METHODOLOGY FOR BUILDING VIRTUAL REALITY MOBILE APPLICATIONS FOR BLIND PEOPLE ON ADVANCED VISITS TO UNKNOWN INTERIOR SPACES

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ABSTRACT

Virtual reality applications for blind people in smartphones were used to make virtual visits in advance to unknown spaces; these need to include a set of cognitive and sensitive interfaces that allow users to use their other sensory capabilities to understand information about their environment and facilitate the interaction with the application, so that the user can make a mental representation of the unknown space. Some strategies were designed to provide continuous and clear information to the user, so that he can perform exploration activities within a virtual environment generated from a real environment with the help of nineteen blind people and five visually impaired people who participated in the development and tests carried out into six workshops, during twenty-four months. During each workshop took logs about the activities that the user did for the recognized and location of objects and structures indoors. This information was stored in a database to be analyzed and interpreted in order to make subsequent modifications to the application, until achieving a tool that is sufficiently useful, safe and accepted for the user. The last applications were built with voice patterns, beeps, vibrations and gestures called sensitive interfaces, and also with a cognitive interface called "Focus of attention" based on proximity and remote exploration. There was is a thirty-eight percent of improved when the participants choose to remote explore the virtual environment with regard to proximity exploration, also there was preference to be warned with low to medium frequency beeps, a fast reproduction of the voice to receive information on objects and structures and simple gestures for the interaction with Smartphone. In the last experience, we used a structure sensor coupled to the Smartphone for user tracking, and bone conduction headphones to reproduce spatial sounds; they said was pleasing to hear 3D sounds with personalized response in bone earphones, for locating objects inside the test scenario; there was a twenty-one percent of improved when the participants using beeps instead of vocals or musical instruments.

KEYWORDS

Virtual Reality Applications (VRA), Interfaces for Blind People, Cognitive Mapping, Sounds 3D

1. INTRODUCTION

The population with visual impairment on our planet is close to 300 million, of which 45 million are blind, made up mostly of people over 50 years (*WHO | Visual impairment and blindness*, 2014), only a 28% are people of working age; the dependence and the fear to move through new environments limits their social and economic growth. In addition, there are 7.1 billion mobile phone owners and 48% of the population has Internet access, with Europe being the most connected (Silvio P. Mariotti (World Health Organization), 2010). Given the technological evolution, a Smartphone is clearly one of the most useful and necessary things in our daily life, thanks to some services and features that provide user (Anshari and Alas, 2015). It is possible to take advantage of current technology and develop virtual reality applications on phones so that blind people use them to perceive the world around them; mobile learning based on the knowledge of the reality and the experiences of the actors in the training process(Liu *et al.*, 2017), can greatly contribute to the generation of alternatives that will be addressed during the investigation. The operating systems that lead the global mobile market are Android and iOS (Baker *et al.*, no date); Unity3D (Unity, 2017) is a multiplatform game development environment that allows the development of high-contrast virtual reality applications and Vibro-Tactile-Auditory support for people who are blind or very low-vision. The systems which use Braille are getting less used by blind people (Leuthold Stefan, Bargas-Avila Javier, 2008), because of the development of new tools with improved interfaces that seize their other senses and fit better to their needs.

One area of virtual reality applications is assisted navigation that allows people to go from one point to another (Karimi, 2011). Outdoor navigation is done using geo-positioning technologies and assisted navigation in unknown home environments require devices and support tools and Wi-Fi/RFID/Bluetooth technologies to store and deliver data to users. Inland navigation requires the development of information models whose construction depends on the spatial complexity and the amount of static data they generate for processing. When the user is blind, the information is centered on audio description, the use of tactile maps or the combination of both; to be able to make a mental representation of its surroundings.

Cobo (Cobo *et al.*, 2017) proposes the use of virtual reality to simulate real spaces as a means for blind people to obtain spatial knowledge of a place before visiting it.

Picinali (Picinali *et al.*, 2014) investigated the possibilities of helping blind people, through learning in a virtual reality environment, by means the construction of mental maps using spatial audio events and their possible interactions in interior spaces.

Orly Lahav (Lahav *et al.*, 2012)(Lahav, Schloerb and Srinivasan, 2015) uses virtual reality applications to help blind people with an early exploration of an environment, allowing participants to develop cognitive maps of the virtual environment. Subsequently with its results the team creates two rehabilitation programs to improve the orientation and mobility of blind people through training in virtual environments.

Rodríguez (Rodriguez-Sanchez *et al.*, 2014), describes several problems in the use of some tactile interfaces and the possibilities of guiding the user by a route, using a way finding application. This research shows how to combine text, map, auditory and tactile feedback to provide the information, where the user moves his fingers over fixed regions on the touch screen receiving information that allows him to go to different points of interest in a test scenario. Orientation is done by combining DGPS, compass and route information, with an accuracy of about 1 to 3 meters.

Virtual Reality Applications (VRA) used by blind people to know unknown place must allow them built a quality's cognitive-map of that location, through continuous information and relevant content delivered by means physical and cognitive interfaces (Cobo *et al.*, 2017)(Härmä *et al.*, 2004)(Serrão *et al.*, 2012)(Sanabria, 2007), that allows them to explore their environment in advance and build own spatial knowledge over entities and objects of interest to the user.

Kitchin (Kitchin, 2001) mentions that blind people are able to have a spacial thought just like people with vision, if they have enough information, Majerova (Majerova, 2017) emphasizes that spatial mental mapping in an individual with visual impairment should be as an integral and distinctive because the learning is a conjunction between cognitive and perceptual learning skills of an individual. Blind people with no previous visual experience seem to be more dependent on egocentric strategies for coding and representing space during exploration than with allocentric strategies that are more preferred by people with prior visual experience (Pasqualotto *et al.*, 2013).

It is said that sound is very important to develop the sense of orientation and spatial distance (Härmä *et al.*, 2004); and that auditory and haptic feedback allows blind users interacting with different structures and virtual objects (De Felice *et al.*, 2007). For this reason, this work researched the use of different patterns of sounds, gestures and vibrations as physical interface in the construction of virtual reality applications; the use the proximity exploration as a cognitive interface (allocentric & orientation tasks) and the use remote exploration as a cognitive interface to perform egocentric tasks; which together provide the user with an understanding of the virtually visited space. In order to the participants can work with relative ease on their mobile devices, which could significantly increase their willingness to participate in mobile learning programs (Hwang, Chu and Lai, 2017), we proposed and implemented some applications in the iOS system after initially testing Android.

2. VIRTUAL REALITY APPLICATIONS AND THE ACQUISITION OF KNOWLEDGE

We want to help blind users with applications installed on their own phones so they can know in advance the interior of an unknown space, which helps them make their own decisions and feel more comfortable and safe when they go to new places. This is possible thanks to the use of multi-sensitive interfaces that allow explaining and describing the space, so that the user can explore the virtual world in their own way, through egocentric and allocentric activities in this spaces.

2.1 Information Model

Over time two models of information were developed. The Figure **1**.a (first model with only one room) shows the basic relationships between the objects, the avatar and the tools to give information to the user in basic environments. The Figure **1**.b shows the relationships in more complex environments (some rooms on one floor). Where:

The Safety Zones (SZ) are built as physical objects which move and rotate with the user's avatar, their purpose is to alert the user to the presence of objects while your avatar is walking.

The Focus of Attention (FoA) is an object that points in the direction that the user is looking at and move together. We use three methods: flat, spherical and without focus.

Notifications are handled by scripts associated with scene objects. Provide alerts and information to the user during testing.

Avatar represents the blind person inside the application or to the User; the avatar's orientation and movement direction are obtained by the Smartphone's inertial sensors.

Item is each object and structural component in the environment. Common features can group them.

Place represents each space to which the avatar can be directed and if the user chooses one, it adds objects contained in an Entity of the game.

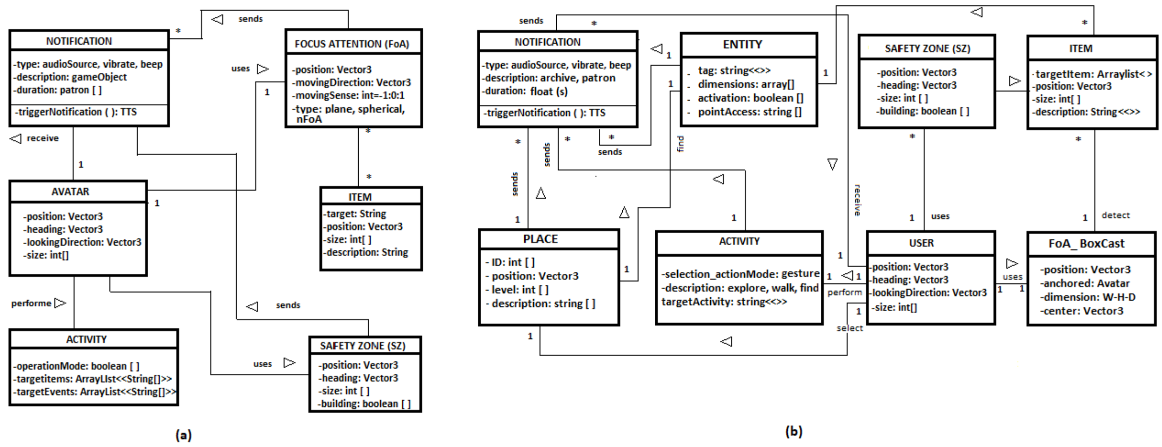

Figure 1. Information Model; a) Basic environment; b) Complex environment

2.1.1 Spatial Coding

The interfaces used in the application depend on the spatial relationship of the avatar with the objects and structures of the environment, for which it is necessary to activate the type of exploration that the user performs (See Table **1**). Where:

Remote Exploration: The locations of objects in space are relative to the axes of the user's body. The user makes gestures on the phone' screen to activate information options (Kozhevnikov, Blazhenkova and Obana, 2017).

Proximity Exploration: The location of an object is defined in relation to the location of other objects. The proximity between the objects and the security zones establishes the information that must be given to the user. The vibration is active as the avatar walks in the virtual environment.

Table 1. Spatial Coding Activation

Mode	Cognitive Interface	Sensitive Interface	Tasks
Remote Exploration	FoA Plane, FoA Spherical	Notification, Gesture	Egocentric
Proximity Exploration.	Safe-Zone, nFoA	Vibration, Notification, Beeps, Gesture	Allocentric

2.2 Methodology

The Smartphone has been used on a number of projects with blind or visually impaired people to provide help to locate, explore and navigate through known and unknown environments (Lahav, Schloerb and Srinivasan, 2015)(Miesenberger *et al.*, 2014)(Hicks *et al.*, 2013)(Callejas Cuervo and Medina Sánchez, 2014); there is talk of the importance of including visually impaired users from an early stage for the design of these systems in order to develop a reality-based learning design (Liu *et al.*, 2017) and also the right develop of interfaces in mobile applications as a basic key for the development of accessibility services (Rodriguez-Sanchez *et al.*, 2014) and . We believe that blind people who use virtual reality applications with sensitive interfaces to make visits in advance to unknown spaces solve with greater confidence and security the tasks of locating objects and structures in the interior of the place visited. Also, we thought that mobile multisensory information along with other various activities help project participants to make a mental representation of their environment.

Six workshops were developed to evaluate the cognitive and physical interfaces used in the development of virtual reality applications, in each workshop were performed, first the welcome, training after, then exploring, at the end of the workshop, participants completed tasks-support. Each experience is recorded with the consent of the participants, observation logs, questionnaires pos-test and application data are stored to the project server. In each new workshop the previous results were considered, as well as the suggestions of the participants listed below.

2.2.1 Workshop I

Fifteen blind and visually impaired people (See Table 2) were recruited through ONCE foundation and through word of mouth, for the initial diagnosis. They signed confidentiality and collaborate agreement with the research group. All the participants had knowledge in the use of the mobile and some applications to convert text into voice. One of the participants has a hearing problem.

Table 2. Participants First Workshop

	Blind people	Visually impaired	Age	Working	Student	Retired	Other
Men	5	3	31-66	13,3%	6,6%	33,3%	
Women	2	5	21-48	33,3%	6,6%		6,6%

With the data collected, it was planned to build a first application based on audio and gestures, taking into account the interests and technical skills of the participants.

2.2.2 Workshop II

Four participants, two blind and two visually impaired (average age 41, SD= 16.5) taken part in the validation of the first VRA where the participant should explore the virtual space sitting on a gyratory armchair. The application was built with three frontals SZ placed to 1, 2 and 3 meters (Figure 2) since centre user's position. There are six objects inside a room placed on different locations. A post-test questionnaire was developed to evaluate the parameters of performance, usability and user satisfaction. For the validation we built scale models of the room and the objects, where the participants were to place this objects in the same position according they remembered. The proximity and remote exploration modes are integrated in a single virtual reality application.

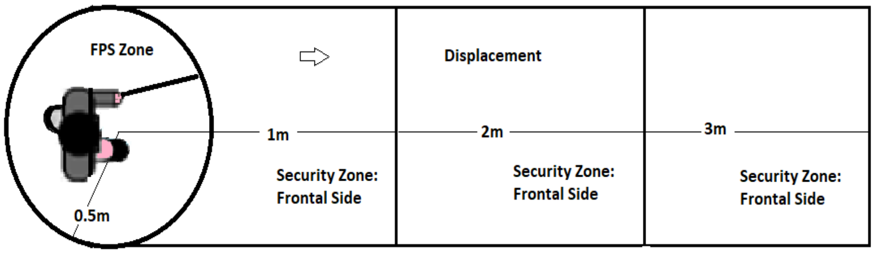

Figure 2. SZ in the first application

The vibration was used to notify the user the avatar is walking, and the variation of the vibration pattern informs the user the closeness to the object. Nevertheless, the users were not sure if the avatar was walking because when the objects entered SZ, the Smartphone kept on vibrating, but the avatar just was stopped. In the construction of this application was used a sphere with a 1 meter diameter as FoA, it was traveling in front the user to know objects ahead. The FoA allowed detecting objects and structures, with some difficulties in the corners. The users suggested numbering the walls and adding beeps to warn on near-avatar objects.

2.2.3 Workshop III

Five participants (average age 40, SD=14.4) took part in the assessment of the second VRA. The same scene with and without objects placed in different places was used for the test. The application had two fronts SZ placed to 1 and 2 meters since centre user's position.

In this application, the user can choose to walk through the virtual scene by touching the screen of the mobile or exploring the virtual environment making a horizontal stroke in the screen. To give information about the type of object, which gets into the safe-zones, high, medium and low frequency beep patterns are created to replace the varying vibration used in the Workshop previous. Since this workshop, the vibration only will have one pattern; it means the avatar is walking in the virtual environment. The participants do the avatar continue colliding with the objects, because there is no chance to stop as an action included in the application. So, for the next application, it was decided to develop an option that allows the avatar to stop, then explore and finally keep on walking by where there are not any objects. The users suggest that the application informs about the objects, which are on their right or on their left, to be able to rotate when there are no objects, so, for the next application, we should be develop Laterals Safety Zones.

The first application built without objects allowed to users recognizes structures as doors, windows and wall indoor, and the second application with objects was used to locate objects. Both applications used two spheres placed one to one into eyes of avatar to reach objects the user is gazing, also we use a voice and vibration patron as output interfaces and gestures on the screen as input interfaces. To assess the application, there was used a small scale model of the room and objects, where the participants were to place this objects in the same position according they remembered, and addition a post-test questionnaire to determine users´ level of satisfaction and efficacy of the tool.

2.2.4 Workshop IV

Three woman, one with visually impaired and two blind (average age 42, SD=8.1) participated in the validation of the next virtual reality application, where laterals SZ was add by to deliver information about objects to the sides (Figure 3).

In Addition the spheres used as FoA was changed by a cube with similar height to the avatar (BoxCastAll) to facilitate programming and reduce changes triggered by any shaking unwanted on the mobile. One application was built to integrate actions as walk, stop and exploring using gestures. Moreover, there were evaluated in four new applications, twenty vibration patterns, thirty-six beep patterns, ten gesture patterns and 25 voice patterns to choose three representative patterns of each option in order to use them in the next application. Owing to the large number of data that we would obtain in the next evaluation, we decided to separate the proximity exploration mode and the remote exploration mode in two applications; these will be used for the next validation with all participants.

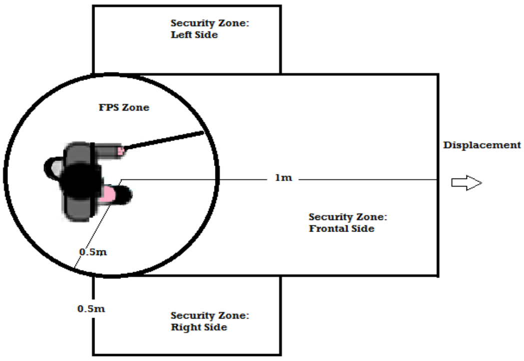

Figure 3. SZ Developed for the Third Application

2.2.5 Workshop V

In this workshop, twelve blind people joined to the work group, totaling twenty blind participants (11 men, 9 women, average age 52.2, SD=14.1) to carry out twelve individual experiences. This workshop is the most representative of the others, since it will allow evaluating the most satisfactory interfaces for the users, their effectiveness and efficiency in the recognition and location of objects and structures with the entire conglomerate of blind people of the project.

Implementation:

A Web server TS140 (Apache, MySQL, PhpMyAdmin) with client-server architecture handles the registration and labeling of users and the database where the registrations of each experience are downloaded. The Smartphone BQ Aquaris E5, SAMSUNG Galaxy S4 and S5, with Android OS 4.4.4 and 5.0, are used to test the developed applications (figure 4). The data about the path are sent to an email address and then they are stored in the SQL Server. The development environment for the Smartphone applications is Unity 3D version 5.3.2 (https://store.unity.com/es), which provides native support for mobile platforms like Android and iOS. Each application has two laterals safety zones and 2 front safety zones placed to 1 and 1.5 meters since centre user's position.

1) Scale models: There were built 24 cardboard scale models (57cm x 32cm) of the structure and 36 scale models of the object for two working teams. Each participant had to identify the scale model of the virtually visited place and put the scale models of the correct objects in this, after having made the virtual visit.

2) Real Environments: There were used three rectangular places in a building that is owned by the Technical University of Madrid. The first space represents an office, the other a bedroom and the third a pub. Each one has the same measure: 10mx6mx3m, where six objects are located in different positions and orientations, totaling 18 actual size objects taken from the building or made with cardboard, wood and plastic.

3) Number of experiences: Twelve experiences per user were defined, making a total of 81 configurations, which make it possible to test three cognitive interfaces and ten sensitive interfaces; taking into account that not every sensitive case can be applied to every cognitive case. Every configuration is labeled with a sensitive interface number (s1-s10), one or two letters for the cognitive interface (sFoA or spherical FoA; fFoA or flat FoA; noFoA or without FoA), three letters for the kind of place (ofi/Office, bed/Bedroom, pub/Pub). Finally, the last letter refers to the position of the objects in the scene (r-Red; b-Black; y-Yellow), as show in the Table 3.

Table 3. Configuration of Application

Experience	Configuration	Cognitive Interfaces	Scene	Sensitive Interfaces Sensitive beeps	 Sensitive voice	 Sensitive gestures
1 to 12	Sensitive+FoA+Scene+colour	fFoA/sFoA/noFoA	Office/Room/Pub	S1 to S3	S4 to S7	S8 to S10

Sensitive interfaces:

1) Beep patterns: used to alert the user about obstacles. The wave frequency (f1<f2<f3<f4<f5) is used to make a difference between the low, middle or high obstacles, and the combination of pulse duration (d) and separation between (δ) waves make the user to know the distance to the obstacle (See Table 4). These patterns (S1, S2, and S3) are shown in the table 4.

Table 4. Sensitive Beep Interface

Pattern	Distance (m)	High object	Middle object	Low object
S1	1.5	f5, δ2, d2	f3, δ2, d2	f1, δ2, d2
S1	1	f6, δ1, d1	f4, δ1, d1	f2, δ1, d1
S2	1.5	f5, δ1, d1	f4, δ2, d1	f2, δ1, d2
S2	1	f4, δ2, d3	f3, δ1, d1	f2, δ2, d1
S3	1.5	f3, δ1, d3	f4, δ1, d2	f1, δ1, d1
S3	1	f3, δ1, d2	f4, δ2, d2	f2, δ1, d3

2) Voice patterns: used to inform the user about the distance and the relative position to the object or structures, and the way to give a feedback when the user activates or deactivates the exploration. The voice patterns (S4, S5, and S6) are specified in the Table 5.

Table 5. Sensitive Voice Interface

Pattern	Voice for distance	Speed	Action modes	Objects in laterals SZ
S4	Steps	Normal	Active/Disable	object out by left/right
S5	Meters	Fast	Start/End	left/right free way
S6	Further, Closer	Very Fast	Enabled/Disable	nothing thing left/right

3) Gesture patterns: determine the better way the user interacts with the system, touching the screen of the Smartphone. They are used to activate/deactivate the exploration as well as identifying structures or objects which are nearer or closer in front of the user. These patterns are detailed in the Table 6.

Table 6. Sensitive Gesture Interface

Pattern	Walk/Stop	Activation/D. Exploration	Object Changing
S7	Single touch	Horizontal swipe	Vertical swipe
S8	Double touch	Vertical swipe	Horizontal swipe
S9	Single touch with sound	Horizontal swipe with sound	Vertical swipe with sounds
S10	Extended touch 1.5 sec.	Vertical swipe with sound	Horizontal swipe with sound

Cognitive Interfaces:

1) Flat Focus of Attention: Consists on a rectangular prism which has the measures of the avatar and moves 30 meters in the horizontal direction (only X and Z coordinates) the person is looking at, and gets the name and the distance to the person of every object it collides with. In this mode, the SZ are not included, and the avatar is always in the same position.

2) Spherical Focus of Attention: Is based on a one-meter-diameter sphere, which moves from the head of the avatar through the vector that represents the direction (X, Y and Z coordinates) the person is looking at. Just as the previous mode, the sphere collides with the objects in that direction and obtains the name and the distance. The SZ do not exist in this cognitive interface. The avatar does not move in the environment, so the user always explores from the same position.

3) No FoA: In this case the user has to explore the virtual environment only with the walking mode and using the information given by the SZ.

2.2.6 Workshop VI

Six blind participants (5 men, 1 woman, average age 48.8 years, SD = 14.9) performed the validation of six VRAs that were installed on an iPhone 6S. The application reproduced 3D sounds in wireless bone headphones to report on the location of objects and structures inside the space. An occipital structure sensor (Occipital, 2017) was also used to track the position of the participant when walking in the real environment and update the position of the avatar in the application (See Figure 4). It was virtualized the Living Lab Smart House (LST-UPM, 2017) of the Polytechnic University of Madrid, which is fully equipped for testing.

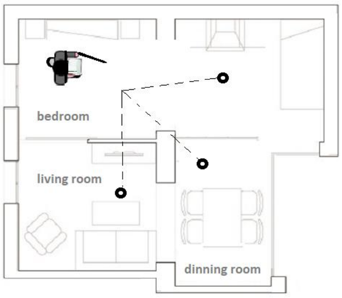

Figure 4. Experience Workshop VI

During the experience each participant should come to three equidistant points, using an auditory output interface. The mobile sends to the bone headphones three types of audio, which are voice, tones and the sound of a musical instrument, using low power Bluetooth. Most users came directly to the proposed points without any difficulty, so we believe that virtual reality applications should include 3D sounds during the exploration.

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2.3 Results

During six workshops, one hundred and twenty-four VRAs were tested, each of which used different sensitive and cognitive interfaces, which were developed to satisfy the majority of participants and to meet the necessary standards of quality. After each workshop, a test based on the Likert scale (5 highest, 1 lowest) and control registers was used to know the level of acceptance of the application in terms of usability and level of satisfaction.

In the Workshop I, the participants gave some information to start the development of the first application. Most the participants had knowledge and experience in using an iPhone, using email, text to speech application and some of them used other electronics devices. One participant appeared to show deafness features.

In workshop II, participants used the first application to explore a room in a virtual way, through a questionnaire the quality and clarity of the information received by voice was evaluated, as well as the intensity of the vibration to recognize the proximity to the inside objects, as well as the gestures used to begin the exploration. The results are showed in Figure 5, where 5 represents fully agree and 1 disagrees. The suggestions of the participants to reinforce the actions with sounds were used to make some modifications in the design of the next application.

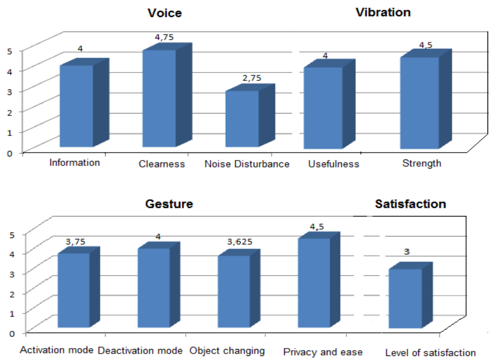

Figure 5. Results Workshop II

In the Workshop III, the activation and deactivation the exploration mode by gestures were reinforced with sounds. The first application allowed environment structure recognizing, with 83.5% success (Figure 6). The second application allowed environment's objects recognizing, with 100% success. Participants performed three tasks that consisted of addressing three points inside virtual environment with a 94.4% success; sometimes the help of researchers was required. In addition, they had to recognize and locate several objects inside a scale model. The participants mention the interest in being informed about objects that appear virtually on their right and left side, because the application only reports about objects in line of sight with the avatar.

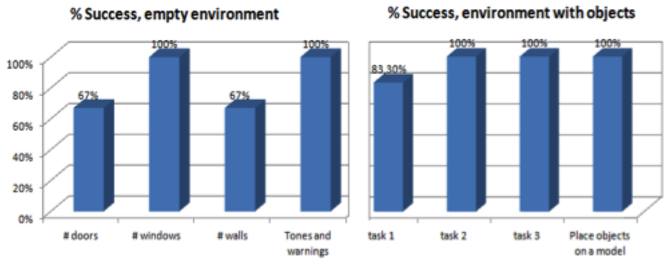

Figure 6. Results Workshop III

In Workshop IV, applications were built with lateral and frontal safety zones, participants assessed proximity and remote exploration with 100% success in the task of localization and recognition, the results are shown in Figure 7, where 5 represents totally agree and 1 disagree.

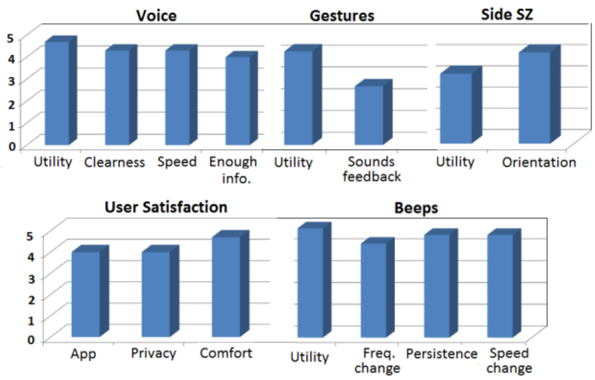

Figure 7. Results Workshop IV

During this workshop they chose patterns of voice, beeps, vibrations and gestures, whose preferences are shown in the Table 7 and Table 8.

Table 7. Vibration, Beep and Voice Patterns Selected

Pattern	P1	P2	P3
Vibration	d=200ms/δ= 400ms	d1=100ms/δ1= 200ms d2=200ms/δ2= 400ms	d=1000ms/δ= 2000ms
Beep High; d>1m	Very sharp and elongated sound	Sharp and fast sound	Sound slow
Beep Medium; d>1m	Cardiac monitor	Sharp and more paused	Cardiac monitor more sharp
Beep Low; d>1m	Slow and paused	Few slow and more paused	Low and fast sound
Beep H-M-L; d<1m	Very sharp, fast and rackety	Cardiac monitor more sharp	Heartbeat
Voice-Mode remote	Exploration mode enabled	Exploration enabled	Exploration
Voice-Mode proximity	Walk mode enable	Walk enable	Walk
Voice- Distance	Meters	Steps	Closer/ Further
Voice- Windows/Doors	Window/Door Open	Size Window/Door + open	Window/Door
Voice- Objects in lateral SZ	Enters from the left/ right	Right blocked/ Left blocked	Enters on the left /right side
Voice-Orientation	Turn right/left	Go to the right/left	Change direction

Table 8. Gesture Patterns Selected

Pattern	Walk /Stop	Exploration Act./Dis.	Object Change
Gesture S7	Single Touch	Horizontal line	Vertical line
Gesture S8	Double touch	Vertical line	Horizontal line
Gesture S9	Single touch with sound	Horizontal line with sound	Vertical line with sounds
Gesture S10	Extended touch of 1.5 sec.	Vertical line with sound	Horizontal line with sound

The logs show that the lateral safety- zones have been well accepted by the participants. They told us that they prefer audio-descriptions of the space and the most representative objects before starting the exploration and that auditory feedback is very important when they made a gesture on the screen to know if they did it correctly. The next step will be build new applications by combining patterns preferred by users to determine their efficiency and effectiveness in the mental representation of space.

In the Workshop V, were assessment separately three cognitive interfaces (flat FoA, spherical FoA, not FoA) and ten sensitive interfaces (S1-S10), totaling eighty one application, where it could be determined that:

1) The remote exploration using a plane FoA reach better users' acceptance and seem to optimize the time in the recognition the structures and objects. There is a 38% of improved when the participants choose the focus of attention to explore the virtual environment remotely. The percentage of correct location of objects in scale models is less than 29%, it is proposed to improve this percentage by using spatial sounds.
2) More than a 70% of the blind users are capable of recognizing high-speed voices, what makes it possible to reduce exploration time.
3) Less than a 33% of the participants are satisfied with the persistence of the beep that takes place when an object enters in his frontal SZ. Nevertheless, their opinion is that it is very useful when avoiding colliding with objects. They prefer since low until medium frequencies as warning, around 500Hz for regular size objects was a beep more comfortable.
4) All participants used a single touch, double touch and vertical and horizontal strokes without difficulty, but the efficiency of the time was greater when using a simple touch. The extended touch and the touch with the sound caused largest time and errors when beginning the exploration.

In Workshop VI, participants used virtual reality applications to locate objects and structures within an unknown environment using 3D sounds with 81.48% success. Users took less time to reach the object when they used the custom audio response, achieving greater efficiency with 440Hz tones (Figure 8).

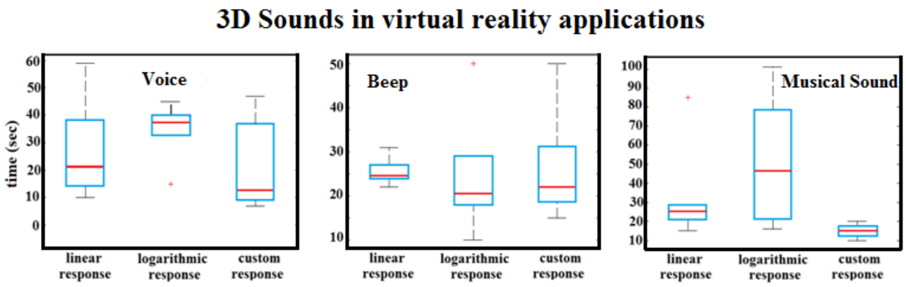

Figure 8. Results Workshop VI

The musical sound seemed to please them as the output interface; however this interface registered the lowest scores in the scale implemented and the highest times to reach the object. According to the participants, the use of 3D sounds produces a substantial improvement in the location of objects and structures in the environment compared to other previously tested applications.

3. CONCLUSIONS

The methodology developed for the construction of virtual reality applications to be used by people who are blind is based on an information model that has allowed us to construct, modify and integrate the physical and cognitive interfaces in each application in a simple way, reusing code and with ease to increase or remove components to the system.

Based on the recommendations provided by users during the evaluation, the logs provided by the system and the observations recorded in each developed experience, an adequate tool has been obtained so that participants with visual impairment can mentally represent the space they visit for the first time, through virtual explorations in advance.

The participants who evaluated the RV applications were able to locate objects and structures within an unknown environment, with confidence and security. The importance of working continuously with a group of people with blindness and low vision is reflected in the level of satisfaction registered in the surveys. Each new application had some modifications and the number of users for evaluation was limited. It will be necessary to carry out a final evaluation with a greater number of users, integrating all the improvements learned during the development of this methodology.

The voice response is very important when: the user touches the screen, because it reinforces the result of the user's intention in each action carried out; also to inform you about objects or structures near your Safety Zone, which allow you to change your orientation and avoid possible collisions. The user's request through a gesture on the screen is also used to remember something that was previously reported. At the same time, it is necessary to limit the amount of information to ensure that it is clear and relevant during the virtual exploration.

The use of 3D sounds to guide the user inside the space and to locate of an object, through a personalized audio response, reduces the amount of information required by the system to produce better results in terms of accuracy and user satisfaction. It is still necessary to integrate all the development achieved with this methodology into new experiences with a greater number of users, which allows establishing the percentages of increase in efficiency and performance with respect to previous applications. It is necessary to increase the number of virtualized scenarios, so that new ones are unknown by the participants.

The percentage of evaluation in the aspects of quality and user satisfaction, allows us to believe that this tool can be used both as training to visit new places in advance and as a tiflo-game (game for blind people); this should be evaluated later.

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