HOMERE: a Multimodal System for Visually Impaired People to Explore Virtual Environments

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Abstract

This paper describes the HOMERE system: a multimodal system dedicated to visually impaired people to explore and navigate inside virtual environments. The system addresses three main applications: the preparation to the visit of an existing site, the training for the use of the blind cane, and the ludic exploration of virtual worlds.

The HOMERE system provides the user with different sensations when navigating inside a virtual world: a force feedback corresponding to the manipulation of a virtual blind cane, a thermal feedback corresponding to the simulation of a virtual sun, and an auditory feedback in spatialized conditions corresponding to the ambient atmosphere and specific events in the simulation. A visual feedback of the scene is also provided to enable sighted people to follow the navigation of the main user.

HOMERE has been tested by several visually impaired people who were all confident about the potential of this prototype.

1. Introduction

Virtual Reality (VR) systems are generally assimilated to the use of a head mounted display or another immersive visual interface. This definition - based essentially on visual restitution - disables visually impaired people from using VR systems and prevents them from immersing themselves into virtual worlds.

However, new kinds of VR interfaces have recently appeared, addressing new human sensory modalities other than vision. These are haptic interfaces [6] [12] and auditory ones [26]. They imply other means of exploring Virtual Environments (VE) and virtual objects which can be used by visually impaired people [32] [7].

HOMERE - Haptic and audiO Multimodality to Explore and Recognize the Environment - is a VR system focused on three main applications for blind and visually impaired people:

- Preparation to the visit of an existing real site (touristic site, administrative building, airport, train station, etc),
- Training for the use of the blind cane within a reeducation system in "safe" conditions,
- Ludic exploration of virtual worlds.

To reach this aim, the HOMERE system proposes an approach based on multimodal immersion of the user inside a virtual environment on scale 1. HOMERE addresses different modalities of the *haptic* sense - with a force feedback corresponding to the manipulation of a virtual blind cane and a thermal feedback corresponding to the simulation of a virtual sun in the simulation - and of the *auditory* sense - with various sounds corresponding to the ambient atmosphere and to specific events in the simulation.

This paper begins with a description of previous work in the field of the use of VR for visually impaired people. Then it describes the different parts of the HOMERE system. It gives the results of an informal evaluation of the prototype made by several visually impaired people. It ends with a conclusion and an extension to future work.

2. Previous Work

In everyday life, how do blind people experience the information treated with vision by sighted people when they navigate? The haptic channel is exploited via the white cane to scan the environment, detect obstacles and identify distances between him/her and the obstacles [21]. It is also exploited via the palm and fingers to recognize the shape and texture of objects with precision and via the legs for the ground surface [21]. The proprioceptive sense allows perceiving information about displacement of the body and position of the limbs [31]. The auditory channel

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provides information about external events, presence of other people, material of objects and distances in the surrounding space [21]. Sounds may also be used to give spatial orientation, alert, detect and avoid obstacles [16]. The blind people have maybe a "sixth sense" - the sense of presence - which is the ability to be aware of the presence of an object in the environment [29]. Multimodality (i.e. the combination of several sensory modalities) generally provides both blind and sighted people with the best perception of the environment and allows the successful accomplishment of everyday tasks [18] [36].

Nowadays, a wide number of systems based on haptic and/or auditory feedback are developed and commercialized to guide blind people when they navigate in the real world [1] [3] [11]. As an example, different types of "augmented" or "smart" canes offer the possibility to detect obstacles in the real environment and to generate audio or haptic feedback [1].

Virtual reality technologies were applied from the very beginning to the assistance of people with special needs [22] [34]. Virtual reality systems were developed for them to: develop new skills (learn how to cross streets [16] or communicate more easily [22]), train for specific tasks (use of the wheel chair [15]) or simply for fun (interactive games [22]).

The recent diffusion of haptic [6] [12] and auditory [37] interfaces enabled developments of VR systems for blind people [7]. Haptic feedback has been proposed to blind people for: reading (tactile stimulation of Braille text [27]), drawing and artistic creation [20], the display of "visual information" (haptic "translation" of 3D or 2D images [18] [32]), education (haptic display of maths and graphs [33] [38]) and Computer Human Interface (tactile access to the web or other hypermedia by translating traditional GUI into haptic ones [25] [13]). Haptic Interfaces have also been used for the study of blind people's perception (studies on haptic perception of space [21] and objects [17] [8]), re-education and training (mobility training [21], training for the use of the blind cane [35]) and finally gaming (memory game [33] or battleship game [32]). In most of these applications, the haptic feedback is combined with an auditory one. Auditory feedback is specifically used for reading, displaying visual information in a verbal or non-verbal manner [10], navigation in hypermedia and/or virtual environments [37] [26], or gaming (auditory Quake™ [2]).

The use of haptic interfaces by blind people to navigate in virtual environments has been recently studied [21] [19] [18] [35] [31]. Virtual objects or virtual worlds are sometimes represented in 3D [21], but more generally in 2D [19] [18] [35] [31] - for example by displaying a 2D cutting-plane of a building [19] [35]. The VE is directly explored with the hand. The haptic interface used is: a tactile matrix [18], an exoskeleton glove [35], a force feedback joystick [21] or a pen-based device [19] [31]. The haptic device is used to display the "realistic" contact with the geometric surface of the objects [31] or a "simplified" effect - for example a vibration when crossing a virtual wall [35]. Researchers [31] [21] observed that haptic feedback and haptic exploration enabled and helped blind people to develop cognitive maps of the environment.

With the help of these exploratory studies, researchers made several remarks about the development of haptic-based VR systems for blind people. It seems important to display reference points to the user [8]. This system of reference must remain stable and easy to find [33]. The problem of understanding the scale factor between the virtual and the real environment may occur [31]. At last, the interaction with the haptic interface must be intuitive and easy to understand [8]. Even in this case, the persons may have different mental representations of this interaction [8].

3. The HOMERE System

The user of the HOMERE system is immerged inside the virtual model of the *Cité des Sciences et de l'Industrie* of *La Villette* in Paris (see Figure 1). A virtual guide is present and assists orally the user during the navigation.

The user navigates inside the virtual model on a pre-defined path. This pre-defined path corresponds to the path actually dedicated to the guidance of blind people through the real *Cité des Sciences et de l'Industrie*. In the *Cité,* this path is indicated by a specific surface on the ground which blind people can easily recognize. The choice of a pre-defined path system was made by experts of the Laboratory of Ergonomic Computer Science of University of Paris V and specialists of the *Cité*. This choice was made first to prevent blind users from getting lost in the virtual mock-up, and second because the aim of the HOMERE prototype is to test the possibility for a blind people to learn easily one pathway inside a virtual environment.

The user sits on a stool in the center of the system (see Figure 2). He/she manipulates a virtual blind cane with the dominant hand and controls the navigation (forward/stop/backward) with the non-dominant hand.

During the navigation, the system provides the user with 4 different types of sensory feedback:

- a <u>force feedback</u> corresponding to the manipulation of a blind cane
- a <u>thermal feedback</u> corresponding to the simulation of the sun
- an <u>auditory feedback</u> of the ambient atmosphere and of other specific events

- a <u>visual feedback</u> which is proposed to partially-sighted people or to sighted people who want to follow the navigation of the main user in the VE

The different types of sensory feedback and their implementation are now detailed separately in the following paragraphs.

Figure 1. Virtual Scene: the *Cité des Sciences* of *La Villette*

Figure 2. The HOMERE System

3.1. Force Feedback

The force feedback of the HOMERE system consists in providing the user with the sensation of manipulating a blind cane. With the virtual cane, the user can detect obstacles and appreciate the textures on the ground or on some objects of the VE.

To reach this aim, the system uses a force feedback arm: the VIRTUOSE™ 3D [12] (see Figure 3). This interface is a 6 DOF in input and 3 DOF in output device, commercialized by the HAPTION company. The workspace of the extremity of the VIRTUOSE™ 3D is of 42x49x92cm^3. The maximum peak force of the device is of 34N, and its maximum continuous force is of 11N.

In order to provide the user with a very intuitive interface, the "prop[1]" of a blind cane has been placed at the extremity of the VIRTUOSE™ (see Figure 3). The length of the cane prop is of 50cm - i.e. shorter than a real blind cane. This prop is also useful to make up for the lack of torque feedback of the VIRTUOSE™ 3D. Thanks to the lever-effect that is naturally induced by the use of a cane, the force feedback of the device implies a partial torque feedback.

The different types of haptic effects simulated with the VIRTUOSE™ are:

- <u>Collision Feedback</u>: simulates a shock between the virtual cane and another object of the VE.
- <u>Texture Feedback</u>: simulates the texture of the ground or of an object in the VE.
- <u>Navigation Effects</u>: haptic effects related to the motion of the user during the navigation (i.e. forward, backward and turn effects). The haptic navigation effects correspond to a force feedback applied in the direction corresponding to the user's motion. When the user rotates, the cane is slightly pulled to the right or left depending on the direction of the turn. When the user advances or when he/she goes back, the cane is pulled forwards or backwards.

The haptic rendering of the contact of the blind cane with an object of the VE is performed in 4 steps: (1) collision detection, (2) dynamic simulation of the VE, (3) computation of the force feedback, (4) perturbation of the force feedback due to the texture of the object.

The computation and control of the force feedback (steps 1, 2 and 3) refer to previous work in the field of collision rendering [23] [5]. It uses the model of a virtual

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[1]Hinckley et al. [14] have proposed the notion of "*passive interface prop*" for the design of 3D user-interfaces. This represents a "*physical manipulation of familiar real-world objects in the user's real environment*" [14].

link - made of a spring and a damper - between the haptic device and the virtual object representing the blind cane.

Figure 3. Prop-Based Interaction with the Haptic Device via a Blind Cane

The perturbation of the force feedback due to the texture of the object (step 4) is calculated by referring to the techniques described in a previous work by Basdogan et al. [4]. This consists in applying a graphic *bump-mapping* technique to the haptic rendering. The force vector is modified according to the local geometry at the level of the contact point - this geometry being calculated with the gray level of the corresponding texel [4]. When compared with the techniques described in Basdogan et al. [4], the algorithm proposed in the HOMERE system disturbs only the tangential component of the reaction force, since it has been previously shown that the tangential component dominates the normal one in the perception of macroscopic texture [28] [24]. The Figure 4 shows several images of texture that were mapped onto the objects of our haptic database.

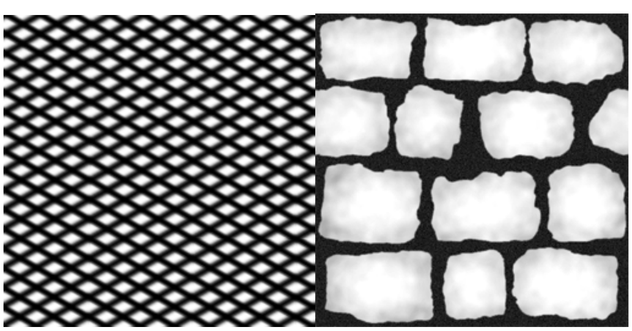

Figure 4. Images Used for Bump-Mapped Haptic Textures

The frequency of the force feedback of the system is of approximately 500Hz.

3.2. Thermal Feedback

The HOMERE system provides the user with a thermal feedback corresponding to a "virtual sun[2]". This thermal feedback depends on the orientation of the user according to the sun in the simulation. It may thus be used as a thermal compass.

The thermal feedback of HOMERE is generated by 12 infrared lamps of 150W each. The lamps are located on a circular structure of a 2-meter diameter which surrounds the user at a 2-meter altitude (see Figure 2). The lamps are activated by a RS232 controlled relay bank (National Instruments Field Point).

During the simulation, only one lamp is activated at a time. This implies that the virtual sun's location has a resolution of 30 degrees. When the user walks inside a building, the lamp is turned off. The constant altitude of the lamps implies that the sun is always simulated at the same time of the day.

3.3. Auditory Feedback

When the user navigates inside the VE, the system also provides the user with an auditory feedback in spatialized conditions.

The HOMERE system uses a "Home Cinema" 5.1 system: a SONY™ amplificatory with a BOSE™ set of 4 speakers positioned around the user in a symmetrical manner (see Figure 2).

The auditory feedback consists in 4 different types of sound:

- <u>Ambient atmosphere</u>: children playing, people talking, street sounds, elevators, etc. The variation of this sound provides information about the user's motion.
- <u>Oral comments of the virtual guide</u>: "mind the stairs", "there is an elevator on your left", etc. These sounds are activated in some specific places of the virtual site.
- <u>Footstep of the virtual guide</u>: when the user is in motion, a sound of footstep is activated. This sound corresponds to the footstep of the virtual guide who is located 4 meters ahead of the user in the simulation. This sound represents an indicator of the

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[2] The presence of a "virtual sun" to facilitate the wayfinding has been proposed by Darken and Sibert [9] within a VE based exclusively on visual feedback. This solution has apparently provided good results [9]. However, another experiment made by Rudle et al. [30] showed that the presence of a visual compass - a symbolic one - in a VE did not ameliorate the spatial knowledge of this VE.

speed of motion as well as of the direction of the turns on the pre-defined path (if the sound goes to the left, it indicates that a turn to the left is approaching).

- Haptic related sounds: these are collision and texture sounds. They are activated when the virtual cane collides and when it is rubbed along the ground or along an object. These sounds depend on the material of the encountered object and on the characteristics of the physical contact (speed, strength, etc).

The sounds were mainly recorded on the real site of the *Cité des Sciences et de l'Industrie* with a DAT recorder system. The oral comments of the virtual guide were composed with the help of the Laboratory of Ergonomic Computer Science of University of Paris V.

The sampling rate of the auditory feedback is of 44.1 kHz.

3.4. Visual Feedback

A visual feedback is also available when the user is not totally blind or when a sighted person wants to follow the navigation of the main user visually.

Figure 5. Visual Feedback

The visual feedback displays the avatars of both the main user and the virtual guide (see Figure 5). In the event of a contact, the texture of the touched object is displayed on the upper right side of the screen (see Figure 5) with the corresponding impact point.

The visual feedback is provided in monoscopic conditions by using a simple workstation screen (see Figure 2).

The frame rate of the visual feedback is of approximately 20Hz.

3.5. Interaction and Navigation

The main user navigates inside the virtual model along a pre-defined path. The user keeps the possibility to go forwards, to stop or to go backwards along this path.

To enter the navigation command (forward, stop or backward), he/she uses a wireless gamepad: the Guillemot™ Thrustmaster™ Gamepad. This gamepad is manipulated with the non-dominant hand (see Figure 2). Three buttons of the gamepad are used to enter the three possible choices.

During the motion, the speed of navigation remains constant. After some preliminary testing, it was arbitrarily set at 1 meter/second.

Thus, the user of the HOMERE system uses both his/her hands to explore the virtual model: the dominant hand to catch the virtual blind cane and the non-dominant hand to control his/her navigation inside the environment.

As an illustration of the multimodality of HOMERE, a left turn is represented successively by: a change in the spatialization of the sound of the ambient atmosphere and of the footstep, a pull of the blind cane to the left, and a change of position of the virtual sun.

3.6. Software Platform

The software architecture of the HOMERE system relies mainly on two separated applications: one "scenario application" and one "haptic application" (see Figure 6).

The scenario application is in charge of the course of the scenario and of the rendering of the visual, auditory and thermal feedback. The haptic application is in charge of the collision detection, the dynamic simulation of the VE and the computation of the force feedback command. Both applications are run on the same PC (Bi-Processor PC).

A second PC (PC-286) is used to control the force feedback of the VIRTUOSE™. It runs a control loop which uses, as input, the haptic command sent by the "haptic application".

The HOMERE system relies on the WorldToolKit™ (WTK™) API of Sense8™ for the graphic rendering. It also uses the VORTEX™ 1.5 software of CM-Labs™ for the collision detection and the dynamic simulation of the VE.

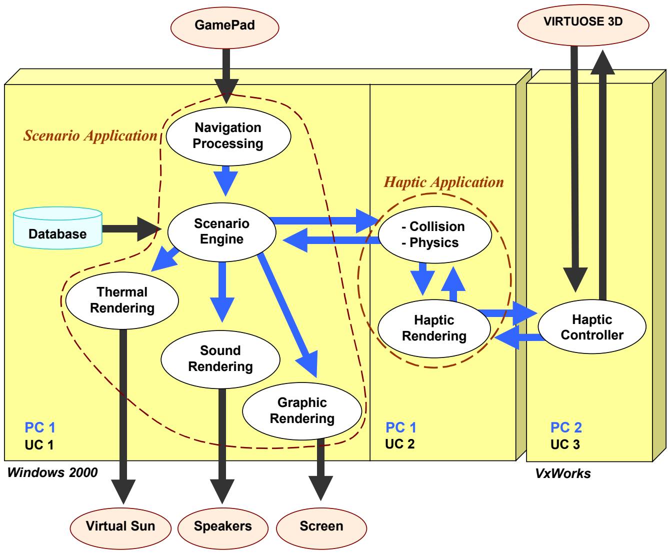

Figure 6. Software Architecture

In order to match the different input formats of VORTEX™ and WTK™, two different databases are used. The visual database used for WTK™ is made of 30K textured polygons. It was modeled using 3DSMax™ software of Autodesk™, based on the real model of the *Cité des Sciences et de l'Industrie* of *La Villette*. The haptic database used by VORTEX™ is simplified when compared with the visual one. It is limited to the objects located along the pre-defined path. Due to the current specifications of VORTEX™ 1.5, the objects of the haptic database are simple primitives: boxes, spheres, cylinders and cones.

4. Informal Evaluation

4.1. Conditions

Nine people with visual impairments performed an informal evaluation of the HOMERE system. One person was partially blind while the 8 other people were totally blind. Among the 8 blind people, 5 people were born-blind and 3 were late blind. Each person had approximately 15 minutes to test the different possibilities of the prototype and the different types of sensory feedback. However, the noise level and the temperature in the evaluation hall were slightly high for the experience.

After the testing sequence, people had to complete orally a questionnaire.

4.2. Results

The results of this informal evaluation are presented and discussed hereafter in a descriptive manner.

4.2.1. The System

Global Usefulness

Usefulness of the system is obvious for most subjects.
Preparing a navigation in an unknown environment is the major application cited. The rehabilitation teachers who were present suggested that it could also be used for mobility training (use of the cane).

Interaction with the Blind Cane

The cane is a familiar and intuitive metaphor.
However, there are different types and models of blind cane associated with different sensations and manipulation strategies. It is necessary to take into consideration the variability of this component.
Furthermore, the force feedback applied via the cane was dedicated to two different uses: an active exploration of the surrounding space (collisions and textures feedback) as well as a passive guidance (navigation effects). In the latter use, the cane may be more assimilated to the lead of the leader dog. This "double metaphor" has sometimes confused the users.

Workspace

Within the HOMERE system the workspace of the virtual cane is narrower than a real one. But when the physical workspace of the device was well explained to the subject, there were only a few misunderstandings (i.e. confusion between a collision and a thrust of the VIRTUOSE™).

4.2.2. The Sensory Modalities

Force Feedback

Force feedback sensations are well appreciated by most subjects.
On the one hand, subjects have a good perception of the presence of obstacles despite a bad perception of the geometry of some objects (maybe due to the lack of torque feedback or to a lowness of the maximum stiffness simulated by the VIRTUOSE™).
The different textures of the ground are also well perceived via the cane even though this perception is more naturally achieved with the foot-plant.
On the other hand, the cane is perceived as very heavy. This is mainly due to the fact that the gravity was not simulated in the VE. This implies that one had to force on the cane to move it and to feel textures and obstacles.

Auditory Feedback

The *ambient atmosphere* was very well perceived even though the evaluation hall was quite noisy. The *sound of footstep* was also appreciated for its realism. It provided good information about the displacement of the subject (speed of motion and turns).

Thermal Feedback

It appears that only few subjects have well perceived the thermal compass - i.e. the virtual sun.

This might be due to the ambient temperature during the evaluation, which was already very high. In addition, there were few changes of direction during each navigation (and consequently few changes of position of the virtual sun), and people are probably more sensitive to changes of temperature. At last, two subjects tried the system only inside the building, when the virtual sun is not activated.

Additional work seems necessary to test the thermal compass in appropriate conditions.

4.2.3. The Navigation

Passive Navigation

The criticism that was made the most often concerns the "passivity" of the navigation provided by the system. In real life, a blind person is active in his/her search for his/her route. He/she chooses his/her route according to his/her objectives and to the information at his/her disposal (obstacles detected with the cane, sound information, previous knowledge of the environment, etc). Thus, being displaced by the system on a pre-defined path did not suit the people who tried the HOMERE system.

Changes of Direction

Changes of direction that are haptically guided (i.e. turn effects) are well perceived and understood.

Meanwhile they are not always appreciated. Some subjects found it too rough or too quick. Furthermore, most of the subjects would prefer to detect the changes of direction without being imposed and directed by the system.

Speed of Navigation

Some subjects found the constant speed of navigation (1m/s) too slow while others found it too fast.

Thus, the speed navigation must be regulated directly by the user and if possible this speed must vary according to the user's intention.

4.3. Perspective

This evaluation - though incomplete - is useful for future developments.

Detection of obstacles with the virtual cane proves very efficient even if some improvements must be done: a presence of torque feedback, a harder stiffness of the haptic device, etc. Navigation in the VE must be particularly improved. While keeping the hands on the system, the user must be able to control the navigation speed and direction. He/she must also be able to regulate auditory feedback and other parameters of the simulation. Changes of direction can be accompanied by the system but must be initiated by the user.

Other demands collected during the evaluation should be tested: ask for additional information when necessary, explore pavements with feet rather than with the virtual cane, standing and walking while using the system (with a running treadmill for example), have a global map of the environment at disposal.

5. Conclusion

This paper has presented the HOMERE system. HOMERE is a multimodal system dedicated to visually impaired people to explore and navigate inside virtual environments.

Three main applications for blind people are addressed by this system: the preparation to the visit of an existing site, the training for the use of the blind cane and the purely ludic exploration of virtual worlds.

The user of the HOMERE system is immerged inside a virtual site. He/she is addressed on different sensory modalities on both *haptic* and *auditory* modes.

In addition to previous work, HOMERE proposes an approach based on a multimodal immersion of the user on scale 1, an intuitive manipulation via a virtual blind cane and a use of thermal feedback to simulate a virtual sun.

An informal evaluation made by visually impaired people showed the potential of this system. All subjects were enthusiastic about it. The detection of obstacles with the cane is very efficient. Auditory cues are extremely appreciated. Active navigation inside the VE seems very important. Thermal feedback seems apparently difficult to use for the moment and its implementation must be improved.

Future work. Future work deals with the improvement of the haptic feedback: simulation of torque feedback by using a 6 DOF in output device, simulation of contact with complex shapes (trimesh objects), improvement of the thermal stimulation, etc. The "active" navigation must also be implemented. At last, a more quantitative analysis of the prototype is also needed to adapt our system to its potential users.

Acknowledgements.

The authors would like to thank the *Institut pour la ville en mouvement-PSA Peugeot Citroën* for initiating the HOMERE project. They would like to thank Pr. P.R. Persiaux for his valuable remarks. They would also like to thank M. Apel-Muller, F. Ascher, L. Chodorge, H. Corvest and the *Cité des Sciences et de l'Industrie* of *La Villette*, R. Fournier and G. Uzan for their precious help on this project.

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