The Design and Evaluation of a Computer Game for the Blind in the GRAB Haptic Audio Virtual Environment

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Keywords: GRAB, haptic, audio, virtual environment, games, visually impaired.

Abstract. This paper describes the development and evaluation of a computer game for blind and visually impaired people using a new haptic audio virtual environment (HAVE). The GRAB HAVE consists of a new two-finger haptic interface and Haptic Geometric Modeller which enables people to locate and interact with 3D computer-generated objects using their sense of touch and audio feedback. A simple 3D search and adventure game was developed and tested with fifteen blind participants in three countries. The results show that it is possible to create an enjoyable and immersive game using this approach. This offers hope for combating the exclusion of blind and visually impaired people from what is fast becoming one of the favourite leisure activities of the public.

1 Introduction

In the last few years the software industry, spurred on by legislation in both Europe and the United States,[1] has become increasingly aware of the need to design for all, including people with disabilities. As a result, access for blind and visually impaired users to important software is gradually improving. However, the computer and video game industry, with no legislative requirements to motivate it, has been slow to address the exclusion of blind and visually impaired people.

Computer and video games are playing a large and growing part in the leisure activities of the public. In the largest market, the United States, entertainment software

[1] For example, in the United States, Section 508 of the Rehabilitation Act was amended in 1998 to mandate that any information technology products acquired by a federal body must be accessible to employees or members of the public with disabilities.

sales amounted to $6.9 billion in 2002 [1]. A similar situation exists in Europe, where, for example, UK Consumers are now reported to be spending more on leisure software than on video rental and cinema [2]. As the popularity of computer and video games increases, the exclusion of blind and visually impaired people from these activities is becoming more of an issue.

An increasing amount of work is being done on accessible computer games, either through research projects or by small, independent games companies. ZForm[2], a company established in 1997 to design and market games accessible to visually impaired people, have described the creation of a 3D search and adventure game [3]. This game was made accessible by modifying id Software's[3] Quake 1 game engine source code to facilitate an audio user interface and provision of audio cues for player navigation. ZForm's efforts have focused on conventional means of access to computer systems using screen readers, audio cues, and screen magnification technology. They have not yet made use of haptics in user interfaces for their games. Their first published game is an online version of five card draw poker, featuring an audio user interface for the blind and a visual user interface for people with low vision.

The TIM (Tactile Interactive Multimedia)[4] project makes use of tactile boards and move detectors as part of a flexible multimodal games interface designed for blind and visually impaired children. The approach taken by TIM is to adapt existing games and educational software by providing a description of the software in a specially developed scripting language. The script for the game is interpreted by the TIM games platform, which facilitates access to the game through a flexible multimodal user interface. This interface can be tailored to the needs of different children and can incorporate a wide range of input and output devices.

A wide range of accessible computer games are available from small companies such as Accessible Games[5]. Accessible Games took the important step of bundling speech synthesis software with their games, making them self voicing and reducing the dependence of visually impaired gamers on expensive third party software such as JAWS for Windows. Accessible Games begam by publishing conversions of traditional board or card games such as Free Cell and Battleships. However, they are now concentrating on online games such as their latest title, Starfight, which enables players to compete against opponents on the Internet. These games provide players with the opportunity to interact using an IRC chat client, introducing an element of social interaction and community building to the game experience.

A discussion of accessible games would not be complete without mentioning GMA Games[6] Shades of Doom. This game brings ID Software's[7] seminal Doom title to the visually impaired. GMA Games have ensured that Shades of Doom is self voicing so that no third party Speech Synthesis software is required. Players can navigate through the 3D environment using rich audio cues such as the sound of the wind, footstep echoes, and the noises made by machinery and equipment in the game environment. Additional guidance is provided by the clever inclusion of an 'environment

[2] You can find ZForm on the web at www.zform.com.
[3] You can find idSoftware and the Quake engine source code online at www.idsoftware.com.
[4] Details of the TIM project are available from http://inova.snv.jussieu.fr/tim/.
[5] Accessible Games are on the web at www.gamesfortheblind.com.
[6] GMA Games and Shades of Doom can be found online at www.gmagames.com.
[7] ID Software are on thye web at www.idsoftware.com.

analyzer computer' in the player's inventory, which can be used to get help on the game environment when a player becomes lost or disoriented.

These projects are encouraging, but more needs to be done to make game and entertainment software accessible. The scarcity of accessible games may be due in part to the inherently visual nature of the medium. Interaction with complex 3D game environments poses many more problems than access to 2D application software. To provide a rich user experience, multimodal user interfaces incorporating haptics will be essential. The GRAB project will contribute to this goal by examining basic methods of interaction in a 3D game environment using a haptic/audio user interface.

1.1 An overview of the GRAB Project

The GRAB project concerns the development of a haptic audio virtual environment (HAVE) that enables people to locate and interact with 3D computer-generated objects using their sense of touch and audio feedback. Although GRAB is being developed specifically to benefit blind and visually impaired users, the technology and approach have wider applications.

The project is part funded by the EU Information Society Technologies programme and involves a multinational consortium of six partner organisations:

- Fundación Labein, Spain, software development.
- Scuola Superiore S. Anna - PERCRO, Italy, hardware development.
- National Council for the Blind of Ireland, Ireland, application design and evaluation.
- Royal National Institute for the Blind, United Kingdom, application design and evaluation.
- Unidad Tiflotécnica - ONCE, Spain, application design and evaluation.
- Haptica Ltd., Ireland, dissemination and exploitation.

The GRAB system features a new two-finger haptic interface (HI) specifically developed by PERCRO for touching 3D virtual objects with an high degree of force and position resolution. This interface consists of two coordinated arms, each with three degrees of freedom and three more degrees of mobility. It also features a large shared workspace 600mm wide, 400mm high, and 400mmdeep.

Due to its mechanical properties, the HI can simulate many properties of virtual objects, including softness, texture and stickiness. It can also constrain user movement to the boundaries of an object, trajectory, or path and simulate forces of attraction and repulsion. One feature especially useful in a game development context is the collision detection system, which detects collisions between virtual objects as well as between the user and virtual objects.

Fig. 1. The GRAB haptic interface in use

The GRAB system combines PERCRO's HI with a new Haptic Geometric Modeller (HGM) developed by LABEIN. This modeller enables developers to produce and explore virtual objects and environments, including specification of haptic stimuli, audio feedback, audio help and verbal commands. This last feature is made possible by the integration of a commercial speech recognition/synthesis software package, which provides the functionalities required for a verbal/acoustic interaction. Furthermore, the HGM provides a set of add-on functionalities for working in complex workspaces. For example, users can zoom in or out of the workspace and pan left and right, increasing the available resolution and size of the workspace.

2 The Design of the Game

The idea to develop a game that could be played using the GRAB device originated in a series of focus groups that were run early in the project to identify applications. A number of different types of game were considered before a search and adventure game in a 3D environment was selected. This type of game has the advantage that almost any form of interaction with the virtual environment that is possible with the haptic interface can be incorporated into the game play.

2.1 Initial Considerations

Because so little was known about how haptic interaction works for the blind in the context of a game, there were many basic research questions to answer. The fundamental question was ‘Is the GRAB environment suitable for playing a search and adventure game?’. Answering this involved asking specific questions concerning the elements of game play and how they relate to the interactions made possible by the GRAB user interface. The first step in the design process was to list these questions so that they would act as a guide for all later design decisions. The list of questions was as follows:

- What is required to strike the correct balance between making objects too easy or too difficult to find?
- Can users understand what they have found when they find it?
- Can users manipulate objects and perceive changed states that result from such manipulation?
- Do users feel that their actions are having a direct and immediate effect on the state of the system?
- Can users understand when they have completed a task successfully or unsuccessfully?
- Can users perceive when the game has come to an end?
- How do we communicate to the user how well they performed?
- Are users able to make use of different strategies to complete the game?
- Are users satisfied with the aesthetics of the interface (in this case audio and tactile aesthetics)?
- Is it possible for users to improve their ability to play with practice?
- Is the experience of playing the game rewarding?
- Does the game challenge users?
- Is the experience of playing the game engaging?
- The design of the game to be used in the evaluation was crucial. The GRAB HAVE provides a rich set of functionality making it possible to create a highly complex game environment containing objects with precisely modelled forms and attributes. It would be possible for players to interact with those objects in constrained or unconstrained ways, pick up and move objects, gain any amount of information or assistance through audio help and explore the environment by manipulating their point of view. However, the need to focus on the fundamental question of the suitability of the GRAB environment for gaming made it important that the game should not be too complex. If the difficulty of learning to use the interface were to get in the way of game play, the evaluation might reveal a lot about the details of the GRAB user interface but not much about the suitability of a haptic audio environment for playing search and adventure games. This was to be avoided.

It was also important to avoid producing a game which was so difficult that players would get stuck and become frustrated. A further consideration was the need to avoid including too many potential sources of difficulty. Given a combination of factors, it might be impossible to determine which were contributing most to players' problems.

It was therefore decided that a sensible first step would be to create a simple game. Consequently, many of the advanced features of the GRAB system, such as object surface attributes, picking up and moving objects, zooming, panning and constrained movement, were deliberately excluded from the game design. The design process was focused on producing a static environment that afforded simple game-centred interactions such as finding objects, identifying them, acquiring them and so on.

2.2 Game Play

Consideration was also given to the game play in the design process. To provide a meaningful experience the game had to have an objective for players to pursue, decisions the players could make, sufficient information to make these decisions, resources they must manage, and obstacles to their success [8]. As many of the basic research questions concerned users' ability to locate, identify and acquire objects, it was decided that the objective should be to search the virtual environment and acquire specified objects. These objectives are called 'Points' in the game and there are two of them to be collected. They are represented as cube-shaped objects placed on the floor of the virtual environment.

Decision making and resource management were built in to the game design by providing the player with 'lives', the opportunity to lose a life, and the opportunity to gain an extra life by finding and pressing a large button. To provide the player with sufficient information about the game environment, an inventory feature was added to the game. This uses the system's speech synthesis capabilities to read the player a list of items in the current room. The player can also request the system to read the game objectives if s/he wants to hear these again.

There are a number of obstacles to success in the game. One such is the attractive trap, which is represented as a small sphere that floats above the ground in the virtual environment. It exerts an attractive force on the player's finger if it passes within a certain radius and holds the captured finger, making it difficult for the player to move it. To escape from the trap, the player must locate and press a trap deactivator button located on a nearby wall.

There are also two bombs in the game, which are represented as cylindrical objects that are activated when touched. When activated, a forty-second countdown begins

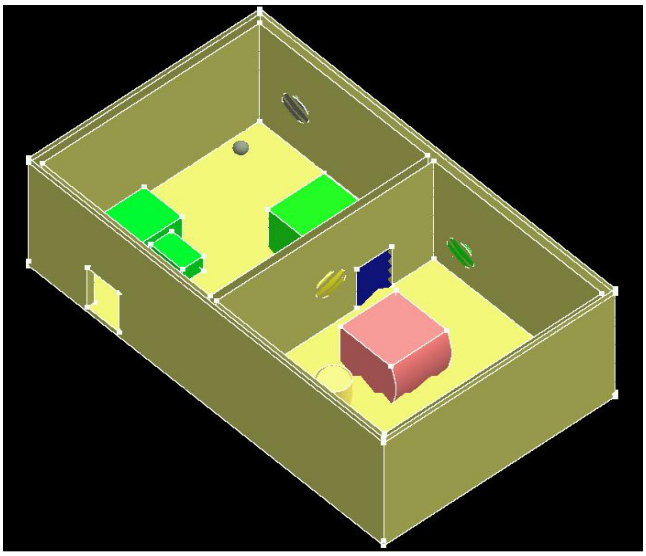

Fig. 2. A view of the game environment as represented in the Haptic Geometric Modeller

and the remaining time is periodically announced to the player. The player can deactivate the bomb by locating and pressing one of two bomb deactivator buttons located on nearby walls. If the countdown reaches zero, the bomb explodes and takes one of the player's lives. If the player has only one life, they are killed and the game ends.

The game environment is a building with one entrance/exit, illustrated above. It is divided into two rooms that have a connecting door, which is locked. The first room contains the entrance door, the extra life, the attractive trap, the trap deactivator switch, one of the two points, and the key to the connecting door. To pass through the locked door to the second room, the player simply picks up the key before opening the door. The second room contains the second of the two points, both of the touch-sensitive bombs and two bomb deactivator switches located on the walls.

Players start the game outside the building and must locate the entrance to move in to the first room. Although the illustration seems to show that the rooms are open at the top, there is in fact a ceiling so the rooms are totally enclosed. The modeller software renders the top of the building transparent so that activity inside the building can be observed. When the haptic interface is active, each finger is represented as a red dot in the game environment so that the player's movements can be tracked on screen.

2.3 Interaction Design

The principle interaction design problems addressed in the game concern how users acquire objects, how the buttons operate, how the doors operate, and how the inventory/objectives feature is activated. It was necessary to keep these interactions simple so that they would not get in the way of game play and so that users could carry them out using the haptic interface only. After testing a number of prototype models it was found that tapping on an object was the most effective way to interact with it for the purposes of the game. For example, to pick up the key in room one, the user simply taps on the top surface of the key three times and the item is acquired by the player and removed from the game environment. The same method is used to acquire the points and to activate the inventory/objectives feature. In this last case, the player taps three times on the floor to listen to an inventory of objects in the room and twice more to hear a statement of the objectives of the game.

The buttons, used to acquire the extra life and to deactivate the attractive trap and the touch-sensitive bombs, are modelled as convex buttons surrounded by a rim. These virtual buttons can be depressed just like their physical counterparts and provide audio feedback in the form of a 'click' sound sample when pressed and released. Finally, the doors used the same tap interaction as the other objects, so that tapping three times on the door produces audio feedback in the form of a 'knock' audio sample and causes the door to open so that the player's fingers can pass through.

Audio help is provided to players to aid in orientation and identification of objects in the game. If an object is touched, the game speaks the object's name. Audio help is also used to provide hints to the player. For example, if the player knocks on the connecting door without having collected the key first, the game informs the player that the door is locked and they need to collect the key.

3 Evaluation Methodology

The evaluation methodology was designed to collect both quantitative and qualitative data. The quantitative data was required to measure the degree of player improvement over time, in terms of total time taken to play and time taken on specific tasks such as locating and pressing a bomb deactivator button. The qualitative data was used to ascertain the success of the application as an engaging, rewarding experience and to identify sources of difficulties or frustrations and possibilities for improvement.

3.1 Test Design

The evaluation test used a repeated measures design to facilitate the measurement of improvements over time. This entailed each participant playing the game in two sessions with each session on a separate day. Each session involved twenty minutes of game play, with the player making as many attempts as possible at completing the game during that time frame.

Data collection was accomplished using three instruments. First, the game application logged player activity with a time stamped record of actions taken during each game. This log also recorded such statistics as the total time taken for each game and the number of models touched by the player. Second, the person administering the evaluation recorded written notes concerning players' behaviour and comments, such as each occasion when the player asked for help or commented on their strategy, impressions of the game, perception of the state of play and so on. Third, a questionnaire was designed to collect data from the player at the end of each session. The same questionnaire was applied at the end of both sessions.

3.2 Participant Profiles

Five blind participants were involved in the game testing at each of the three user organisations (NCBI, RNIB and ONCE) for a total of fifteen participants. All the participants had previously taken part in the testing of early prototype models in the GRAB HAVE in 2002. The five participants who had shown good aptitude for using the GRAB device in these earlier tests at each user organisation were selected to participate in tests of the game.

3.3 The Test Procedure

In the first of the two evaluation sessions the test participant was allowed to refamiliarise themselves with the GRAB device by exploring a model that contained some of the game objects for about five minutes. Next, instructions for the playing the game were read to the participant.

Each user was then allowed to play the game as many times as they could for a period of twenty minutes. Following this, the questionnaire was administered. The second session was identical, except that it did not begin with a familiarisation session. There was a gap of at least twenty four hours and not more than one week between the first and second test sessions.

4 Findings

Analysis of the quantitative data from the logs revealed that strict analysis of this data in isolation from the qualitative observations could be very misleading. For example, the test design assumed that the time taken to complete the game might indicate whether players were improving over time. However, it transpired that player behaviour was too complex to be measured in this fashion. In many cases, players mastered the game quickly and spent subsequent games in the session exploring the game environment or different outcomes of play, such as what would happen if they allowed the bombs to explode. Therefore, time taken could increase or decrease with familiarity and could not be relied on as an indicator of improved skill.

The most telling findings from the evaluation sessions were the questionnaire responses and the observers' notes, although the log data was useful for providing additional detail and context for the observers' notes. For example, noted comments that indicated frustration with some aspect of the game could be traced to repeated, unsuccessful attempts to open a door or some other specific task recorded in the log files.

4.1 Test Participant's Impressions of the Game

Analysis of the questionnaire returns showed that participants did find the game to be an enjoyable and rewarding experience. However, the simplicity of the game made it too easy for participants to master, so expressions of enthusiasm were almost always tempered by comments to the effect that more complexity and depth of challenge was necessary for a truly engaging experience.

Out of thirty responses, twenty-four indicated that the game was too easy and six that it was neither too easy nor too difficult. It is reassuring that the game was felt to be too easy by participants, because there are clear ways to make it more complex (provide more objects, arrange them randomly, and so on). Had the game been found to be too difficult, it would be hard to say whether that was because the game was too difficult to master, or because the device is not providing a suitable environment for gaming. It is very clear from the testing performed, that the GRAB environment is suitable for gaming.

One interesting finding from questionnaire responses is that despite the simplicity of the game, participants reported that they imagined premises for the game that were not part of the game design or test materials. For example, one participant imagined that the game involved exploration of a haunted house while another imagined the building was a ruin and was therefore disappointed that the doors did not creak when opened. This suggests that players will actively participate in creating an immersive experience if the game provides any opportunity for such play at all.

4.2 Interaction with Game Elements

Participants could all easily identify the objects in the game and unanimously identified the audio help feature as the reason for this. The sharp edges on the points and the key model also helped some participants identify objects, as did memory of the

position of objects on second and subsequent plays. However, some participants noted that not enough was made of texture and other haptic feedback mechanisms and that the object models were not detailed enough to identify without the audio help or prior knowledge of their purpose.

Participants also indicated that the key and point models were too large, making them too easy to find. Early prototypes of the game had these models much (50%) smaller and floating in the air rather than sitting on the ground. Preliminary tests showed that these models were difficult for even a sighted person to locate in the game environment, so the larger models were introduced and they were placed on the ground for the version of the game that was formally evaluated. It seems that the decision to place game objects on the floor or wall surfaces was correct, as participants were often observed searching wall and floor surfaces systematically.

Test participants were observed to have learned the position of game objects in the environment very quickly (often with near perfect recall on the second or third play) so the obstacles such as the trap or the bombs could be avoided with little trouble. In fact none of the participants who activated a bomb failed to deactivate it before it exploded. However, several participants allowed the bombs to explode in order to find out what would happen.

The tapping interaction used to acquire the key or the points in the game was very successful and participants very quickly mastered it. However, this same mechanism was much less successful when used on the doors. Opening the doors caused more difficulty and more adverse comment than any other aspect of the game. The problem seems to lie in the algorithm used to detect a knock on the door. If any other object is touched between knocks, the necessary series of three knocks is interrupted and the count is reset. This was compounded by a requirement to move the finger 1 cm away from the door between each knock for the action to be valid. Finally, the door was a harder target than the points or the key. It was a smaller target but also the target surface was perpendicular to the floor which seemed to make it more difficult to hit. The result was a frustrating experience for the players, who had to tap repeatedly on the doors until by chance they registered a series of three valid knocks.

4.3 Player Improvement Over Time

Almost all participants (28 out of thirty) said that they were able to improve their ability to play the game with practice over the test sessions. However, the simplicity of the game was a factor here too. Over the total of thirty responses, eighteen indicated that more improvement would be possible with yet more practice, but twelve responses indicated that a limit had already been reached in terms of speed or skill in playing the game. Users also felt that the game design restricted the potential for strategic play.

In terms of improvement in the time taken to complete a game successfully, the data showed that after a very few plays participants were able to finish the game in extremely fast times. Two participants recorded times of 48 and 45 seconds total to complete the game.

4.4 System Feedback

Participants were generally able to understand when they had done something successfully or unsuccessfully within the game, because of the speech and non-speech audio feedback that they received. There were problems with the audio feedback, however, as it was sometimes delayed and therefore delivered out of context. For example if a user touched an object and then immediately touched another, the audio feedback for the first object touched would play as the second object was touched.

A related problem was that the audio help was uninterruptible. This meant that objects or actions that had long sequences of synthesized speech associated with them, for example the inventory feature, would commandeer the system for some time when invoked, whatever actions the user subsequently took. The result of this was to cause even more confusion as the audio associated with objects touched after these long sequences began would remain in the queue and be delivered completely out of context after the long sequence ended. These problems with uninterruptible and unresponsive audio tended to decouple user actions and audio feedback, often making for a very disorientating audio environment.

5 Conclusions

One of the aims of this project was to answer some very basic questions, such as: Can users find game objects and identify them when they find them? How can they effect changes to the game environment and can they perceive such changes when they occur? In fact, the viability of a search and adventure style game in the HAVE system was in question. As a result, a relatively simple gaming environment was produced and correspondingly simple objectives were set for test participants. This environment served to answer all of these basic questions in the course of the tests.

The fact that players mastered the game in a very short time indeed indicates that the challenge presented to the players was insufficient. Furthermore, feedback in the questionnaires makes it clear that the challenge of the game is not a simple matter of the difficulty associated with any single task. The key factor seems to be the range of possible interactions and game states accessible to the player. Future game applications must offer a more complex environment to create a sufficiently challenging game and a rewarding experience.

On the positive side, many test participants did find the game an immersive experience despite its simplicity. Some test participants even reported that they imagined a background scenario while playing that explained the premise of the game, for example that they were exploring a haunted house. This seemed to have added much to their enjoyment of the game, and indicates that players will actively participate in the creation of an immersive experience if the game offers any opportunity for this sort of play at all. This is something that future games should exploit.

In summary, the testing has shown that the GRAB environment is suitable for gaming. The next step will be to produce a more complex and challenging game based upon these findings. This will involve improvements to the way the current functionality is used within the game but may also mean exploiting more of the advanced

functionality of the GRAB HAVE, with the criteria being that it should offer clear benefits for the design of a compelling game.

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