to go, in order to then make decisions on how to take the optimal route to get there. It is as such that, as a way to help a visually disabled person, the question emerges on how it would be possible to provide the information that a sighed person acquires through vision efficiently.

In providing access to information, it is important to represent such information in a way that is coherent and comprehensible for the person who needs it. In the case of people who are blind, a virtual representation of real space can be created, and they can be made to interact with such a virtual environment. A transfer of what has been learned virtually can then occur, navigating in the real-world environment (Sánchez, Sáenz and Ripoll, 2009). Another option is to take certain contextual information and supply assistance through a technological aide, providing the user with information that allows him to make decisions (Angin, Bhargava and Helal, 2010; Yaagoubi, Edwards and Badard, 2009).

Be it the former or the latter option, the development of an audio-based interface to represent and interact with the real or a virtual environment is feasible. Through the use of audio-based cues, a person who is blind is able to locate objects of interest, just as a sighted person would be able to do (Crossan and Brewster, 2006). The creation of these interfaces requires a careful design, so that the user does not feel saturated with an excessive amount of information (Loomis, Marston, Golledge and Kaltzky, 2005).

The concept of Augmented Reality (AR) was coined long ago. This concept consists of providing the user with annexed information on the environment, either directly or indirectly, by either visual or auditory means. The elements of this information are augmented by a virtual image created by the computer. To do this, it is possible to take a video image from the real environment and superimpose adequately scaled virtual objects over it, which are oriented in relation to the objects in the real environment in real time (Azuma, Baillot, Behringer, Reiner, Julier and MacIntyre, 2001; Bimber and Raskar, 2005). This can be extended not only to virtual objects represented with 3D models, but to the use of 3D sounds as well (Azuma, 1997; Sodnik, Tomazic, Grasset, Duenser and Billinghurst, 2006), with which the objective of adding extra information to the real context is achieved.

In this research we present the design, development and evaluation of ARTAB, a technological assistant for people who are blind that uses Augmented Reality to identify a set of objects in an indoor environment.

2. ARTAB

The ARTAB software (Augmented Reality Tags for Assisting the Blind) has been designed and developed by using a user-centered methodology (Deutsches Institut fu□r Normung, 1998), working with the end user from the very beginning of the design process, considering his ways of interaction and interests, and making him an active participant in the design and development process. In order to achieve this, usability methodologies were fully used (Nielsen, 1993; Wells, 2006) in the various stages for the design and development of the application.

2.1 Architecture Model

For the design of ARTAB, a development model of mobile applications was used (Sánchez, Sáenz and Baloian, 2007; Sánchez, Flores and Baloian, 2007).

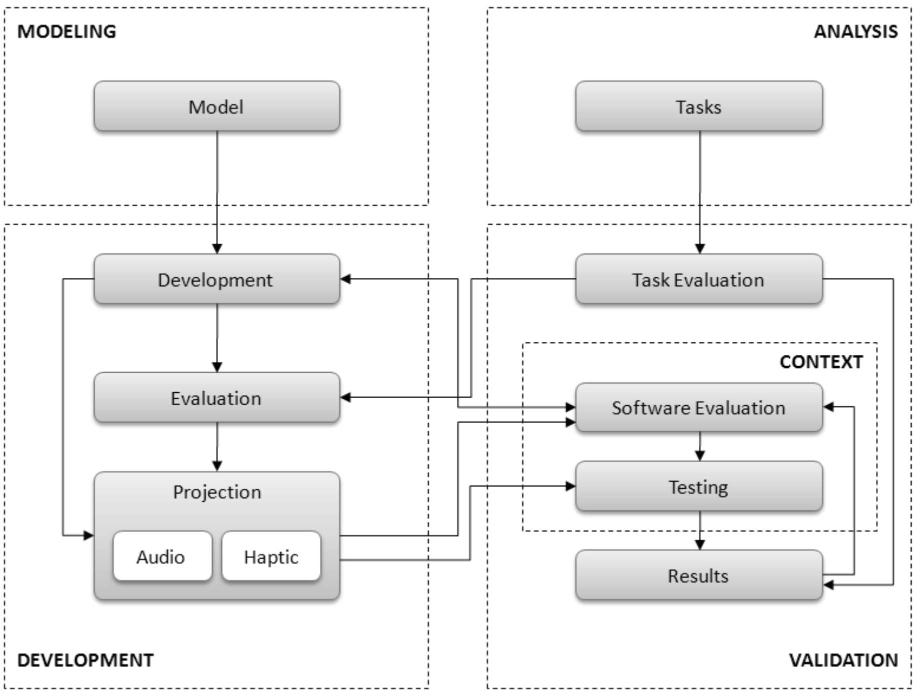

Figure 1. *Model used for the design of ARTAB (*Sánchez, Sáenz and Baloian, 2007).

Modeling: This component corresponds mainly to how the environment that the user will navigate will be represented. To do this, parts of the environment have been marked with special tags for the significant points and objects. These tags will be recorded through a video capture device, and interpreted by ARTAB.

Development: The development process of the system consists of specific stages that allow for the creation of an application that fulfills the proposed objectives. Overall, the application is to be accessible for people with visual disabilities. In the case of ARTAB, accessibility is provided by an audio-based and haptic interface, and by the navigation pad used to ask questions of the system. ARTAB provides information (output) through pre-recorded TTS (Text to Speech) and spatialized audio. The user's interaction with the device (input) is performed through his position relative to the camera, regarding the tags and a navigation pad.

The projection determines how the information should be represented through audio, and the mode of interaction. This information is necessary for the system to be functional for the user. In ARTAB the spatial sound heard by the user corresponds to his position relative to the tag, measured by the camera that the user wears. The evaluation implies determining whether or not the system is correct in the data that it evaluates and the information provided to the users.

Analysis: With the purpose of analyzing the use of the system developed, specific tasks had to be designed in order to study the correct impact of the use of the system on the users. To evaluate the usability, tasks involving navigation through places unfamiliar to the users who are blind were designed. The users had to find certain objects, represented by the tags.

Validation: This stage allows for improving the system, redefining the interfaces in order to improve the user's interaction. With the intention to revise the performance of the users on the defined tasks, tests were made that allowed for the correction of errors in the design of the platform. This process was essential for improving the pertinence of the system regarding how the users interact with a mobile system. During this stage, usability evaluations were held in a real-world context that consisted in using the system to evaluate the mode of interaction and the input and output interfaces.

2.2 Interfaces

ARTAB is an application that uses visual tracking, used in Augmented Reality applications, to identify certain objects of interest within a real environment, through the use of a video capture device. The idea is to detect the objects in order to generate a virtual audio-based representation that allows the user to know the objects position within the range of vision allowed by the device.

The application runs on a laptop computer, and prior to its use in the real environment, the important objects in the environment are identified and assigned with a tag, which is a square with a unique monochromatic design (Figure 2). A webcam is situated just on the user's forehead, in order to use neck movements to direct it in a certain direction between the different tags. The user interacts with the application through a small navigation pad.

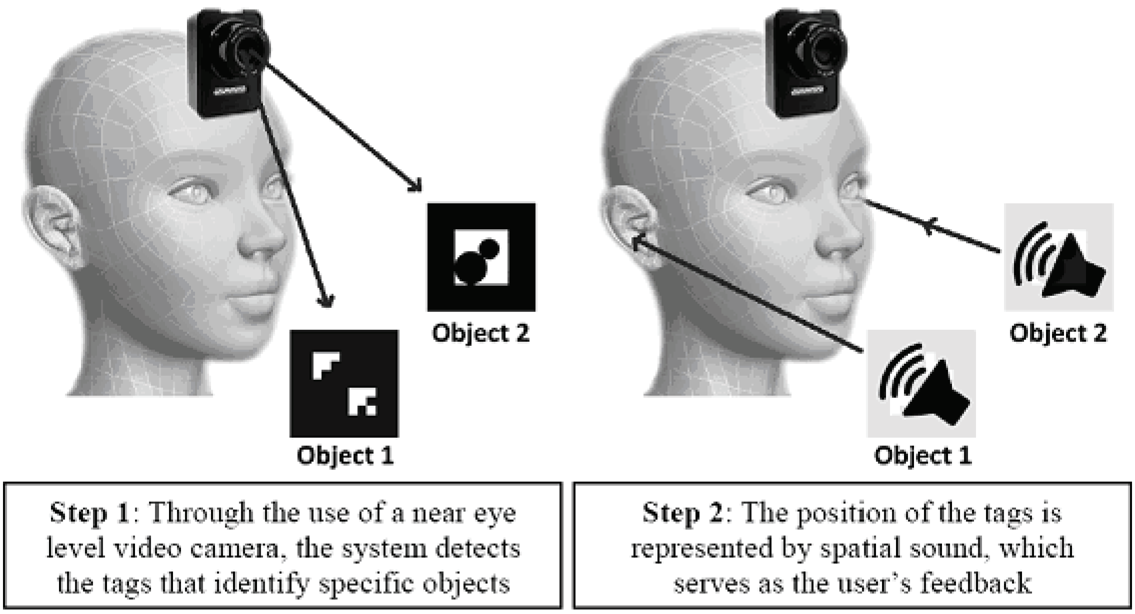

Figure 2. *Overall ARTAB system performance.*

Identification of the tags will only occur within the visual field that the video capture device allows. The image obtained is divided into two, concentric and rectangular sectors (see Figure 3). When a tag is identified within the first sector, a constant and characteristic sound alerts the user of its presence within the visual field. When the user is positioned in the middle, which corresponds to the second sector, he can ask for information on the object by pressing a certain button in the navigation pad.

Due to the fact that the perception of 3D sound varies depending on the hardware that is used (which is to say that using quadraphonic sound is not the same as using stereo headphones), a representation that allows us to position a sound source in a 3D environment by varying certain properties has been developed. For the horizontal axis, the channel varies by where the constant sound is emitted; the vertical axis varies the pitch of the sound, and the axis that is perpendicular to the observer varies the volume.

Although there are approaches that use tracking to identify objects (Zhang, Ong and Nee, 2009), the idea of this study is to incorporate an audio-based interface that allows the user to obtain information when the objects are right in front of him, without feeling saturated by possible information overload.

We believe that the use of this system, and overall of the audio-based interface, will allow users to identify objects more easily in his own context, in such a way that it is almost like being a user without a visual disability.

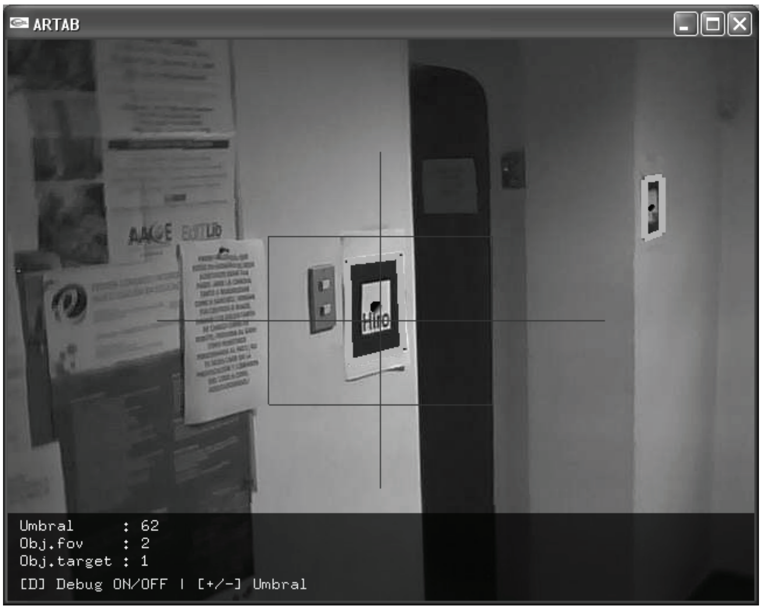

Figure 3. *Graphic interface used by the research team (facilitator), observing the two sectors utilized by ARTAB, When the tag has been identified, the central sector allows the user to ask questions about the object that is in front of him. In being outside, the spatialized sound provides the user with the position of the tag.*

The use of spatial sound is based on previous studies that point out that its use allows for the development of learning and overall cognitive abilities in people who are blind. Several applications use spatial sound to help children to develop navigational and problem-solving abilities. Among these are AbES (Sánchez, Tadres, Pascual-Leone and Merabet, 2009) and AudioDoom (Sánchez and Zúñiga, 2006). Another experience uses stimuli to simulate visual signals in people who are blind, using 3D audio-based interfaces, allowing the users to be able to locate specific points within a 3D space (Sánchez and Sáenz, 2005).

2.3 Development

ARTAB application was developed using Microsoft Visual Studio.NET and C++ programming language, to be used with a Windows XP operating system or newer. This application uses ARToolKit 2.7.1 for tracking and OpenAL 1.1 SDK for 3D sound. A Creative Webcam was used as video capture device, with a resolution of 640 x 480 pixels and a capture rate of 30fps. For testing, we use an Intel Core 2 Duo 2.00GHz and 2 GB of RAM. The installation of the application needs 20 MB of hard disk. The audio output interface was normal headphones without special features.

3. USABILITY EVALUATION

3.1 Sample

For the usability evaluation of ARTAB we have considered a sample of 10 totally blind users with ages that ranged between 15 and 50 years old. All of them lived in the city of Santiago, Chile. The sample was made of 4 women and 6 men. None of them had any other neurological deficits. All of the subjects in the sample are users of the JAWS software (which allows users to read the content presented on a computer screen), and are thus accustomed to listening to TTS instructions at a certain speed.

3.2 Instruments

The Prototype Interface Evaluation Questionnaire was used, which allowed us to quantify the degree to which the sounds used in the application were recognizable. This questionnaire asked questions about the quality of the sounds associated with different actions in the simulator, such as object alerts and TTS. As an annex to this questionnaire, an Understandability Questionnaire was applied to the users, which included questions such as: It was possible to know the relative position of the objects? Did you like the sounds used for feedback in the software? Do you think that the software provides enough information? What other kind of information would you add to the software? The idea was to come to gather knowledge about aspects related to orientation and mobility that make up the focus of the software, as well as the use of the controls, the information provided by the software, and the user's navigation in the virtual environment. The results of this evaluation allowed us to redesign and improve the user interfaces.

Once the corrections and redesign of the software had been carried out, the End-User Questionnaire based on Sanchez's Software Usability for Blind Children Questionnaire (Sánchez, 2003) was administered. This questionnaire consists of 14 items for which the users must define to what degree each of them was fulfilled, using a scale ranging from 1 ("a little") to 10 ("a lot"). The results allowed us to evaluate the usability of the software according to the user's satisfaction, using sentences like that "I like the software", "The software is motivating" and "I will use again this software", the freedom of use and control, using sentences like "I felt in control of the software's situations", "The software is interactive" and "The software is easy to use", and the use of sounds, with the sentences "I like the software's sounds", "The software's sounds are clearly identifiable" and "The software's sounds provide me with information".

3.3 Procedure

Three usability questionnaires were applied. First, the Prototype Interface Evaluation Questionnaire was completed in one 20-minute session, for which the evaluator reproduced each of the sounds and asked the user to provide the sensation or source that he associated with the sound. In addition to this, the tone and speed of the TTS used in the application were tested.

Then, the users worked with ARTAB for a 40-minute session. To do this, a series of tags were placed in a room, in which each one corresponded to a particular object. The users had to navigate the room, locating all of the objects, and informing the facilitator on what they were (Figure 4).

Figure 4. *Users who are blind utilizing ARTAB. A) The user focuses on the object that he wants to ask about, using neck and body movements. B) One member of our research team, in his role as the facilitator, analyzes what the user perceives through the system.*

When the user completes the task of recognizing the tags, he proceeds to respond to the Understandability Questionnaire regarding navigation with the software, taking the amount of time that he deems necessary, with the help of a facilitator.

Finally, the user completed the End-User Questionnaire with the help of a facilitator, who reads the questions and completes the answers given by the user. By considering the results and data obtained from all these evaluations, the software was redesigned to improve the audio interface.

3.4 Results

From the End-User Questionnaire, we can interpret that the software was highly usable and understandable by blind users (Satisfaction=8.4 points and Control & Use=7.4 points, out of a maximum of 10) (Figure 5). In the "Satisfaction" category, the statements that obtained the highest scores from the users corresponded to "I will use again this software" and "The software is motivating" (9.3 points).

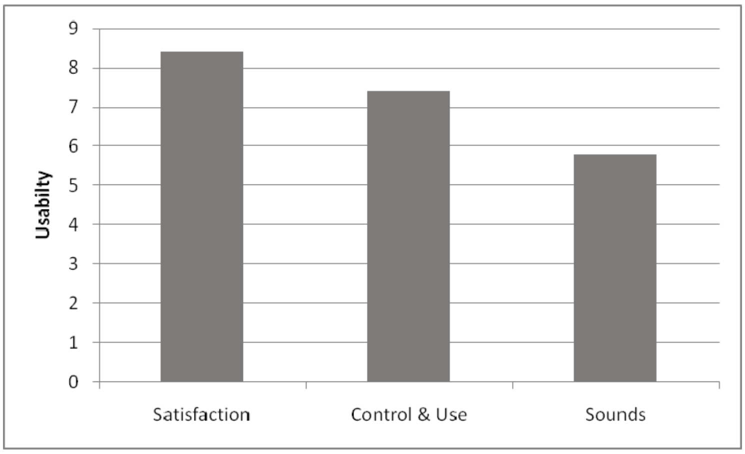

Figure 5. *Results of the End-User Questionnaire.*

The "Control & Use" category obtained a score of 7.4 points due mostly to the fact that the system does not allow for total control by the blind users. That is to say, they could not access the initial configuration menus, nor can they initiate a new navigation, and thus they are limited in that they must be in the company of a sighted person as a facilitator in order to initiate a session. This was reflected in the score obtained by the statement, "I felt in control of the software's situations", which received 6 points of a total of 10, which represents the lowest evaluation in this category. Also in this category, however, the statement that obtained the highest score was "The software is easy to use" (8.7 points). This result denoted the ease of use achieved by ARTAB. The statement with the second highest score was "The software is interactive" with 7.7 points. The "Sounds" category obtained the same results for its two statements, "I like the software's sounds", "The software's sounds are clearly identifiable" (5.3 points). The third statement, "The software's sounds provide me with information" obtained 6.7 points. The problem was that the users who are blind do not note the pitch differences to represent up and down location of the objects.

Regarding the questions on the Understandability Questionnaire, the users recognize that ARTAB allows them to locate objects of interest immediately within the context in which the system is used. They believe that the use of the TTS is adequate, and that this tool can be effective and useful. However, it was noted that in several cases the users did not like the audio feedback used to represent the position of an object that much. They suggested that instead of using a sound that is similar to radar, musical notes should be used in order to indicate the vertical position of the object. The increase or decrease of the volume, as related to the depth, should be more notable, and the navigation bar should be taken better advantage of, in that with 4 buttons the users think that the three remaining buttons might include some additional functions. Together with this, the users that tried the tool felt that ARTAB could be useful and even found other possible applications, such as labeling medicine jars, in which a system with such characteristics could make life easier for them, and make them more independent.

4. PRELIMINARY COGNITIVE EVALUATION

4.1 Sample

For the preliminary cognitive evaluation of ARTAB we considered a sample of 3 users who are blind (totally blind) with ages that ranged between 21 and 30 years old. The sample was made of one woman and two men. None of them had any other neurological deficits.

4.2 Instruments

All the users participated in a test session, for which the material that appears in Figure 6 was created. This material is a representation of what the camera records. The recording is divided into sectors, and subdivided into quadrants. The borders of these quadrants are highlighted, so that the user who is blind is able to distinguish them.

To obtain quantifiable results with this material, an instrument was designed to measure the level of cognition regarding recognition of the laterality of the sounds. To do this, the evaluation consisted of 3 evaluative criteria: (1) Achieved, if at the time of the evaluation the activity could be performed in its entirety, and independently, for which the user was assigned 2 points; (2) In process, if at the time of the evaluation the user was incapable of performing the activity, being assigned a score of 0 points. The maximum score that could be achieved was 10 points, which is consistent with having correctly located 5 sounds in their corresponding quadrants. This instrument was validated by educators who are experts in visual disorders.

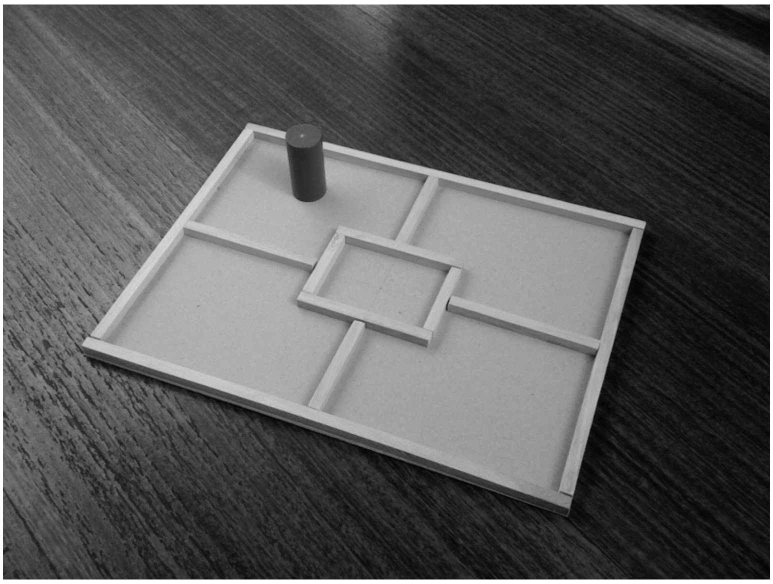

Figure 6. *Test material utilized for ARTAB.*

In addition to using this instrument, non-participant observation was performed in order to detect the way in which the users worked with the ARTAB system while they navigated through an unfamiliar indoor space.

4.3 Procedure

The users were presented with the test material and the division of the sectors was explained. Then, sounds corresponding to the 3D location of the object were played (depth was not used), and the participants had to position the cylinder in the sector that represented the location of the sound in the given quadrant. Five different sounds were played, with differing positions. As the user worked on the material and sounds were played, the facilitator filled in the level of the user's achievement on the specified guideline sheet.

Once the testing had finished, the users navigated using the system by following a route within an indoor space. To do this, they had to navigate from the parking garage on the first floor of the building to the hallway on the second floor. They had to identify doors and the stairway through the use of the proposed system. It is worth noting that the building that they navigated was totally unknown to them.

4.4 Results

The results obtained show that the blind users are able to identify the horizontal sounds represented without any difficulties (9.0 points out of a total of 10 possible points), indicating with precision whether these were located to the right, left or directly in front of them. However, the results obtained regarding identification of the vertical sounds were low (5.0 points). During the test, the users were not able to distinguish if the sound was coming from above or below them. This meant that they were sure of where the object was located horizontally, but not vertically, which translated into frustration due to the fact that the users constantly asked the application about an object that they thought was right in front of them. This brought us to understand that identification of up and down is not a trivial matter for the users, utilizing a system of pitch change in the audio (2 points).

It was observed that the association of the pitch with height was only achieved when the users compared the sound with that which was emitted if the object was correctly centered. This comparison caused the users to spend more time on the vertical alignment than on the horizontal alignment. This implied the provision of assistance in order to indicate when the object was vertically centered, so that the users could then identify if the source was originally above or below them.

The mental model of the users allowed them to associate horizontality with the use of the left and right channels, and depth with volume; but regarding height, there was no unanimity as far as how to represent it. This dispersal was observed from the evaluation performed, and is key to be able to provide users who are blind with autonomy.

The non-participant observation shows us that the users have problems navigating naturally with the device. This is to say that the ARTAB system is not fast enough in its detection of tags, and thus is not able to identify the objects and transmit the information to users who are blind.

The users are able to control the system with slower movements, so that the camera is able to detect the tags and is thus able to provide the user with correct information. Once the users were able to correctly manage the system, it allowed them to find the correct route adequately. The three participants were able to perform the entire route with total autonomy, using only the proposed system. It was even possible for them to be able to identify the stairway and the landing that is half way up the stairs, without the need for any assistance whatsoever. The level of tags used allowed them to be able to identify navigational routes through the building; however it is not very probable that it would be possible to provide them with specific information on the smaller objects located in the space. This is due to the visual tracking that is provided.

It was also observed during the tests that the younger users were able to use ARTAB more fluidly than the older participants. The younger users, who still had problems using the pitch effect in order to identify the vertical position, were able to overcome this weakness quite well after a few minutes of practice. Although this is positive, we cannot fail to mention the users that did experience difficulties, as this is a point that could mark the difference between choosing to use ARTAB or not.

5. CONCLUSIONS

The main purpose of this research was to design, develop and evaluate ARTAB, a technological assistant for people who are blind that uses Augmented Reality to identify a set of objects in an indoor environment. As a result, we generated audio-based representations that allow a user to determine the position of an object relative to the angle of vision of the video capture device for navigation purposes.

ARTAB is a tool that seeks to assist people who are blind in contexts in which it is necessary to identify certain objects of interest in order to perform a specific navigational activity. It was sought to utilize a representation that would allow users to identify the position of an object relative to themselves through the use of sources of spatialized audio that can be heard through stereo headphones. Due to the fact that the use of the headphones does not allow for the three-dimensional perception of the height and depth from the audio sources, we chose to assign the variations by pitch and volume respectively for the representation of these elements.

According to the usability results from the Understandability Questionnaire, it is clear that the representation on the horizontal axis of a sound source, using the left and right channels respectively, is natural for the users. Even during testing, not one participant had problems aligning the objects on this axis.

One negative point that was detected was the use of the pitch effect. Although in the test activity, the users were told of the significance of this variation, it was quite difficult for them to detect the position of a particular tone. This is to say, the users had to vary the sound manually, moving their head up and down, in order to know the vertical position of the object, represented by a certain audio source.

The users determined that the representation of distance through volume is adequate, granting this aspect a positive affordance. However, it ended up that the variation of this element was too dramatic, in that many participants felt that this aspect of the sound lacked a clear contrast in order to be able to obtain more specific information.

Even taking these negative points of usability into account, the users felt that ARTAB is a useful application that could help them in their daily orientation and mobility tasks. In responding to the End-User Questionnaire, the users even proposed more specific uses for this application, such as for detecting medicines and the contents of containers, thus increasing their autonomy.

Finally, the users that tried ARTAB felt quite enthusiastic about the application, and hope that corrections are made regarding the vertical and depth positioning, in order to be able to use it in environments that they navigate on a daily basis.

6. FUTURE WORK

It is necessary to continue improving the ARTAB system in light of the usability results obtained. In a new version of the system, the upper and lower parts will be divided into 4 sections each, making for a total of 8 sections. When an object is located within a particular section, it will be represented vertically by a musical note. In this way, ARTAB will represent the vertical position of the objects with a musical octave. We believe that by optimizing the vertical plane, users will be better able to vertically align the objects, generating detection ranges and by using clearly identifiable sounds.

Together with this, the variation of the volume according to the distance must be corrected, adding the function of being able to obtain the approximate distance to an object in meters. This can be achieved by associating the size of the object with its tag, and estimating the distance from the video device based on the dimensions that the object has in the image from which it is viewed.

Once the improvements in the interface have been completed, efforts should be focused on improving the visual tracking system, using other software libraries. This can lead to working directly with computer vision algorithms, transforming the data obtained from an image into information that can be used by our interface.

Currently, we are working on a refactoring process. In particular, the code is being modularized with three main modules: (1) Interface, (2) Application Intelligence, and (3) Modeling the data captured, following an MVC pattern (Gamma, 1995).

Finally, we want to study the option of bringing the system closer to the reality of users who are blind, providing it for use with other hardware platforms to which such users have accesses, such as mobile phones. To do this, it is necessary to consider the processing ability of the phone, to determine if it is possible to perform visual tracking in an optimal way, and to support the energy that is required for the generation of spatialized audio feedback.

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