Using augmented reality to support the understanding of three-dimensional concepts by blind people

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ABSTRACT

Seeing and describing real and imaginary three-dimensional scenes from the observer's viewpoint is an intuitive activity for non-impaired people, but it is difficult for congenitally blind people, once it involves abstract concepts for them, such as: perspective, depth planes, occlusion, etc. This paper discusses the problem related to understanding three-dimensional concepts by blind people and presents physical environments and procedures supported by an augmented reality tool in order to help blind people to understand, describe and convert three-dimensional scenes into two-dimensional embossed representations, like painting. To verify how the blind people can acquire those concepts, we developed an augmented reality application, working as an audio spatial tutor to make the perspective learning process easy. That application was tested with ten congenitally blind people, who understood the perspective concepts and made comments about the experience. Finally, we discuss the learning method and technical aspects, pointing out directions to improve the augmented reality application and ways to release it.

1. INTRODUCTION

Access to information depends mainly on visualization to understand complex structures based on texts, graphics, representations, pictures, animations, videos, etc. In this way, the main problem caused by blindness is the absence of visualization requiring another senses to replace the vision function, such as touch and sound (IMS GLC, 2002), whose use depends on different technologies and application domains.

The first approach to give information to blind people involved embossed writing, Braille writing and talking books (recorded speeches). Using computer and new technologies, many other resources came to help blind people, such as: screen readers, audio browsers, digital talking books, multimodal hypermedia interfaces, synthetic human speeches, non-speech sounds, tactile graphic displays, video description, haptic devices, etc. (Spirkovska, 2004). The newest technologies, involving virtual reality and augmented reality (Kirner and Kirner, 2008; Azuma, 1997), extended the concept of information for blind people, giving them access to static and dynamic spatial information in real-time with the use of GPS, three-dimensional (3D) accelerometers, computer vision, sounds and speeches. Nowadays, blind people can see with their ears, recognizing sound patterns associated with things and scenes through augmented reality technology (Meijer, 2010; Layar, 2010), using notebook or mobile phone.

By another side, there are many specific domains of information that depends on modes of presentation that fall outside the bounds of pure text (IMS GLC, 2002). Among those contents, there are: Mathematics, sciences, charts, diagrams and tables, Geography and maps, arts, etc. For those areas, 3D concepts involving perspective, depth perception, shadow, occlusion, etc. are too important but difficult to understand by congenitally blind people.

Sighted people use perspective and related concepts intuitively during the vision process, but they need to learn how to represent 3D onto a flat plate. Those concepts appear in photos, realistic pictures and in textual or oral description of real scenes. Congenitally blind people, who never had experienced vision, present

difficulty to understand depth in a picture converted into embossed print or draw. They understand a scene made by 3D models (miniature) and the surfaces of the models or the front plane of a picture.

This paper has some questions to be answered, such as: (i) How can blind people learn 3D concepts aiming to be able to convert explored 3D environments into pictures? (ii) How can we develop a spatial audio tutor with augmented reality technology to make easy the understanding of 3D concepts by blind people?

This paper presents an augmented reality application working as a spatial audio tutor to make easy the understanding of perspective and related concepts without the necessity of a specialist to conduct the learning process. The system uses audio streams associated with spatial positions that can be activated by blind users. To test the application, ten congenitally people have used it, making comments about the learning of perspective concepts.

2. RELATED WORK

Visual concepts for blind people, like perspective draw and spatial cognition representation from several viewpoints, are themes studied and experimented by scientists who are searching technologies and methods to allow teaching and learning spatial representation.

Kennedy, Gabias and Heller (Cheadle, 1990) have discussed the relations about pictures and the blind, showing that is possible for the blind to understand and represent space as he/she is intensively exposed to tactile drawings.

How can a congenitally blind recognize an embossed picture by touch if he/she did not have experience with objects and space representation? (Kennedy, 1993) The answer for this question involves studies of vision properties, geometry, depth, projection, occlusion, scale, edges, vertices, corners, surfaces and color shades, among others, by blind people (Kennedy and Juricevic, 2006; Heller and Kennedy, 1990; Klingenberg, 2007). It is a difficult process, as it involves abstract concepts for congenitally blind people, but these concepts can be learned and trained, giving them better conditions to recognize real and imaginary world representations and even represent them (Heller et al, 2005).

Pictures for listening (Othman and Levanto, 1996) was a project developed with a partnership, involving an art university, a museum, an association of visually handicapped and a broadcasted company, aiming to plan and produce packages containing relief pictures, booklets in bold type and Braille and sound pictures. A sound picture is an audio mixed with narrated text and sound effects.

Otherwise, projects like ACCESS (Petrie et al, 1996) have explored the access to information in computer hypermedia system including effective representation of information in Braille, synthetic speech and sound with support for navigation and use by blind students.

However, it is important to associate sound, speech and force feedback to points in 3D space to allow blind people to explore spatial environment with feedback. Virtual reality provides a model to explore 3D virtual space with feedback, as it allows spatial control by the user through special devices, such as: gloves, haptic devices, etc. The blind user could explore the virtual environment, sensing or touching things by sound or force feedback and navigating on it from different heights and viewpoints (Brewster and Pengelli, 1998; Inman et al, 2000). The advantage of this approach is the freedom to choose height, speed, scale and other parameters when the user explores the virtual environment. The disadvantage of that approach is that the virtual environment is not real and untouchable with free hands.

To overcome the disadvantage of virtual reality environments, augmented reality can be used to superimpose virtual environments over real environments allowing the transference of sound properties from virtual objects to real objects, which are coincident. In this way, when the user touches a real object with his/her hand, the augmented reality system can identify that collision activating a specific sound or speech. Figure 1 shows the activation of a 3D object with its sound in an augmented reality application using cards (markers) interaction under a webcam.
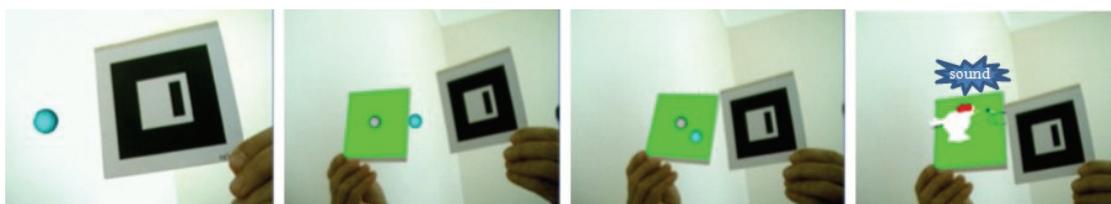
Figure 1. *Activating sound in an augmented reality application based on cards.*

Products, such as Layar (Layar, 2010) and The vOICe (Meijer, 2010), are exploring augmented reality systems associated with GPS and spatial orientation to produce sounds and speeches related to the point of interest or patterns of the scene. Projects, such as: Hear & There (Rozier et al, 2000), Guide by Voices (Lyons et al, 2000) and Outdoor Augmented Reality Environments (Goudeseune and Kaczmarshi, 2001), also explore sounds and speeches in outdoor environments with augmented reality technology.

3. ENVIRONMENT TO UNDERSTAND THREE-DIMENSIONAL CONCEPTS

Blind people have natural perception skills for touching and recognizing miniature spatial environments and embossed front pictures, according to Figure 2. So, it is necessary to find a way to convert those representations to embossed two-dimensional (2D) representations showing mainly depth and scale variation of objects in a 3D scene.

Figure 2. *Handling a miniature environment and embossed front pictures.*

We decided to use a method based on four environments, according to Figure 3, to do that conversion.

a) Miniature 3D environment.　　b) 3D perspective representation.

c) 3D Perspective with embossed models.　d) Perspective embossed representation.
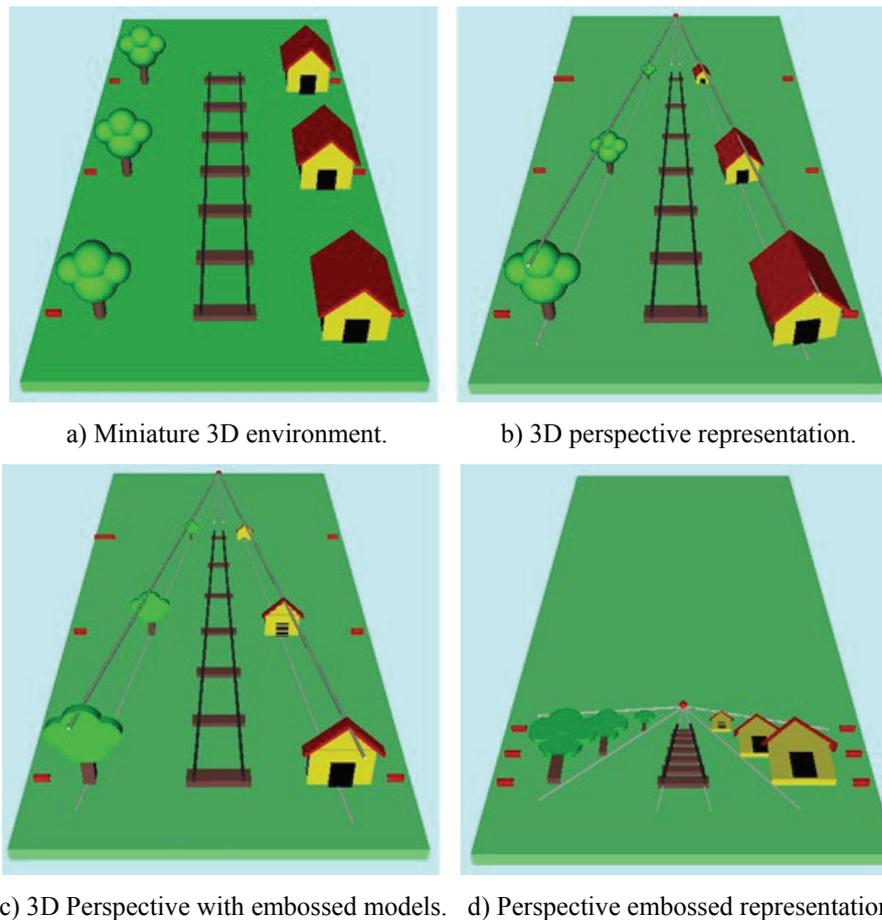
Figure 3. *Four environments used to learn 3D concepts.*

The four environments are the following:

i) Miniature 3D environment using simplified 3D models of houses, trees and railroad;

ii) 3D perspective representation of the first environment using different scales of those 3D models, depending on the depth, and showing the convergence lines going from the observer to a specific point. Big models are closed to the observer and small models are far from the observer considering a specific viewpoint;

iii) Representation of the second environment using embossed 2D models replacing the 3D models. Besides the different scales, the 2D models present different thickness, so that closed models are thick and distant models are thin. To get the embossed representation, all 2D embossed objects need to be laid on the picture plane;

iv) 2D embossed representation of the third environment compressing the depth planes, or relocating the convergence point. This representation is an embossed picture.

Using the four representations, blind people can explore the environments to learn 3D concepts and a technique aiming to convert real or mental scenes in an embossed picture.

In the first environment (miniature 3D environment), the idea is to allow blind people to explore a specific miniature 3D environment in order to be familiar with the objects in the scene.

In the second environment (3D perspective representation), the blind users could learn concepts of perspectives, including depth planes, different scales of the same object depending on depth, convergence lines, etc.

The third environment (3D Perspective with embossed models) only replaces the miniature objects by equivalent embossed objects with different thickness depending on its position in the scene. On the first depth plane, embossed object representations are thick and on the last depth plane, embossed object representations are thin. This environment is intermediary between the second and fourth and prepares objects to be placed in the fourth environment.

In the fourth environment (Perspective embossed representation), when the blind user would be already familiar with the miniature environment and its respective perspective 3D representations, he/she could pick up the scaled thick or thin embossed objects to adjust them laid on a flat (2D) plate, creating an embossed picture. This action creates an embossed picture so that objects with specific thickness participate on specific depth planes. In this case, occlusions can appear when a laid object from one depth plane overlaps another object from other depth plane.

Once a blind user understands the whole representation process, converting a miniature 3D environment into a 2D embossed picture, he/she can execute the reverse process converting embossed pictures into real or mental 3D environments. In this way, a blind user can express himself/herself in graphical arts, creating and explaining embossed pictures for his/her visually impaired colleagues and non-impaired people.

4. AUGMENTED REALITY TOOL TO SUPPORT BLIND PEOPLE IN LEARNING PROCESS

An augmented reality tool to support blind people in learning process must present characteristics and satisfy certain requirements, such as: spatial positions defined by authors, virtual objects with associated sounds, simple installation, easy authoring, authoring independent of programming, intuitive use, tolerance in touching spatial positions.

In order to support blind people in learning 3D concepts, we developed an augmented reality tool named "Augmented Reality Authoring Tool for Non-Programmers - ARAS-NP" (Kirner and Santin, 2010) using ARToolKit (Kato and Billinghurst, 1999). With this tool, an author can develop applications for blind users defining and associating touchable spatial positions with virtual objects and sounds (Figure 4a). Virtual objects are used to guide the authoring while sounds are used by blind users. To develop applications, the user can use paddles and functions keys (Figure 4b). To explore applications, blind users can manipulate one or two markers to activate points and hear their sounds.

4.1   Structure of the Augmented Reality Environment

The augmented reality environment, as considered in this work, presents virtual objects with their respective sounds on spatial points defined by the developer (Figure 5a). In order to be touchable by the blind user, each spatial point has an embossed point on the physical board or over the physical objects of the environment, in

which audible information will be retrieved. Each spatial point can have associated with it only one pair of virtual object and its sound or a sequence of several pairs, which will be activated by blind user one by one when he/she place a marker over the embossed point.

| a) Spatial points. | b) Paddles and function keys. |

Figure 4. *Augmented reality environment for blind users.*

Moreover, the augmented reality environment can be customized after authoring through copying, moving and deleting specific points and virtual objects with their respective sounds.

4.2   Data Structure and Folders

The data structure of the augmented reality environment to be authored comprises reference markers, which have associated virtual boards, and their respective elements (points, virtual objects and sounds) that appear on the board, according to Figure 5b. Those elements must be placed in folders (Figure 5c) that the developer needs to manipulate to create the augmented reality environment.
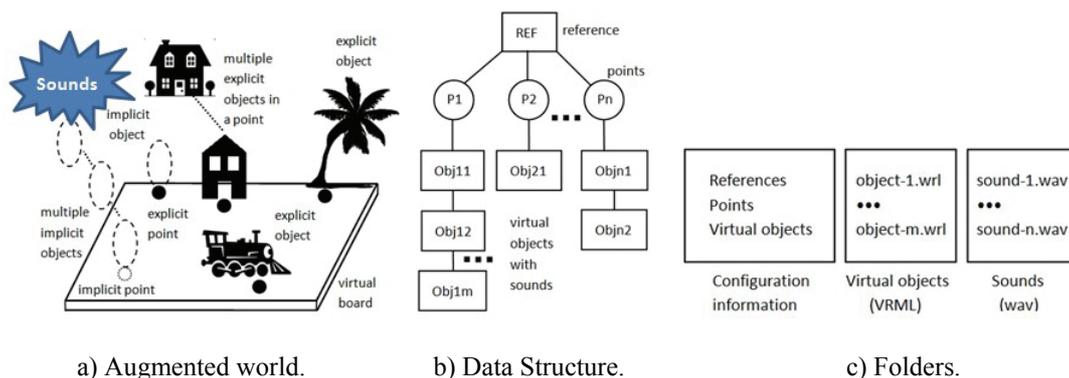
| a) Augmented world. | b) Data Structure. | c) Folders. |

Figure 5. *Structure of the augmented reality environment.*

The tool has three folders: configuration, virtual objects and sounds. Details about folders will be explained in the next subsection.

4.3   Authoring Interface

In the authoring phase, the application can be developed in two ways: i) visual actions carried out under a webcam (Figure 6a) complemented by editing file; ii) editing files associating points, objects and sounds. The resources, which are used to create points and associated objects with sounds, comprise action markers, keyboard keys, mouse buttons, configuration files and folders.

4.3.1 Action Markers. Action markers allow tangible actions interacting with spatial points and virtual objects (with sounds) placed on or over a virtual board, according to Figure 6. They can be used during authoring or utilization phases.

In the augmented environment, spatial points and virtual objects have visible or invisible virtual spheres associated with them, whose radius can be adjusted by the user, allowing variation in precision during the selection process. Each marker also has an associated visible virtual sphere that can collide with the virtual spheres of points and virtual objects.

An action marker can select a point or virtual object and carry out a specific function on it. The movement of an action marker in the board area allows collision of its virtual sphere with the virtual sphere of a point or virtual object of the augmented environment, selecting or deselecting the point or virtual object and activating the respective sound. The gesture of the action marker, like inclination, occlusion, or time remained selecting, can execute actions on the selected point or virtual object, activating sounds.
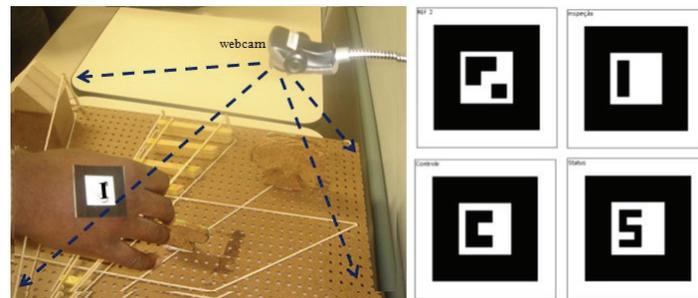
Figure 6. *Action marker working under a webcam.*

These markers are: inspect (show the virtual object of the selected point, activating its sound); control (show the next virtual object of a list associated with the point, activating its sound); transport (take a virtual object from a position to another one); erase (delete a point and its associated virtual object with sound or list); status (show a virtual plate with information about the system); lock (lock or unlock remote actions on virtual objects associated with a point, being useful in collaboration tasks); copy (replicate a virtual object with sound to be placed in a position of other reference environment), and path (allow the creation and visualization of a visual path from a position to another one).

Simple applications can be developed with no markers and used with one or two markers and simple few configuration files, making easy the development.

4.3.2 Keyboard Keys and Mouse Buttons. Specific keyboard keys and mouse buttons activate complimentary actions working alone or in conjunction with action markers.

Those keys and buttons can activate or deactivate: visualization of points and virtual objects, activating the respective sounds; remote operations; path creation; status visualization; persistence of virtual objects; etc. They can also control the position and radius of the sphere associated with the marker, aiming to improve precision and performance in the selection process. As less is the radius of the sphere, more difficult is the selection, but in some cases, when there are many closed points, it is necessary to get better precision to be successful in the operation.

Mouse buttons actuating in conjunction with the inspector marker allow visual creation of points in the augmented environment and in the respective file that can be configured later by editing.

4.3.3 Configuration Files. Configuration files must be created by the user or edited from the sample files available in the authoring system or from previously created files in the visually points creation process.

Those files contain authoring information supplied by the user in order to prepare the augmented reality environment for use or for complimentary visual configuration. The configuration files are:

- *Reference Marker Information (one file for each reference marker).* This file contains: address, position, orientation, scale and sound of the virtual board and address of the points list associated with the marker;

- *Points List of a Reference Marker (one file for each reference marker):* This file contains: position and list of virtual objects (with sounds) associated with the point 1; …; position and list of virtual objects (with sounds) associated with the point n.

- *Virtual Objects List of a Point (one file for each point).* This file contains: address, position, orientation, scale and sound of the virtual object 1; …; address, position, orientation, scale and sound of the virtual object m.

A simple text editor should be used to create or edit configuration files.

4.3.4 Folders. Folders are resources filled by non-programmer developer, which contain useful information to create the augmented reality environment. There are three folders: configuration information, virtual objects, and sounds, according to Figure 3.

Configuration information folder contains configuration files related to reference markers, points, virtual objects and behavior vectors. Virtual object folder contains VRML three-dimensional models, found on the Internet or created by three-dimensional authoring software. Sounds folder contains sounds associated to virtual objects found in sounds libraries or recorded by the developer.

The contents of folders must be filled before using, but they can be modified during the utilization phase, mainly some configuration files.

The system also has commands to save and recover it in order to allow the interruption of the authoring process, which can be continued later.

4.4 Utilization Procedures

In the utilization phase, the blind user should manipulate the augmented reality using tangible actions with specific markers. The most used is the inspector marker, which allows the exploration of the environment, placing it over embossed spatial points and hearing their respective sounds. The use of control marker allows the exploration of sounds from the list of pairs (virtual object and sound) associated with a specific point.

However, aiming at giving more power to the system, it is possible to reconfigure the environment during the utilization phase, changing the initial situation of the authoring.

Besides, the system has a specific marker (collaborative ref marker), which allows the networking among several remote users, implementing collaborative tasks. Although potentially interesting, we did not think to use this feature with blind users, exploring sounds in this phase.

5. DEVELOPMENT AND TEST OF AN AUDIO SPATIAL TUTOR

In order to test the learning process of 3D concepts by blind people using augmented reality environment, we used the ARAS-NP tool to develop an audio spatial tutor, which allows blind people to activate spatial points to render sounds and speeches. The application contains spatial points with sounds in two levels (Figure 7): the first level uses the Inspection Marker to activate each spatial point rendering sounds and speeches giving general information about that point; the second level uses the Control Marker to activate each spatial point rendering sounds and speeches from a sequence giving detailed information about that point.
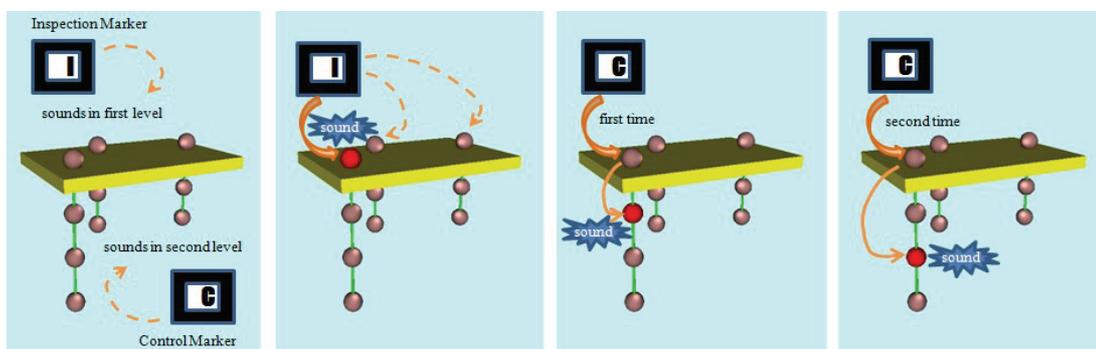
Figure 7. *Activating spatial points with sounds in two levels.*

5.1 Learning 3D Concepts with the Audio Spatial Tutor

The four physical environments used to explain 3D concepts involve 3D miniature environment with 3D objects, 3D perspective representation with scaled 3D objects, 3D perspective representation with embossed scaled 2D objects and 2D perspective representation with laid on embossed scaled 2D objects with occlusion. Those environments were enriched with embossed points over the physical board and objects from which blind users can hear audible information when using the Audio Spatial Tutor configured for each environment. The configured Audio Spatial Tutor contains spatial virtual points, which are coincident with specific spatial physical points of each environment, so that each point contains audio information, which can be activated by certain markers generating sounds. When the blind user explores the physical environment and senses an embossed physical point, he/she places an action marker (Inspector or Control) over the point hearing the audible information, which explains 3D concepts about that situation.

To make the user interaction easy, the markers can be adjusted on a finger or over the hand since the application calibration takes each situation in account.

Blind users have freedom to explore those environments by themselves acquiring knowledge in an independent way and working on a personalized rhythm and navigation in different sequences.

5.2   Testing the Audio Spatial Tutor

To test the Audio Spatial Tutor, we selected a set of ten congenitally blind persons with the following characteristics: four participants were graduate students and six were professionals; seven participants were female and three were male; the participant's age varied from 20 to 53 years.

After a brief instructional session, all participants were exposed to the interactive augmented reality environment, which was composed by the four physical environments augmented with the configured Audio Spatial Tutor.

In the first environment (3D miniature environment), the blind users recognized the physical objects (trees, houses, railroad, etc.) using their natural perception (touching) and hearing information about the scene and objects when they placed markers on the embossed spatial points of the environment.

The second environment (3D perspective representation with 3D models) introduced 3D concepts, such as: perspective, convergence lines, depth planes, viewpoints, etc., using objects with different scales, depending on the spatial depth plane in which the object was placed.

In the third environment (3D perspective representation with 2D embossed models), the depth plane was represented by the thickness of the 2D embossed objects, allowing the perception of distance with different objects and different sizes.

Finally, the fourth environment (2D perspective representation with laid on 2D embossed models) is an embossed with laid on objects. In this case, when embossed 2D objects from the third environment are laid on, some of them can overlap others and the overlapped part of the thin objects need to be cut off to be adjusted. The resulting environment is an embossed picture that can be recognized by vision and by touch, once it contains perspective scaled objects whose thickness represents the depth planes of the scene.

In all four environments, the Audio Spatial Tutor delivered general or detailed audio information to the blind users on each embossed point allowing them to learn perspective concepts and the perspective representation process starting from a miniature environment and reaching an embossed picture (Figure 8).

Figure 8. The *Audio Spatial Tutor in action.*

In order to activate sounds on spatial points, blind users tried to use small size markers on the finger and big size markers over the hand. The webcam was placed on the top of the environment pointing to down (Figure 8).
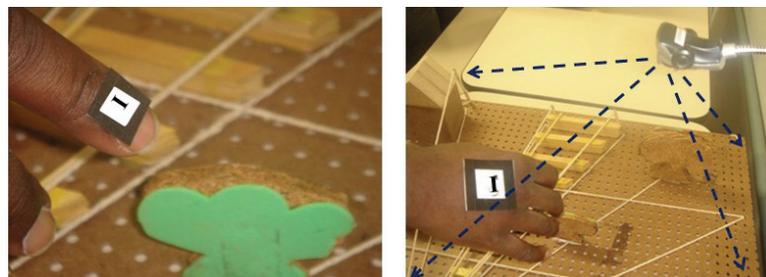
a) Marker on a finger.   b) Marker over the hand.

Figure 9. *Using markers to help the environment exploration.*

Due to the camera quality, light conditions, sizing of the colliding sphere of points and other factors, the blind participants presented initially some difficulty to activate the sounds delaying about one minute to do

that. With the improvement of system calibration and user experience, the time to activate the sounds went down to some seconds.

With this process, congenitally blind users learned how to represent a miniature environment from a viewpoint (front, side, rear, etc.), once they were only familiar with the top representation before. Other important learned concepts were scaled objects depending on the distance of the observer and occlusion of objects depending on the depth planes, which are unusual and abstract for congenitally blind people.

When the blind user is well-acquainted with the perspective representation process, he/she can hear and understand oral descriptions of a 3D scene or picture, such as: what is closed to or far from the observer, what is small or larger depending on the real size and the distance of the observer, what is occluded by other things, etc. Moreover, the blind user can make oral descriptions of real scenes that he/she sensed or imaginary scenes.

At the end of the test, blind users made declarations about the experience, pointing out the acquired knowledge, emphasizing the understanding of embossed or described paintings, the understanding of oral description of real scenes and the ability to draw perspective pictures representing real or imaginary 3D scenes.

6. CONCLUSIONS

We presented and discussed the problem related to understanding three-dimensional concepts by congenitally blind people, showing a learning method, an augmented reality application to support learning (Audio Spatial Tutor) based on audio and spatial positions and an augmented reality tool used to develop the application.

The understanding process occurs in four phases involving a 3D miniature environment, a 3D perspective representation based on scaled 3D objects, a 3D perspective representation based on scaled embossed objects and a 2D embossed picture.

Although 3D concepts are intuitive for non-impaired people, they are abstract concepts for congenitally blind people that can be understood and learned. The congenitally blind people acquired concepts, such as: perspective representation, depth planes, convergence lines, viewpoint, scale dependent on the distance from observer, objects occlusion, etc.

Ten congenitally blind people tested the learning system based on spatial positions and sounds (Audio Spatial Tutor) acquiring 3D concepts in order to be able to perceive, understand and produce embossed pictures representing real and imaginary 3D scenes. After learning 3D concepts, blind people were able to understand descriptions of 3D scenes narrated by non impaired people and to do the same thing increasing his/her social inclusion.

Blind users explored the four learning environments, touching the embossed points and objects and hearing information about them in the 3D and perspective representation context. Using markers on a finger or over a hand under the webcam, the blind user could activate sounds and speeches explaining the concepts related to perspective representation of 3D scenes.

The augmented reality support works as an audio spatial tutor in which sounds and speeches have one or more instances able to be activated in the same point by markers.

Moreover, augmented reality applications for blind users, emphasizing sounds on spatial points, can be authored by non-programmers making easy this task. Blind users can also be authors preparing sound and speech records and configuring files using screen readers.

The Audio Spatial Tutor is being prepared to be distributed for any language as a pack containing: i) plans of the four environments with draws for implementation in foldable paper, or tables with size specifications to be used with other materials like wood; ii) ARAS-NP tool; iii) configured Audio Spatial Tutor for the four environments without speeches; iv) texts of speeches in English to be translated to and recorded in any language; v) free audio recording tool; vi) installing and using instructions and tutorials.

Although the system was conceived to be used by blind people, it can be useful to non-impaired people, who need to learn how to represent perspective draw of 3D scenes.

Finally, we believe that the Audio Spatial Tutor, including the physical environments, learning methods and augmented reality tool can be improved to deal with other abstract concepts for congenitally blind people, such as colors, transparency, shades, etc., giving them better conditions to perceive, represent and describe the world in which they live.

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