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MICOLE

Multimodal collaboration environment for inclusion of visually impaired children

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Deliverable D6: Report of the Design and Evaluation of Basic Multimodal Navigation Tools

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PU	Public	**X**
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Summary

This report describes the work done by eight different partners (UTA, UGLAS, METZ, UPPSALA, ULUND, KTH, SU and FORTH) in Work Package 2, Senses and Accessibility, and in particular task 2.2 Multimodal control and Navigation, subtask 2.2.1 Basic Navigation and Interaction. The key aims of research in this area were to look at how we could provide the basic techniques needed to allow users to control and navigate information non-visually using sound, touch and combinations of the senses.

We investigated basic presentation and interaction techniques using haptic, audio and multimodal displays to look at the possibilities of the different senses, and to see how they could provide access to a range of new applications (Section 3). We focused on sonic techniques (UTA, KTH), gestures and force-feedback (METZ, UGLAS, KTH) and tactile interactions (METZ). This gave us much knowledge about how to use the different senses and ways that we could apply them in our application domains.

We applied our knowledge of the basic techniques to the design of non-visual games (Section 4). Many of the challenges that need to be addressed to play a game successfully can be generalised to the challenges faced in designing any accessible interface. Games are dynamic and really show up the difficulties faced by blind people when interacting with complex information. They allowed us to test out ideas for the different modalities individually and in combination for multimodal solutions. We looked at audio only games (the work from UTA and KTH), haptic (using both force-feedback and tactile displays from UGLAS and ULUND) and multimodal games using sound and haptics (FORTH and ULUND).

Finally, we investigated the design of tactile maps and how users might interact with them (Section 5). UPPSALA looked at tactile and force-feedback interactions in maps and SU with audio displays (with some additional tactile feedback).

From all of this work we have distilled a set of design guidelines for others to use. We have made an excellent start in this area with good ideas on how to proceed further.

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1. INTRODUCTION

This deliverable report focuses on Work Package 2, *Senses and Accessibility*, and in particular task 2.2 *Multimodal control and Navigation*, subtask 2.2.1 *Basic Navigation and Interaction*. The key aims of research in this area were to look at how we could provide the basic techniques needed to allow users to control and navigate information. We investigated basic presentation and interaction techniques (see Section 3) and then applied these in the areas of Games (Section 4) and Maps (Section 5).

This introduction gives some background to the main senses we have used in our investigations, we then show how our progress through the 18 months of the work package and our objectives. We continue with a detailed description of the work done by each of the partners involved in this aspect of the deliverable in three main topic areas: basic interaction techniques (looking at some of the important basic questions about how to design with and use the different senses), games (our focus on game begins to apply some of the basic techniques in more realistic scenarios. Games are a good platform as they are very motivating for our users and provide some tricky real-time requirements for our techniques) and finally maps (maps are in some ways the opposite of games; they are static but can be large, complex and are very spatial, thus they offer a range of different challenges for our techniques).

The report finishes with links to some of the demonstrators of the work we have done, other activities in which the work has been presented or partners are involved, design guidelines drawn out of the work we have done, some overall conclusions on the work we have done, and finally a list of papers published by partners as part of the work.

1.1 Haptics

One of the key areas we have focused on has been haptic displays. This section provides a little background to the sense of touch. Our sense of touch can be roughly split into two separate categories: cutaneous and kinaesthetic. Different devices are used for these different categories and there are few that can provide good cues in both. Cutaneous perception refers to the mechanoreceptors contained within the skin, and includes the senses of vibration, temperature and indentation. Two different types of devices are commonly used, appealing to different aspects of the sense. The first uses arrays of small pins (e.g. dynamic Braille cells) to stimulate the fingertip. Such devices can present fine cues for surface texture, edges, lines, etc. The other type uses larger point-contact stimulators (e.g. the vibration motors found in mobile telephones). These vibrotactile cues here are much lower resolution but can exert more force; they can also be distributed over the body to allow multiple simultaneous cues. Particular issues here are the limited size and performance of many vibrotactile displays. The quality of the 'feel' from most devices does not yet come close to our perceptual abilities, making it hard to create realistic feeling surfaces, for example.

Kinaesthetic perception refers to the information arising from forces and positions sensed by the muscles and joints. The sense is bi-directional; one can both perceive and act on the world by exerting forces. Devices use force-feedback to present kinaesthetic stimuli and produce the feeling that the user is interacting with physical objects, such as a line cut into a virtual surface or a solid three-dimensional object. SensAble's PHANTOM (www.sensable.org) is one of the most commonly used devices. Force-feedback devices can create very realistic feeling objects in the right circumstances, but there are limitations. Most use a *point interaction* model; the user is represented by a single point of contact corresponding to the tip of the stylus. This is analogous to exploring the world with a stick thus depriving users of the rich, spatially varying cutaneous cues that arise on the finger pad when contacting a real object. Users must also integrate temporally varying cues as they traverse the structure of virtual objects with the single point of contact, which places considerable demands on short-term memory. This can have a great effect on the success of interactions using these devices and care must be taken when designing the interactions to avoid problems.

1.2 Audio

Audio has been the other key area we have investigated for the deliverable. There are again two parts: speech and non-speech sounds. The use of synthesised speech in our research has been straightforward; we have used it to present key messages and absolute information. We have made no major research contributions, it has been used more as a tool. The whole area of speech has been well investigated and we can build on those results to do what we need. Our focus has been more on non-speech audio.

Our sense of hearing is very powerful and we can extract a wealth of information from the pressure waves entering our ears as sound. Sound gives us a continuous, holistic contact with our environment and what is going on around us; we hear a rich set of sounds from our interactions with objects close to us, familiar sounds of unseen friends or family nearby, noises of things to avoid like traffic, or to attend to like a ringing telephone. Non-speech sounds (such as music, environmental sounds or sound effects) give us different types of information to those provided by speech, they can be more general and more ambient where speech is precise and requires more focus. Non-speech sounds complement speech in the same way as visual icons complement text. For example, icons can present information in a small amount of space as compared to text, non-speech sounds can present information in a small amount of time as compared to speech. There is less research into non-speech than speech interfaces and this chapter will show something of where it has been used and of what it is capable.

1.3 Multimodal Interaction

The combination of haptic and auditory feedback at the user interface is a powerful tool for interaction for blind people. In everyday life, these primary senses combine to give complementary information about the world. Our haptic system gives us detailed information about a small area of focus whereas our auditory system provides general information from all around, alerting us to things outside our view. Blattner & Dannenberg discuss some of the advantages of using this approach in multimedia/multimodal computer systems: “In our interaction with the world around us, we use many senses. Through each sense, we interpret the external world using representations and organizations to accommodate that use. The senses enhance each other in various ways, adding synergies or further informational dimensions”. These advantages can be brought to the multimodal (or multisensory) human-computer interface by the combination of auditory output and haptic input and output. A multimodal interface that integrated both senses could capitalize on the interdependence between them and present information in the most efficient way possible.

1.4 Progress

The work package started in December (month 3) with a 2-day meeting of all of the partners at MLE in Dublin. All partners described the work that they had previously done that would fit into the topics outlined for WP2. We then discussed what areas we might focus on for the first period of the WP that would encompass the aims of the work package and the skills of each of the partners. We came up with: Games, maps and charts, and mathematics. We decided that the best approach was to produce prototype demonstrations of the ideas (with lightweight evaluations) that would then be presented at a later meeting. At that meeting we would consider each prototype and decide whether to take it further on into our first deliverable (D4/D6, month 18).

A workshop for all WP2 contributors was held in Glasgow in May, 2005. This workshop brought together the prototypes developed since the first WP2 meeting held in Dublin, and we decided where to go next. Each partner presented the work on their prototypes and showed demos so that everyone else could try them. We then discussed where the work would go next and developed grouping to allow the partners to work together to develop ideas further.

A final workshop was held in Novermber, 2005 in Lund to discuss how we would evaluate the prototypes built, ready for inclusion into the deliverable. We shared knowledge of evaluation techniques and fed ideas into work package 5 on evaluation.

During the first 18 months MLE withdrew from the project. We rearranged the work so that UTA took over the research that was originally planned for MLE and they employed another researcher.

2. OBJECTIVES OF THE WORK PACKAGE

In WP2 we carry out basic research through empirical experiments and prototypes to find out how to use different senses in user interfaces for visually impaired children. One main objective is to explore the idea of cross-modal equivalence and multi-sensory perception through a series of empirical studies that contrast different representations of information across different modalities (task 2.1). This will allow us to come up with the best methods of presenting information given different disabilities of our users and different technologies that they may have at their disposal.

The second objective is to design, develop and evaluate a range of navigation and control techniques to allow users to explore, navigate and share data, visualisations (such as graphs, tables and charts) and mathematical formulae (task 2.2). These will use combinations of modalities such as sound and touch to enable seamless interaction with data and with other users. By careful design we will ensure that our tools are usable by blind people themselves and that they can be supported by their carers and teachers. This deliverable report (D6) focuses on the work in this task, deliverable D4 focuses on work in task 2.1.

A final, but significant objective, is the construction of design guidelines that inform the creation of multimodal presentation and navigation tools. These guidelines will be used extensively in WP4. There will be a continual effort to feed the results gained in this work package into WP4 throughout, but dedicated time will be assigned to formalising the insights gained from this process towards the end of the work package.

For this deliverable we are presenting work done in subtask 2.2.1 *Basic Navigation and Interaction*. Here we have been investigating how to provide basic tools to allow users to move around and feel/listen to their data. We have built on previous work in this area and extended it to our needs. A key issue has been to ensure that the navigation tools we provide do not get in the way of the data the user is trying to access. One way to avoid this is to use a different modality for the navigation tools than for the data presentation. We have looked at force-feedback, tactile, non-speech audio and synthesised speech to give us a wide range of different presentation and interaction modalities. We iteratively designed and evaluated a range of different tools with our users to provide this basic navigation. We have worked closely with task 2.1 of this work package (many partners are involved in both). We have shared results, knowledge and techniques. We have fed results into work package 4 on software architectures and work package 5 on evaluation.

3. BASIC INTERACTION TECHNIQUES

3.1 Introduction

The following section describes some of the basic interaction techniques that have been developed and evaluated for aiding users in navigating and controlling a computer interface. For accessible interfaces, we rely on auditory, tactile and force-feedback cues to provide some of the information that is usually available through visual means. Through evaluation, successful techniques can be identified and incorporated into future interfaces used in the project.

3.2 UTA - An Exploration of Directional-Predictive Sounds for Non-Visual Interaction with Graphs

3.2.1 Introduction

Over the recent years, there has been an increasing interest into non-visual techniques such as non-speech audio, touch and haptics to signify different forms of information. A demand for multimodal data visualization has become more popular due to increasing diverse mobile computer applications serving the user in unfavourable lighting conditions such as smoke, darkness and other distortion factors which hamper observation. As additional space for imaging, sounds and sonification are used to display the huge data arrays in a compact and convenient way due to temporal sound nature [13].

People could have permanent vision loss or a temporary block when vision is occupied by another task. In both cases, there is a challenge to support data imaging. Special techniques should be developed to augment traditional data presentation forms or/and to support an alternative way.

Sonification is widely discussed as a way to compensate the lack of vision and to provide navigational cues [2, 9, 16] presenting charts and graphs [5, 6] as well as to allow non-visual drawings [4].

Tran et al. in [18] evaluated a sonification model, based on the parameters of the acoustic beacons, in navigation tasks in the real and virtual environments. The study showed that the various auditory parameters have an impact on human accuracy in turning towards the direction of the acoustic beacon. The results revealed that the non-speech beacons were preferred over the speech beacons and a continuous operation of a sound was favoured over a pulsed operation.

The work done by Tran was extended in the research carried out by Walker and Lindsay [19, 20]. Walker and Lindsay concentrated on the usage of the waypoint capture radius of an auditory beacon. They defined "the *capture radius* of an auditory beacon as the range at which the system considers a user to have research the waypoint where beacon in positioned" [19]. In practice, as a person approached to waypoint (nearer the capture radius) sound signal was given as an indication for leading the listener towards the next waypoint in the map. The authors pointed out that the performance on navigation through the given map differed across the capture radius conditions, such as the radius size of the capture.

Contour or shape identification is one of the tasks in non-visual inspection of the graphs. However, when the graphs are exclusively presented through sonification or embossed tactile diagrams, such visualization impoverishes the information the original graph contains. As stated by Jacobson [11]: "*Traditional tactile diagrams are static, unintelligent and inflexible - they can only be read by one person at any time, they cannot be 'questioned', they cannot be manipulated to change scale or perspective*".

Non-visual inspection of the graphs is the alternative visualization technique of the relationships between values of the data array which are being ranged and plotted or displayed with a reference to a set of non-visual cues. Non-visual physical signals such as sounds, force moments, palpable mechanical vibrations and electrical pulses can be applied as feedback cues [3, 5, 9, 14, 17]. The wider dynamic range of the perceptual cues is the more information concerning data relationships might be displayed through these signals. When non-visual cues evoke a diffuse sense, they could be applied to display some generalized features at the comparison of graphs or its segments.

A sonification technique might support the exploration of the graphs on a small touchscreen to provide natural and intuitive interaction for visually impaired users. However, the feedback cues ought to be strictly coordinated with exploratory movements and data visualization of each segment (locus in array) that is being evaluated. Still, the problem is how to minimize the number of sounds and to increase the information they carry to the user, as any signal can distract and affect the integrity of the image perception.

Let us consider the graph that displays an array of eight sequential measurements (Figure 3.2.1). The X-axis shows a number of measurements in a sequence and the Y-axis shows a value of the parameter being measured. Visually, we can observe that the measured parameter did not change regularly. We can also find two local maximums, one local minimum and one point of discontinuity. Moving a cursor along the graph, we can receive information

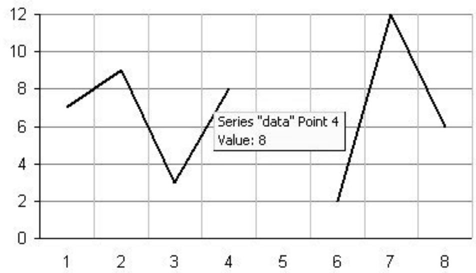


Figure 3.2.1: Graph sample.

concerning each record with a popup label. Gridlines help to interpolate and estimate probable intermediate meanings. Thus, visual tools of the Microsoft Excel, for instance, provide a qualitative data estimation at a glance.

Visualization through sonification (Figure 3.2.2) of the same graph (Figure 3.2.1) during 5 s with a step of 55 ms gives a general impression regarding two local maximums, one local minimum and one point of discontinuity if the listener can correctly discriminate the sonified fragments. There is a special technique to fix attention in particular locations of the virtual sound source to decrease the diffusion area [7]. However, a frequency deviation along Y-axis could also lead to misrepresentation of the linear or non-linear sizes and relationships between the graphic objects due to non-linear hearing sensitivity and the features of the personal hearing experience. As a result, the gap of afferent information in a part of the haptic sensations needed to match virtual locations of the sound source regarding known physical sizes such as length of the hand, for instance, can lead to an inadequate perception or a subjective deformation of the sound image. It is noteworthy that the movements of head and eyes play an important role in visual analysis, and kinesthetic feedback of eye position directly follows the motor cortex which is the main integrative structure of the brain. Thus, the direct sonification (the entire image-to-sound) approach can be applied in a case when increment of the array values is big enough and sound mapping allows to distinguish the differences among data groups. While in a sample (Figure 3.2.2) about 90 points were sonified, only 5 sound fragments could be differentiated with repeated listening. The comprehension of the relationships between graph components still remains vague. Moreover, increasing the number of spots does not necessarily lead to increasing the information that has been presented to a listener regarding each sound fragment.

It is difficult to display the features of homogeneous arrays through non-visual signals when their images look like smooth trajectories. Certainly, it is possible to point out (by hand) and to sonify each of the fragments separately using different cues to display information of the particular segment concerning the whole graph. Still, the graph has to be sonified in such a way that the sound stream would not have been interrupted with speech cues, such simulation of popup labels.

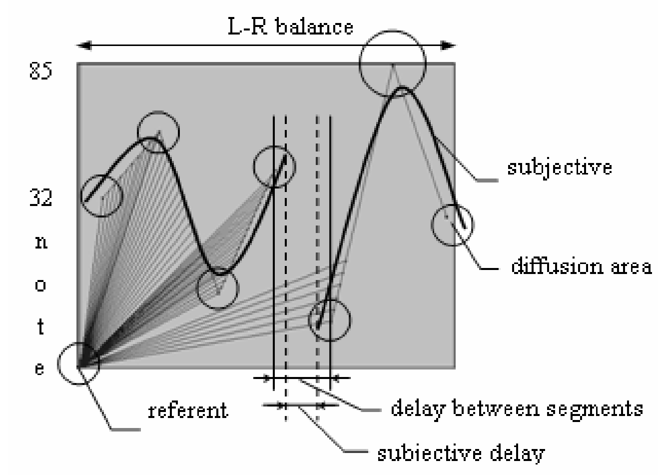


Figure 3.2.2: Graph sonification through MIDI synthesis [8].

As a rule, sonification of the graphics is based on some mapping or a convention regarding which method could be used to transform visual (optical) or physical parameters into sound ones. For instance, depending on image resolution each pixel or a group of pixels in a working field can be assigned with sound attributes such as volume, frequency and timbre, which could be modulated as a function of geometrical or/and optical (brightness, colour) characteristics of the pixels [14]. The conversion 'image-to-sound-to-image' itself can be carried out invariantly with mathematical accuracy.

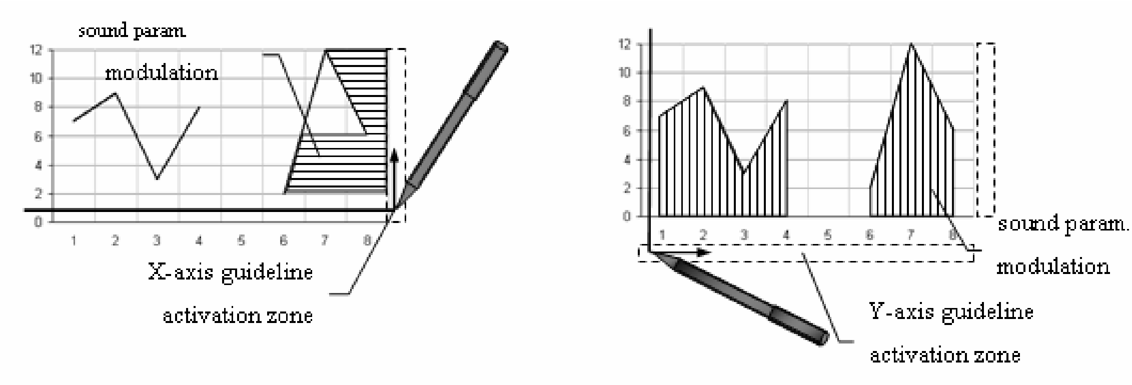


Figure 3.2.3: Graph inspection through (indirect) sonification of the distance between crossing points of the guideline and the graph.

However, this fact does not mean that after long training and perceptive experience the person will comprehend the greater part of the information the sound graph does really contain. Anyway, the person is never a passive observer of the static graph. The analysis of the graph includes dynamic interaction with the data array, and the graphic visualization which in a wide sense is a tool to find the hidden features of the data array.

Researchers often use a case study or simple analogies to build up a basic model for data transformation and then they try to generalize the results in order to prove that the proposed particular image-to-sound mapping can be used as a universal approach. However, sometimes an observer has to outline parts of the graph to concentrate visual attention or to directly feel some irregularity by hand/gesture. It is known from practice that haptic (tactile-kinesthetic) sense of the surface homogeneity is more obvious than it looks. That is, intuitively people involve other modalities (perceptual experience) while interacting with novel data. During such an exploratory behaviour, the motor component plays an important role in integration of the perceptual information and extraction of the features of the data array.

Thus, we have to produce diverse tools for an active inspection of the data values when designing new techniques for data visualization. Some kind of *user-driven filters* synchronized with direct manipulation by stylus or finger could support highly interactive non-visual inspection of the data array (i.e., alternative visualization). In such a way, suitable and continuous recognition of the abstract features, projected onto the behavioural activity and sensible landmarks could be provided. Being the coordinate system in hand, the horizontal and vertical guidelines, which interact with graph, could bring much more information than only the values of crossing points do (Figure 3.2.3).

In the case of interaction with a touchscreen, there are many different possibilities of delivering sound feedback coordinated with exploratory movements of the stylus or finger. If a whole graphic pattern has been presented to the blind person, s/he can never feel the whole image and shall scan it by fingers sequentially, piece by piece. Many researchers concluded that it is not necessary to design a graphical tactile tablet as only a small matrix of the tactile transducers could be placed under the fingertip. A scan process of the graphics could be performed using any pointing input device. A number of devices with built-in tactile transducers has been developed so that people could move their hand along a virtual plane and a limited contact surface would change in dependence on a device location and graphic features of the inspected plot area [17]. Still, this way is unnatural as sliding the fingertip and a direct mechanical contact with the inspected surface brings much more information for a mental reconstruction of the tactile image.

Other techniques have been developed which allow to display not the array values but the result of the interaction dynamics with an array, while the data inspection is being modulated by the observer's gesture and behavioural pattern. For instance, if the step of inspection would be dependent on the movement speed of the stylus, by manipulating guidelines with a different speed, an observer could increment sound modulation in doubtful positions.

When capture radius is being used (Figure 3.2.4), it might also be changed during rough inspection of the plot area and precise exploration within a specific field. Additional information concerning navigation within the plot area could also be provided via sounds. However, a continuous sonification of the distance between stylus and graph could be problematic or unavailing. Directional-predictive signals near the capture radius in respect to a movement towards the graph or backwards could optimize the scan path and decrease time of the non-visual inspection. Thus, there is a challenge to support non-visual inspection and active interaction with graphs making use of sonification of stylus movements accompanied with kinesthetic feedback.

In the present study, we investigated the potential of using directional-predictive sounds (DPS) to support non-visual inspection of the graphs through sonification. Taking into account the concept of capture radius, stylus movements regarding the graph were sonified with three sound signals:

crossing sound (CS) – a single sound indicating when the stylus is within Rc-distance from the graph,

backward sound (BS) – the signal indicating when the stylus moves backward regarding the graph and the distance to the graph is increased up to four Rc-distances, and

toward sound (TS) – the signal indicating when the stylus moves toward the graph within four Rc-distances.

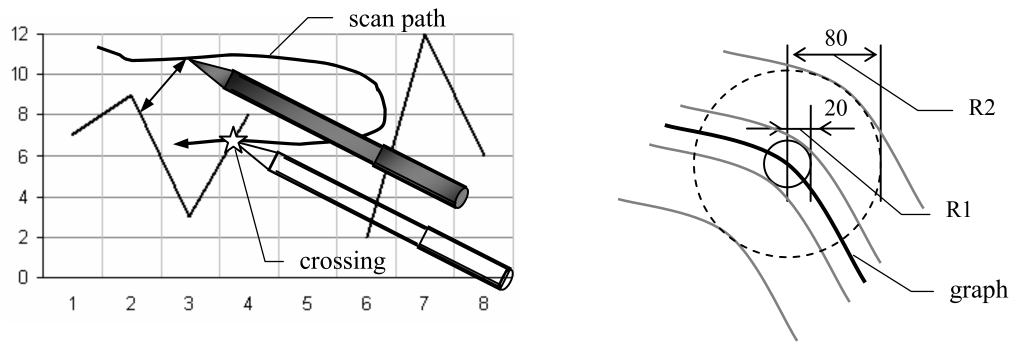


Figure 3.2.4: Sonification of the stylus movements. R1=Rc, Rc – capture radius in pixels, R2=4× Rc.

3.2.2 An Evaluation Method

Participants

Eight unpaid right-handed sighted students (four females and four males) participated in the evaluation of using directional-predictive sounds during non-visual inspection of the graphs. The age of the subjects ranged from 23 to 31 years. They were blindfolded (wore mask) throughout the experiments to avoid visual prediction or/and approximation of the detected positions concerning touchscreen bezel. Graphs were always hidden from the subjects.

Procedure

The study was carried out on iPAQ Pocket PC 3800 series; the processor speed of the PDA used was 200 MHz. The test program was written in Microsoft eMbedded Visual Basic 3.0.

The task of the subjects was detection of the graph features (position and direction of the components) and tracking whole graph under 2-minute inspection by relying on sound and kinesthetic feedback. The subjects were told to follow the graph in question several times without necessity to identify the graph, however, with their best possible speed and accuracy. Upon completion of the task, the subjects had to press a button (down arrow key).

Non-visual inspection of the graphs was investigated under two different sonification conditions: using the *crossing sound* alone and three sounds (CS, BS, TS) accordingly. DPS sounds were the short sound bursts having duration less than 35 ms. The sounds were composed of several sine wave signals with different pitch, timbre and volume in order to facilitate their perception and discrimination each other (Figure 3.2.5).

Two trials were given to familiarize the subjects with the equipment, sonification and interaction techniques. Auditory cues were triggered when a stylus changed position within one or four Rc-distances from the graph but not more often than once in each four pixels. The rounded graphs overlapped and partly coincided within two Rc-distances. Doing the test under time pressure conditions also stimulated the subjects to choose a right strategy to limit random movements. All points of the graphs were plotted in a square of 220 by 220 pixels. Diameter of the circle, shown in the Figure 3.2.6 for a comparison, was equal to $2 \times Rc = 40$ pixels.

The graphs and conditions have been changed randomly. Each of the subjects accomplished the inspection of 5 graphs in 15 trials in 2 conditions. Thus, 600 + 600 scan paths were produced and taken for the statistical analysis in total.

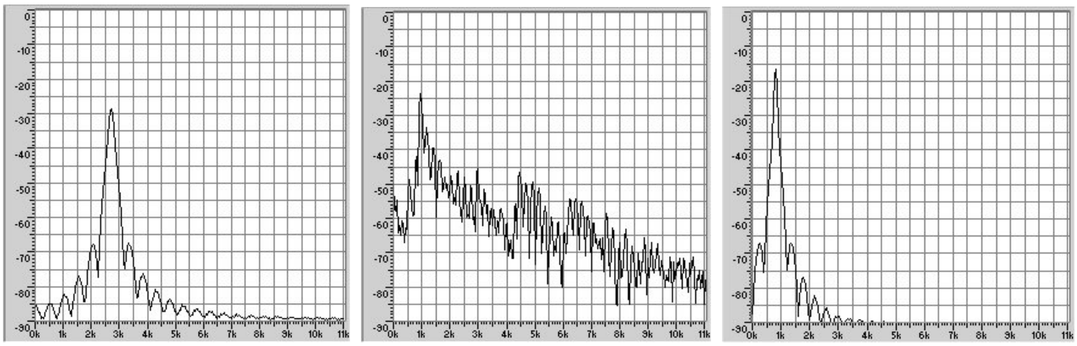


Figure 3.2.5: Spectrograms of the signals which were used to sonify the movements regarding the graph: crossing (15 ms), backward (25 ms) and toward (35 ms) sounds (from left to right).

3.2.3 Results

Figure 3.2.7 shows the movement traces/scanpaths (broken irregular lines) of the subjects when the hidden graphs (continuous solid lines) were inspected with the use of the *crossing* sound alone. These results are representative enough. Some of the subjects could suppose or even recognize a shape of the graphs. Being blindfolded, the person primarily relies on the previous kinesthetic experience as a basic behavioural pattern and uses it in the next trials. A comparison of the first and second, the third and fourth, the fifth and sixth tracks proves such a negative transfer effect which impedes forming the universal strategy within the task and inspected field.

The use of the fixed capture radius and a single feedback signal cannot be suitable and often brings an ambiguousness, especially when the graph has branching and crossing points. Certainly, if the system knows a stylus position and the average speed of the motion, it is possible to predict the points or the nearest field of an inspection and to change the capture radius accordingly. However, this feature is still under investigation and outside the work presented in this paper.

The patterns of the movement traces in inspection of the hidden graphs when tracking was accompanied with DPS sounds are shown in the Figure 3.2.8. As it can be observed from the traces, the subjects did inspection accurately and very quickly. During two minutes, they could even successfully complete detection of the same graph several times (a repetition of scanpaths) or accomplish an additional checking of neighbour fields (the third track). Some of the subjects started the inspection from the left upper corner of the touchscreen by doing the movements across or in a diagonal direction. In the beginning of the test, we also observed the tracks when the subjects learned to move stylus and made the choice between three sounds step by step as it is shown in Figure 3.2.8 (the first behaviuoral pattern on the left). Other subjects started from the right upper corner or any random position. Therefore, we suggested that the average deviation of the movement traces concerning the nearest graph position could be used as a kind of criterion for an evaluation of the performance of the subjects.

Figure 3.2.6: The graphs used in the test and their superposition. Diameter of the circle is equal to 2× Rc.

Figure 3.2.7: Scanpaths at inspection of the hidden graphs when the crossing sound was used alone.

Diameter of the circle is equal to 2× Rc.

Figure 3.2.8: Scanpaths at inspection of the hidden graphs when tracking was accompanied with DPS sounds. Diameter of the circle is equal to 2× Rc.

Figure 8 shows the trendlines in the behaviour of a subject during the inspection of two hidden graphs. As we could observe from all the data in the case of the use of predictive sounds, the deviation of the stylus from the graph inspected had always a smaller mean. That is certainly encouraging because the subjects tended to minimize the deviation gradually when they became the experts in the use of DPS (see trendlines). The deviation was less than a pre-set capture radius value (Rc = 20 pixels). While standard deviation shows that some scanpaths could be more far from the graph than Rc, *backward sound* immediately stimulates the person to move in an opposite direction. Hence, due to BS we could minimize idle search time and speed up the inspection of the hidden graph.

Paired-samples t-test also showed that there was a significant difference in average deviation for both conditions of the feedback provided (CS and DPS), $t = 6.418$, $df=15$, $p < 0.01$ for the first sample, (upper graph in Figure 3.2.9); $t=6.27$, $df = 13$, $p < 0.01$ for the second sample, (bottom graph in Figure 3.2.9).

Rc has to be as small as it is possible in order to increase resolution of the technique in the case of ambiguous points. However, as we monitored and listened to feedbacks during the experiment there was another reason why standard deviation of the deviation of the stylus position was higher than it could be expected regarding the capture radius. We can conclude that the subjects may have been following closely to the graph when doing the inspection through a balance between BS and TS, without crossing.

Finally, we compared all the data (120 scanpaths) gathered in two conditions for each graph throughout the test. All the deviations were averaged and the overall results are shown in Figure 3.2.10. The length of the scanpaths varied in a number of points sonified from 93±23 up to 146±19 in the CS condition and from 75±8 up to 103±11 in the DPS condition. The scanpaths (in pixels) were by 4 times longer, as auditory cues were triggered when a stylus changed position within one or four Rc-distances from the graph but not often than each four pixels. The average time of the blind inspection with a single sound (CS) was about 54.6 s (*SD* = 20.5 s), but when DPS signals were employed the task completion time decreased to about 45 s on average (*SD* = 9.4 s).

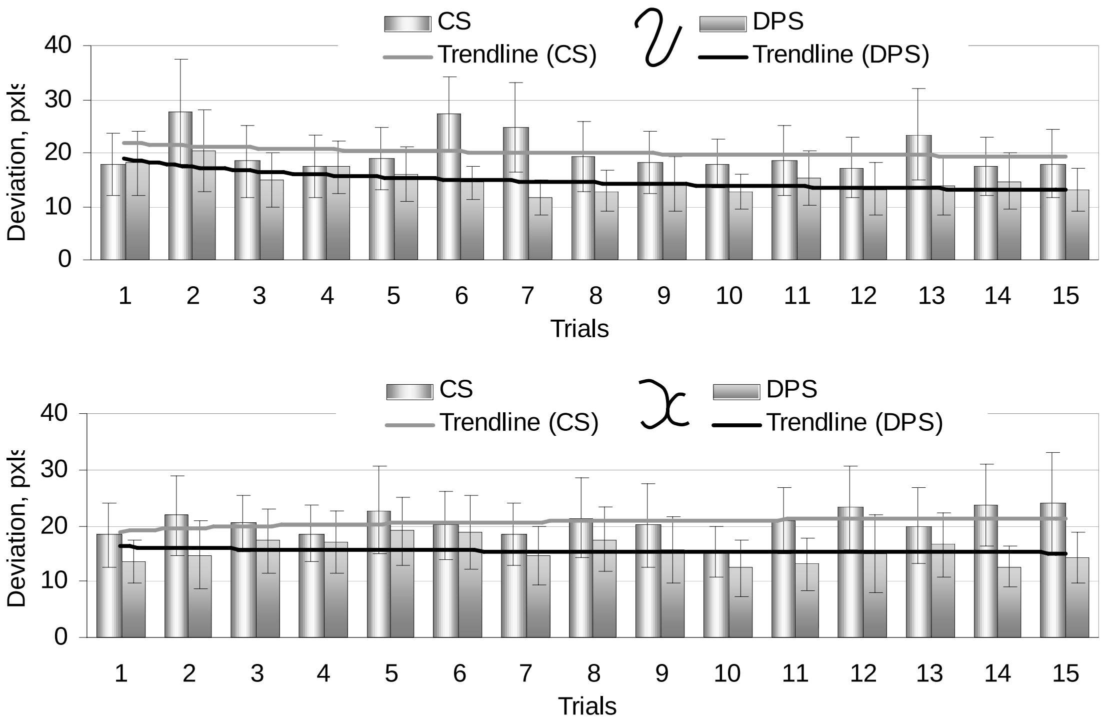


Figure 3.2.9. The average deviation of the stylus position in pixels of the movement traces concerning the graph (shown in a top middle position of #the legend) throughout the test of the same subject.

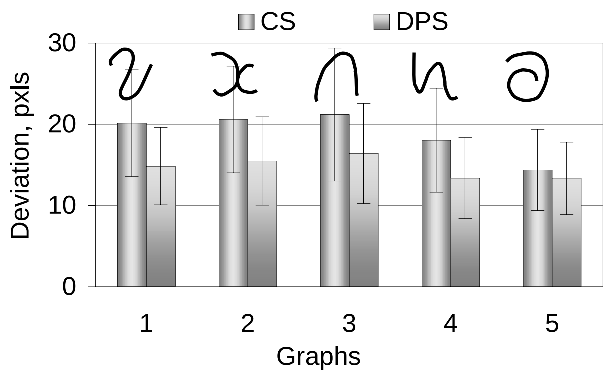


Figure 3.2.10. The deviation of the stylus position (in pixels) of the movement traces concerning the hidden graphs inspected in two conditions. The data averaged from 15 trials with 8 subjects.

Paired-samples t-test showed a significant difference between average deviation for both conditions of the feedback provided (CS and DPS), $t = 5.271$, $df = 4$, $p < 0.01$. In the basic study presented, the deviation of the stylus from the graph inspected had a smaller mean for all the graphs when predictive sounds were used. By using DPS, all the subjects had the average deviation smaller than a pre-set capture radius value (Rc = 20 pixels).

3.3 UGLAS - Gesture Learning through Force Playback

3.3.1 Introduction

"Concepts without images are blurred, Images without concepts are empty"
Immanuel Kant.

Users rely heavily on visual feedback when interacting with a computer. This is particularly the case with the graphical user interface now playing such an important part in interactions with computers. However, computer users with no or very little vision must rely on other modalities to access the same information through similar interfaces. Screen readers have proved to be a successful solution for accessing the textual information required to interact with a computer. However, this information is generally accessible only in a linear manner (from the top left corner of the screen) and non-text information such as pictures and diagrams are not easily displayed in this manner. The goal of this work is to examine techniques to enable users to navigate or control a computer interface and explore information or shapes non-visually in a non-linear manner.

In the previous study, we examined tactile feedback cues for providing information to the user about the direction of movement. Here, a more direct approach is taken. Using a force feedback device, the user is actively dragged through a trajectory. The goal of this is to allow the user to build up a mental representation of the shape of the trajectory by experiencing it through haptic playback. It is still an open question as to whether this method will allow a visually impaired user to perceive shape information.

Gesture has the potential to be a useful technique for blind and visually impaired users. A gesture can be performed with any device that allows continuous interaction such as a mouse. One potential application would be gesture to control an interface. The user would perform the gesture with the system recognising the gesture and performing the actions. Here the gestures can be trajectories relative to the user's current position with the shape of the gesture being the factor. Users do not need to maintain an overview of their position within an environment to perform the gesture. A rich library of simple symbols can be developed to perform intuitive control actions within an interface. The form of haptic playback would also be useful for indicating non-text information to visually impaired users. User's maybe interested in the shape of an object on the screen or the path to be taken to move between two points on a map, or in situations where learning a particular motion is important such as learning to sign his or her name.

A previous study from Zipf-Rougier *et al.* [5] looked at gesture as an interaction mechanism for visually impaired users. The study looked at the performance of a visually impaired group as well as the acceptance of the group of the technology. Results suggested certain gestures (such as a v-shaped gestures) were easy to remember and perform, and were intuitive when the control action for the gesture was chosen carefully.

Feygin *et al.* [3] conduct a study into the possibility of providing gesture training using either visual, haptic, or visual-haptic guidance. Further to this, there were 2 conditions in which participants recalled the gestures. The conditions were haptic-visual where the participants saw their cursor as they attempted to perform the gesture, and haptic where the participants attempted the gesture with no feedback of cursor position. Results showed significant improvement in recreating the gesture in all conditions between the first and the last gesture. The haptic only training mode performed significantly worse than the haptic-visual training mode, but not significantly worse than the visual training mode. Dang *et al.* [2] discusses a constraint-based training system that provides guidance to users by restricting their movements from deviating from a path. This method allows a user to follow the path taken for a procedure by an expert, but allows the user to apply the forces to perform the surgery. Yokokohji *et al.* [7] similarly examine haptic force playback for the purposes of training for simple task. The system they studied actively dragged a user through a task to provide learning in performing that task. Similar techniques have also been applied to teaching Chinese handwriting. Teo *et al.* [6] demonstrate a system where the position of a teacher can be recorded and played back to a student to aid in forming characters. Gentry *et al.* [4] demonstrate a system which allows the user and computer to collaborate on a dancing task. Here, the user had to synchronise their moves to music and with the movements of the device.

3.3.2 Haptic Playback

Haptic playback is not a trivial issue. The two main issues to be addressed are stability of the algorithm and safety of the user. Particularly when some haptic devices can apply enough force to injure a user. Loss of control of the effector is a particular safety problem when the user may not be able to see the device. Three algorithms for a playback system were implemented: a point-to-point playback system, a simple implementation of a bead pathway system (developed by Amirabdollahian *et al*. [1]), and A PID Controller system.

Point-to-Point

In the point-to-point system, the trajectory is represented as a series of discrete sample points. The algorithm will play a force of constant magnitude in the direction on the next sample point until the user's cursor is within a certain distance of that sample point. Once close enough to this point, the force direction now changes to drag the user towards the next sample point on the trajectory.

This implementation will lead to poor performance. The system is unstable in that there is no damping factor. If the user‘s cursor passes the sample point but does not get close enough to move the playback to the next sample, point, an artefact will be introduced in to the shape of the trajectory that should not be there.

Bead Pathway

The playback algorithm described in this report is based on the bead pathway model developed in [1]. This was developed for rehabilitation therapy to move the user's hand through a smooth trajectory. The pathways in this study were defined by a spline curve passing through a series of points. The user is pulled along by a spring damper system, with one end of the spring attached to a bead that is constrained to and travels along this path.

PID Controller

For this work, the bead pathway model is extended by replacing the spring damper system with a PID controller. The benefits of this approach are potential for lower error and better adaptability to changes in conditions. The purpose of any controller is to minimize the difference between the current value of some system and target reference system. This difference is referred to as the error. Control is performed by feeding the error back through the system in some manner (a negative feedback loop). Simple proportional control simply applies a multiple of the error to the output actuators. In a force-based system, this is similar to the operation of a Hooke's law spring - force is proportional to the deviation from the set point.

The PID (proportional-integral-derivative) controller is a widely used control algorithm in industrial situations, which has been used in various forms for many years. Its popularity stems from the ease of implementation of a PID controller and its effective performance in a wide range of control problems. A huge range of more sophisticated control methods are of course of available, many of which have much more accurate modelling of the dynamics of the process to be controlled, but the simplicity and effectiveness of PID control makes it a more attractive option in many cases.

The controller extends proportional control by including the integral and derivative of the error into the output term. The integral term serves to drive the error of the system to zero; constant offsets are eliminated. The derivative term increases the response time of the system and reduces overshooting of the reference. In combination, the controller can quickly acquire a new reference value accurately without excessive oscillation. PID controllers require generally require tuning for optimal performance for a given system.

Suboptimal settings lead to sluggish response or highly oscillatory acquisition patterns.

In the implemented system, the PID controller is as used a direct replacement for the spring damper system. The controller's reference value is given by the bead moving along the pathway. The pathway here is defined by linear interpolation between a sequence of sample points along the proposed trajectory.

3.3.3 Experiment

An experiment was conducted to examine the performance of visually impaired users on this system and compare this performance to sighted user.

Methodology

Two groups of participants took part in the study. One group consisted of 9 blind or visually impaired users from the Royal National College for the Blind in Hereford. The second group contained 6 sighted participants to provide a performance baseline for the method. Both groups of participants performed the same task. The task set was to feel a gesture played through haptic force playback and then recreate that shape. The equipment used for the force playback was a PHANTOM OMNI from SensAble Technologies. For the sighted group, the movements of the device and the participant's arm were hidden by placing the device behind a barrier. The barrier provided a large enough gap not to restrict movement, while not allowing a participant to view the device or his or her interactions with it.

Before playing each gesture, the device was centred in the workspace by the PHANTOM motors. This is to ensure that the user starts in a position that has sufficient space in each direction to complete the trajectory. The shape was then played to the participant at an approximately constant rate (depending on the user's varying resistance to the movement) with a pause of 1.5 seconds at the end of the gesture before he or she was returned by the device to the central workspace position. The 1.5 second pause (where no force was supplied) was to provide the user a chance to separate the gesture from the centring force. Each trajectory was played to the user five times before he or she was asked to recreate the movement three times. When drawing the trajectory, participants held down the PHANTOM button on the stylus for the duration of the movement and released it when complete. All shapes played to the user during the study were two dimensional and set in the vertical plane.

Each user initially went through a training period before starting the experiment. All participants performed three gestures before the experiment started. These gestures, shown as gestures 1 to 3 in Figure 3.3.1, were chosen to be simple easy to describe shapes. These were a circle, a triangle and a square. Nine trajectories (chosen to be more abstract and difficult to describe than the training examples) were then played to the participants. These trajectories are shown in Figure 3.3.1 as gestures 4 to 12.

Analysis of the results

The cursor trace data was analysed *post hoc* through a recognition algorithm adapted from a three layer MLP neural net. The neural net was initially trained on the twelve gestures where each gesture was represented by 36 equally spaced points ordered chronologically over the entire trajectory. Recognition was considered successful if the appropriate gesture was the most probable gesture out of the twelve possible gestures returned by the Neural Net. When analysing the user trajectory, two different methods were employed. The trajectory was separated into 36 points for inputs to the neural net equally distributed in either time or in space. Using points equally distributed in time provides recognition of trajectory. Using points equally distributed in space removes the variations in the user speed of movement, leaving recognition on the shape of the trajectory only. As the playback rate is held constant in this study, will be performed on the shape of a participant's trajectory only.

Visual scanning of the cursor trace data was also performed to provide information about where variations in the trajectories were occurring and to identify situations where errors were consistently occurring.

Hypothesis

The hypothesis is that the sighted group of participants will achieve a significantly higher proportion of correctly recognised gestures than the visually impaired group due to the sighted group's greater experience at working with and visualising shapes and images.

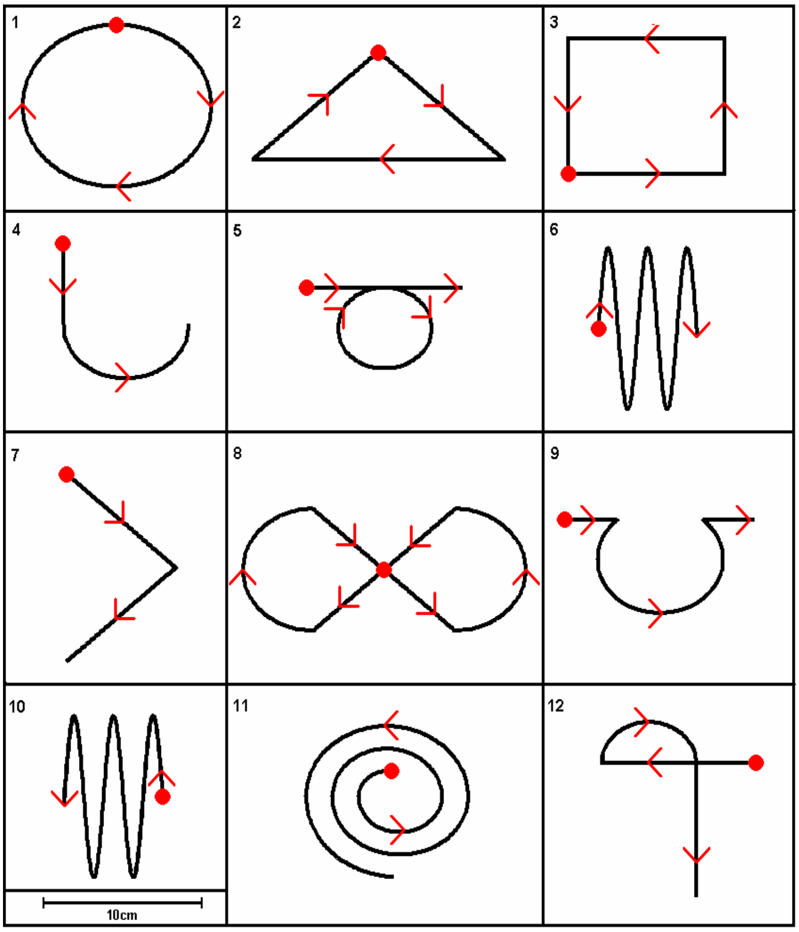


Figure 3.3.1: The gestures used in the study. The circle on the trajectory indicates the start position with arrows indicating direction of movement. Gestures 1-3 were used for the training stage of the experiment with data gathered from gestures 4-12 analysed for the results.

3.3.4 Results

For each participant, percentage of correctly recognised attempts was measured. The mean percentage of correct responses was 51.1% (Std Dev = 26.3) compared with 74.7% (Std Dev = 5.9). These data were analysed using a non-parametric Mann-Whitney test and a significant difference was found ($W = 53.0$, $p < 0.03$). Figure 3.3.2 shows both the percentage of correctly recognised shapes for each participant in the visually impaired group and the sighted group. Figure 3.3.3 shows the percentage of correctly recognised shapes for each individual shape.

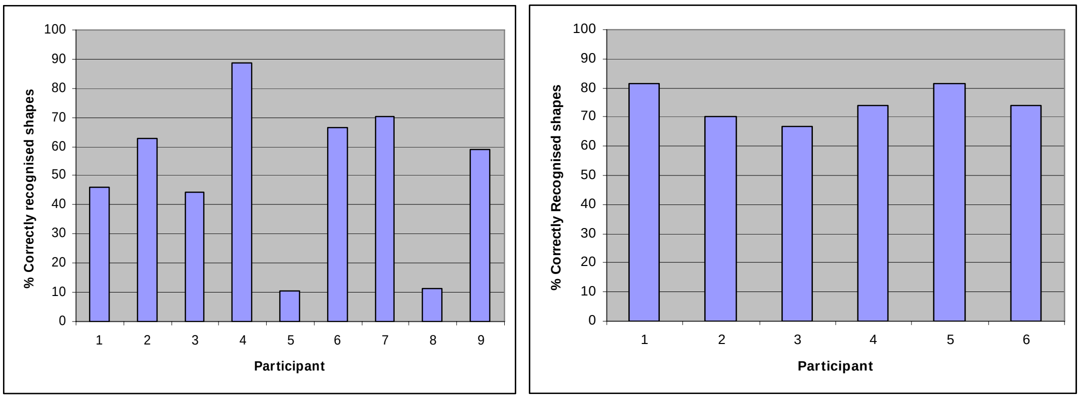


Figure 3.3.2: The percentage of correctly recognised gestures for each participant in the visually impaired group (Left) and the sighted group (Right).

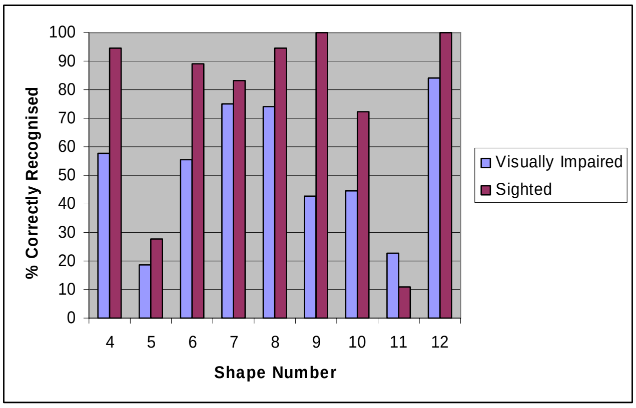


Figure 3.3.3: Percentage of correctly recognised shapes for both groups for each shape.

3.3.5 Discussion

Results suggest that the sighted group were able to perform the task significantly better. This may be expected as the sighted group has everyday experience of gesture as a form of communication. People use visual gestures such as facial expressions and hand gestures everyday to aid communication. The sighted group are use to using and perceiving these movements in everyday life. The sighted group also have more experience in working with and visualising shapes in their everyday life. It is possible that the differences found here are due to the greater experience visualising shape. The task also bears some resemblance to a drawing or handwritten task. Again the sighted group's greater level of experience at these tasks may lead to a higher level of performance. It is interesting to note that the highest level of performance recorded was by a participant in the visually impaired group. There is far more variability in performance in this group, compared to the sighted group whose results display low variability.

From figure 3.3.3, it can be seen that shape 5 and 11 were poorly recognised for both groups. This may indicate the difficulty for the user in recognising and drawing the shape or could be the result of poor performance of the recognition algorithm for these two shapes.

3.3.6 Observational results

After each of the training examples, participants were asked if they recognised the shape of the trajectory. For gestures 1 and 2, participants reported the correct shapes 7 out of 9 times for the visually impaired group and every time in the sighted group. The square represented more of a problem. During playback, the control algorithm attempts to minimise the error between the user's cursor position and the playback position. However, the user's cursor position will lag slightly behind the playback position. When the playback direction turns through a sharp angle, this will have the effect of slightly rounding the corner of the path that the user has been dragged through. This effect is more noticeable when the turn is such that the new direction of movement is downwards. Here, the playback force combines with gravity to emphasise the rounding effect. Square was often represented more as a hemi-sphere when drawn by participants. During playback, the shape felt by the user is perturbed by the weight of the device. Figure 3.3.4 shows one example of the actual position of the user's end effect when dragged through the square gesture. It can be seen from the user's trajectory (the dashed line) that in particular, the sharp change of direction in the downward causes a rounding of the corner.

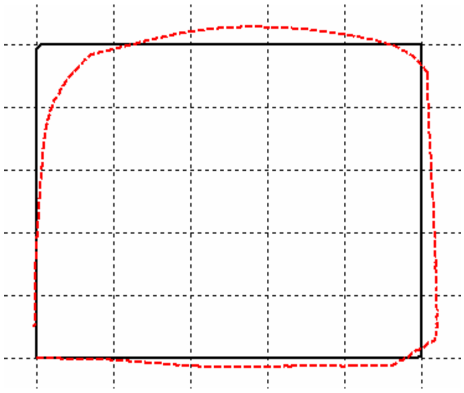


Figure 3.3.4: Shows the trajectory of a user being pulled along in a square trajectory (starting from the bottom left).

One factor in the experiment mentioned by most participants after the experiment was problems in segmenting the trajectories. During the experiment, the participant was initially held in the central position. When the gesture was played, the device dragged the participant through a path. To indicate the end of the gesture, the device stopped applying a force through the device for 1.5 seconds before returning the user to the central position for the next playback. In some instances, the trajectory returning the user to the centre was included in the playback (illustrated for shape 4 in figure 3.3.5 with one participant's attempts to recreate gesture 4). Although this could be seen in a small minority of occasions during *post hoc* analysis of the cursor trace, participants still reported confusion.

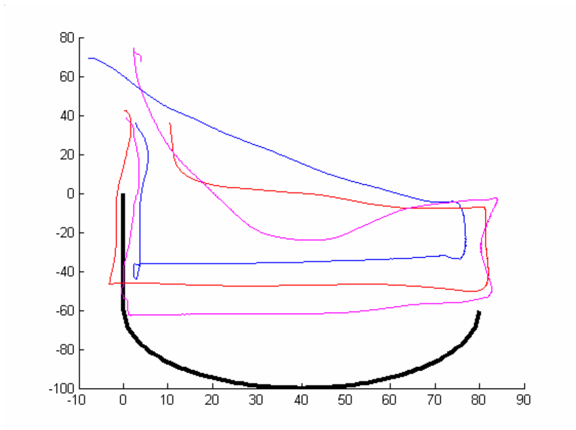


Figure 3.3.5: Three trajectories from one participant recreating shape 4. The centring force played at the end of the shape was mistaken for part of the shape and added in by the user when recreating the shape.

There were further confusions with the segmentation of the gestures that were not reported by participants but observed in some cursor traces. The gestures were all set in the vertical plane. At the end of every gesture playback the device motors were turned off allowing the user to move freely. Once the playback forces were turned off, there was no force from the device supporting the user against gravity. In some occasions the participant's hand then moved downwards due to gravity adding the perception of a downward tail being added to the trajectory.

3.3.7 Discussion and Conclusions

Here we present a study examining perception of shape information through force playback for blind and sighted users. The results suggest that the sighted group of users could perform the task significantly better than the visually impaired group. The level of recognition of

Guidelines

From the above study, the following guidelines can be drawn

- While learning shapes through force playback is possible for both sighted and blind participants, be aware that there is a far greater variability in the level of performance for visually impaired users.
- The perceived shape of the trajectory can be altered when the user is released from the playback constraint once the trajectory is complete. The user's hand has a tendency to sink slightly before compensating for gravity giving the perception of vertical downwards tail to the end of the trajectory.
- Segmentation of multiple shapes felt purely through force playback can be confusing. Multimodal feedback could significantly reduce confusion to the user through, for example, using auditory cues to mark the start and the end of the playback.
- During force playback users will not feel the exact path that is played to them. Perturbations from the users force on the device and gravitational effects can alter the trajectory. The effect will be less for smooth transitions than sharp transitions.

Future Work

There are a number of modifications to the study that should be run before the success of the system is judged. In particular, three main improvements will be implemented.

1. Auditory feedback will be added to help with segmentation of the gestures giving the user a clear indication of when playback trajectory starts and ends. There is also the potential to provide to the user audio cues during the playback that also describe the shape of the trajectory to users as they are feeling it. Separate audio, haptic and combined systems will be tested.
2. Particularly since the gestures are placed in the vertical plain, the user will be constrained to a point at the end of the trajectory. This is to remove the perceived 'tail' effect caused when the user's hand sinks once released at the end of a shape due to gravity.
3. The shapes used for this study were deliberately overly complex when compared to the trajectories that would be used in a gesture-based system for controlling an application. A future study will examine simpler shapes that should be easier for the users to learn and remember.

Conclusions

Force playback has the potential to be a useful mechanism to teach visually impaired users shapes and trajectories. These techniques are envisaged to be used in a gesture based system (to control an interface), a training system (to teach handwriting or geometry) or in a collaborative setting (to aid awareness and provide context information). The study described suggests more work is required if a robust gesture control system is to be implemented. The long term training aspects of the system still need to be examined. Future work will examine the success of these systems in more realistic contexts.

3.4 KTH - Navigation and control in haptic applications shared by blind and sighted users

3.4.1 Introduction

Three prototypes have been evaluated by KTH in order to investigate aspects of interaction by visually impaired and sighted adult users in shared haptic/visual environments. Navigation and control are two important aspects focused on in Task 2.2 in WP2 that this report will also address. The applications that were evaluated in this study have been developed by KTH and were further modified for this evaluation. The purpose of doing the evaluation was to obtain design input that can inform the final design of the multimodal collaborative system designed in MICOLE.

A number of studies have shown that adding haptic force feedback improves single users' performance when manipulating virtual objects. The added value of haptic force feedback lies in peoples' ability to feel the object they manipulate, which makes interaction faster and more precise (Gupta et al., 1997; Hasser et al., 1998). Although not as well studied as single user interface interaction, a number of authors have investigated issues regarding joint manipulation of virtual objects in a haptic collaborative virtual environment (Ishii et al., 1994; Basdogan et al., 2000; Sallnäs et al., 2000; Oakley et al. 2001; Sallnäs 2001; Hubbold, 2002; Jordan et al., 2002; Sallnäs and Zhai, 2003). A number of studies have investigated different interaction techniques including tactile and audio feedback in order to support visually impaired people using computer interfaces individually (Yu et al., 2002; Yu and Brewster, 2002).

In the study presented in this report, joint interaction between visually impaired and sighted people is investigated in a shared haptic/visual virtual environment. The focus in this evaluation has been on how users manage to explore virtual haptic environments, finding reference points and objects, identify objects and their properties, discriminate between objects and hand off objects to each other. It might seem very hard for a visually impaired person to do these tasks in a computer interface. The findings in this study show however, that it is possible even if a number of problems are identified.

3.4.2 Prototypes specification

Prototype 1: Design environment

With this prototype we can investigate how users can collaboratively identify and explore objects and object properties (Figure 3.4.1a and 3.4.1b). The test participants were able to feel the geometrical shape of objects and the objects tactile properties such as surface friction, size and softness. Each participant has a proxy in the environment that they investigate the environment with. The sighted participant could also see a visual representation of the shared environment.

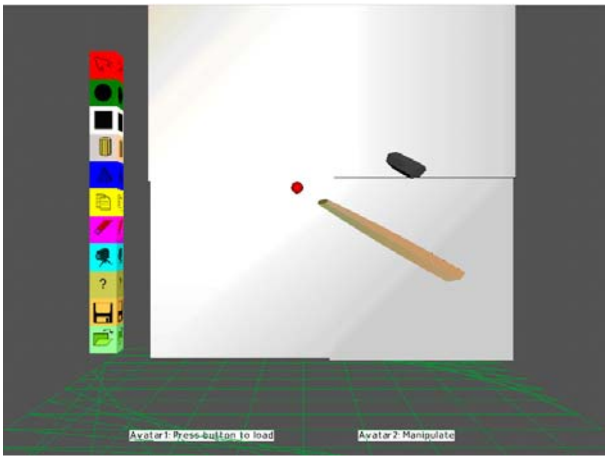


Figure 3.4.1a: The design environment viewed from the front.

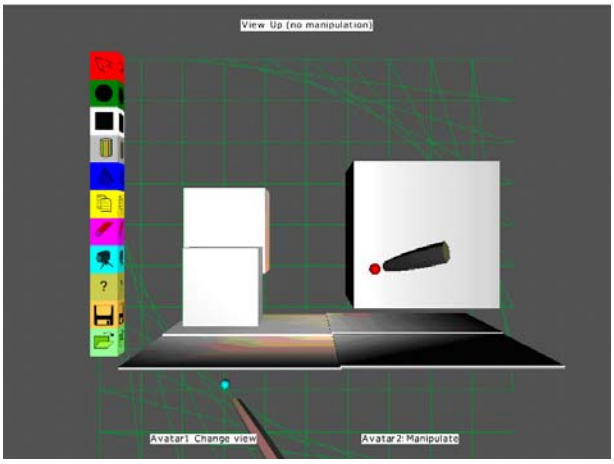


Figure 3.4.1b: The design environment viewed from above.

The experimenter can in this application build a scene by using a haptic menu. It is then possible to simply push at the symbol of a shape on the menu and then place the object anywhere in the virtual space. It is also possible to save a scene, to upload an old scene and to delete an object by first pushing the button with the eraser on the menu and then push at an object. The experimenter can also change an object's size, surface friction and softness by moving a slide bar that can be activated through the menu bar. Finally, the experimenter can make an identical copy of an object that has been modified.

Prototype 2: Box moving environment

This prototype was developed in order to investigate joint lifting of objects. In this box moving application there are eight boxes that move quite easily on the floor that is perceived as rather slippery (Figure 3.4.2). The test participants are represented in the environment by one blue and one green sphere respectively. The participants can in this environment feel collisions between objects and can lift a cube by pushing from each side of it and lift it. The participants then feel the collaborator's forces on the object. It is also possible to feel the shape of the other person's proxy and to hold the other person's proxy by pushing the button on the Phantom pen. In this way participants can shake hands or guide each other. This environment includes gravitation that makes it possible to feel the weight of the cubes.

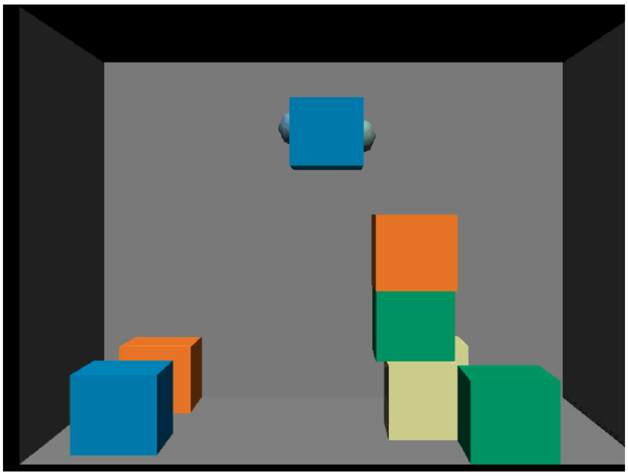


Figure 3.4.2: The box-moving prototype. Two participants push from each side of a cube in order to lift it.

Prototype 3: Hand-off environment

This prototype was used in order to investigate hand-off of objects between two people in a shared environment. The application consists of four shelves and four boxes that sit on the top shelves (Figure 3.4.3). In this environment there are collision between objects and also gravitation. It is also in this environment like in the others possible to feel all the shapes in the virtual environment. What makes this application special is that participants can grasp a cube themselves by placing their proxy at the cube and pushing the button on the Phantom pen. Then a participant can lift the object and hand it off to the other participant. When both participants hold the object they can both feel the other person's pulling forces through the object until someone lets the cube go. In this way it is possible to know when the other participant has the cube securely before letting it go.

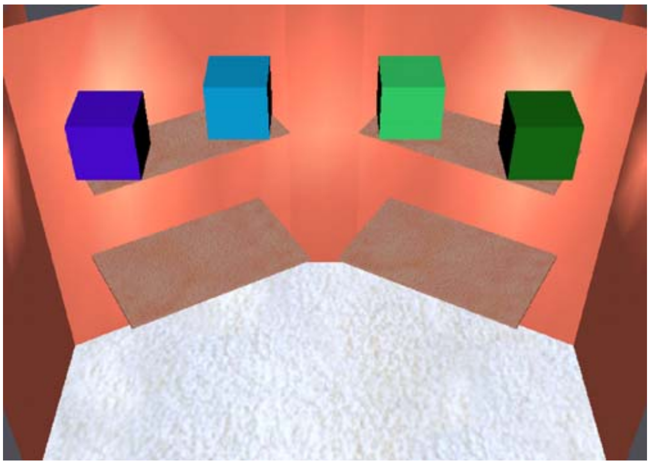


Figure 3.4.3: The hand-off prototype.

3.4.3 Evaluation

A study was performed in order to investigate how a sighted and a blind person can interact with three shared virtual environments that provide visual and haptic feedback. Furthermore, the aim was to investigate how a sighted and a blind person could use these environments in order to solve four tasks together. The test of the three applications was performed in a laboratory at the Royal Institute of Technology.

Participants

Six visually impaired and six sighted adults participated in the laboratory test. The participants in the test were adults.

Apparatus

The haptic feedback system that each person used in this study was a desktop Phantom device with a Reachin display system. The two haptic systems were connected to one computer. The sighted person has stereovision through Stereographics CrystalEyes 3 shutter glasses. Touch and vision are co-located for the sighted person.

Figure 3.4.4: The two test participants sitting in front of one Reachin Display system each.

The navigation and interaction techniques used were the one-point haptic feedback in all of the environments. This made it possible to feel the walls, floor and ceiling when such were present in the environments. The sighted person also relied a lot on the visual feedback.

Procedure

The participants were placed in the same room during the tests. A paper screen was placed so that the sighted person could not see the visually impaired person (Figure 3.4.4). The participants were able to talk to each other during the test.

Before the test the participants explored one of the applications in order to get acquainted with the visual/haptic environment. Before each task the experimenter gave a verbal description of the environment to both subjects at the same time. Both subjects also got each task description verbally. The test sessions were video recorded for later analysis. The computer screen and the hands of the subjects were video recorded.

The test session ended with interviews with the two users together. The video recordings of the interaction in the shared visual/haptic virtual environments including the communication between the participants were analysed.

Tasks

Task number one was to find the objects in the first design application and to decide together which object that was the hardest, which was the softest, which had most surface friction and which had the least surface friction.

Task number two was also performed in the design application but the scene was different. The task was to identify the shape of three objects that were hidden behind a screen and to decide together which object was the largest.

Task number three was to take turns to hold a cube against the floor in the box moving application while the other person explored the shape. Then the participants should push from each side of a cube and lift it. Finally the participants should hold on to each other's proxies and "shake hands" virtually in the environment.

Task number four was performed in the hand-off environment. The participants were instructed to first locate the shelves and cubes. After that one participant was instructed to take one cube from the upper left shelf and give it to the other participant that should put it on the lower right shelf. Then the person that placed the cube on the lower right shelf should take one cube from the upper right shelf and give it to the other person that should place this cube on the lower left shelf.

3.4.4 Results

The interviews were transcribed word for word and analysed. The video recordings were analysed and notations were made of the users interaction with the interface and with each other for each pair respectively. The overall result showed that all participating pairs managed to perform the four tasks even if they encountered a number of difficulties when interacting with the interfaces.

Haptic mental representation

Fixed reference points like walls, floor, ceiling and fixed objects like shelves are important in an environment to support orientation. The blind participants reported that they were able to form a mental haptic representation of the environment after some exploration. In the environments with gravity, the weight of the objects and the fact that a dropped object ended up on the floor underneath the position of the user made it easier to control the objects and find them again when lost.

Even though the blind participants thought that getting a pre-understanding of the context from a verbal description is very important, they thought that the verbal descriptions did not correspond very well to their haptic experience of the environment.

The communication with the co-worker was also a great help when forming a mental representation of the environments.

"…now I should be on the lower left shelf and there should not be any blocks there. But then you also said that but I just wanted to check it".

This example shows that verbal communication between the participants is important to support awareness of the status of the shared environment. The blind participants argued that they could form a good mental picture of an environment but that they needed a bit more time to explore the interface. The blind participants sometimes felt a bit slow compared to the sighted person.

" one can do what everyone else can do but much slower"

Problems with perspective

The blind participants said that angles and inclinations were problematic because they sometimes did not feel natural or realistic and there were very few 90-degree angles. It was sometimes problematic to know the difference between walls and the floor and in one environment there was no ceiling. The participants said that it is better to have restricting surfaces in all directions. Another problem was to understand the perspectives because it was hard to know if the perspective was from above like looking down into a box or from the front like looking into an aquarium. The blind persons are right in that it is not very clear what the perspective is because the workspace is slightly tilted forwards haptically but not visually. Sighted persons do not notice this because of their visual dominance but it gets more obvious for the blind person. This is something that should be improved.

Referring to objects

Referring to objects verbally is relatively easy. This had to do with the fact that both sighted and blind participants felt that they got a good mental representation of the content and layout of the environments. The blind persons said that they had a good understanding of the changes in the environment of the objects that were relevant for the task. One difficulty was however, that the haptic hardware volume limits sometimes were mistaken for being an object in the environment. If the environment does not have restricting surfaces all around, the volume borders of the environment become confusing for the blind person and create problems in the discussion between a sighted and a blind person.

Referring to direction

A problem that both the sighted and the blind persons experienced was that it was hard to talk about directions in the environments. One cause for this problem was that the participants sat almost facing each other physically in the laboratory while they at the same time were talking about directions in the environment. The blind person wondered if they were facing each other in the virtual environment also which they in fact were not. In the virtual environment they had exactly the same view just as if they were sitting beside each other. It was also hard for the blind person to understand what the sighted person meant when she said go backwards. For the blind person that meant moving the hand with the Phantom towards himself whereas the sighted person meant the opposite, which is moving the hand forwards so that the proxy moves more into the virtual environment.

Object handling

Joint manipulation of objects was possible in the environments by the sighted and the visually impaired person. The participants used the haptic feedback for coordination and communication a number of times. There were also some instances of haptic guiding behaviour in the environments. One person then is either grabbed and dragged in a direction or grabs someone in order to be guided.

The participants were in the interview able to talk about their shared experience of solving the tasks together in the environment as if they had both experienced approximately the same place. They could refer to situations in the interaction that both of them remembered and they understood what objects and behaviour the other person was describing.

3.4.5 Conclusions

It is possible to derive a number of important aspects concerning navigation and control from the results of this study. These should be considered when designing applications in the future that aim at supporting joint interaction by a visually impaired and a sighted person in a haptic environment similar to the ones tested in this investigation.

- Predictable behaviour that mimics nature like gravity makes it easier to control objects.
- Fixed reference points like walls, floor, ceiling and fixed objects like shelves are important in an environment in order to support orientation.
- Verbal communication between the participants is important to support awareness of the status of the shared environment.
- It is better to have restricting surfaces in all directions otherwise haptic hardware volume limits sometimes are mistaken for being an object in the environment.
- It is important that perspectives and angles are natural haptically and relevant for the task that is performed as it is very confusing for a blind person to use an unusual haptic perspective with not so common/natural angles.
- Referring to objects is relatively easy because users experienced that they had a good mental representation of the content and layout of the environments.

- It was hard to talk about directions in the environments when both participants were in the same room facing each other. Referencing thus depends on the physical location of the participants during the interaction in the virtual environment.

- Joint manipulation of objects was possible and haptic feedback was used in order to coordinate joint handling of objects.

Generally it is a positive result that all participating pairs managed to perform the tasks in the study together without any major breakdowns. It made it possible to get a multifaceted picture of the problematic aspects as well as the successful design features when analysing the interaction.

The aspects described in the conclusions from this study will be considered in future application development in the MICOLE project.

3.5 KTH - Investigating auditory drag & drop: Supporting overview, location and interaction.

3.5.1 Introduction

This work is about investigating new techniques for giving blind users better access to graphical user interfaces using sound. The major difference between screen reading software for blind computer users and ordinary graphical user interfaces is the difference in presentation of the information, cf. Boyd, Boyd & Vanderheiden (1990). The screen reader presents the contents of the screen in a line-by-line fashion, using speech synthesis or Braille. This linear presentation does not allow for presentation of concurrent and spatial information in the same way as a graphical user interface does.

Ways of presenting graphical user interfaces for blind computer users have been explored a number of times before. For example in the Mercator project (Edwards, Mynatt & Stockton, 1994), the graphical user interface was presented using a hierarchical model of the interface objects where the logical relationship is represented using everyday sounds. In the GUIB project (GUIB Consortium, 1995), the spatial relations of the objects are presented using a novel tactile device.

Building on the experience from earlier studies on auditory direct manipulation (Winberg & Hellström, 2000a, 2000b, 2001), a sonification model has been designed that implements drag and drop, and that has the same resolution as a computer screen.

This study investigates fundamental properties of navigation; getting an overview of a complex space, locating and selecting a specific object and interaction with this object. The reason for studying audio alone with no haptic display is to find out the specific limitations of using audio to navigate a complex data space.

3.5.2 Auditory drag and drop

The prototype described here is designed to support drag and drop, which involves movement of objects by positioning a pointer on the object to be moved, picking it up, dragging it to the desired location and dropping it there. In order to do this, the interface must support getting an overview of all objects, locating a specific object, and interacting with that object.

This is accomplished by using auditory zooming, a technique where the granularity of the auditory display increases when the user “moves closer” to the information, mapping many objects to one sound when far away, and one object to one sound when close (Axen & Choi, 1996; Saue, 2000). In this implementation, the presentation is divided into two levels, the *overview* and the *zoomed view*.

Overview presentation

The overview gives the user a general notion of where there are objects, and approximately how many. This is accomplished by dividing the screen into four quadrants. The location of the objects is presented using four different tones. The tones are separated using pitch (high or low representing top and bottom) and stereo panning (left or right representing left and right), and these tones were repeated in parallel continuously.

Zoomed view

The zoomed view gives the user detailed information about a subset of the display, the quadrant in which the pointer is located. All objects placed in the same quadrant as the pointer are audible. The volume of each object depends on the distance to the pointer; the closer an object is, the higher the volume. The objects are presented one by one.

Objects

All objects have separate sounds. The sound changes depending on where the object is located with respect to the pointer.

A guiding tone is added to the sound (a high, low or middle pitched tone representing above, below or at the same vertical level). The distance between the pointer and the object is presented in two different ways. The intensity (volume) of the object sound and the guide tone is mapped to distance, the closer the pointer is the louder these sounds will play. The guide tone has also a repeating pattern that changes with distance. The total time is always constant, but the number of repetitions increases when the distance decreases. This means that the closer the pointer gets to an object, the faster the guide tone will repeat itself.

The horizontal location is represented using stereo panning (left, right or middle representing left, right or the same horizontal level).

Interaction

The user interacts with the objects using a pen stylus on a graphics tablet. This is used in order to have absolute positioning of the pointer, as opposed to the mouse whose relative positioning makes it harder to use sound as the only output device when the complexity of the display is large (cf. Pitt & Edwards, 1995). Additionally, using the mouse requires sonification of the position of the cursor, which limits the auditory bandwidth left for sonifying other components (cf. Winberg & Hellström, 2001).

There are also event driven sounds that give the user feedback on specific actions, in order to emphasize the directness and physical nature of the interaction. These actions include hitting, picking up, dragging, and dropping an object.

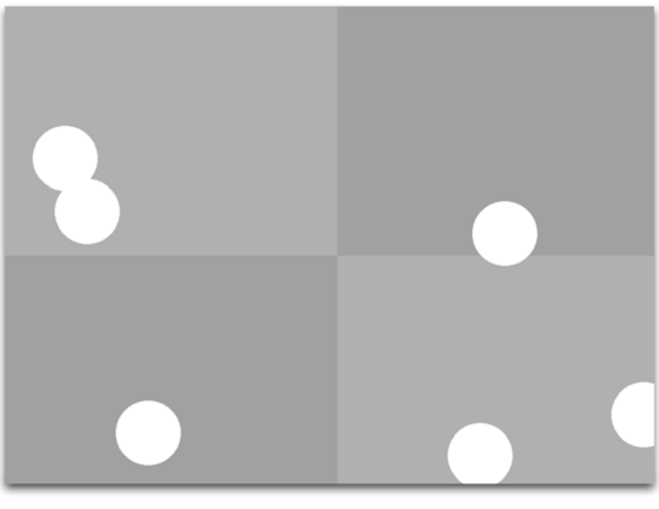


Figure 3.5.1: A graphical representation of the auditory display

3.5.3 Evaluation

The main object of the user study was to get input from the user group in an early stage of the design process. This means that rather than taking quantitative measurements of for example task completion time, concrete design ideas and suggestions for alterations was the main focus.

To further stress this the sessions were kept deliberately informal in order to encourage the subjects to take an active part in the dialogue rather then a passive interviewee.

Each session started with the subject just listening to the different sounds while following the directions from the session leader and getting the different aspects of the auditory display explained in detail. After getting familiar with the interface the subject was encouraged to just play around with the interface. During this play around phase the subject was asked to perform a number of specific tasks; counting the total number of objects and moving all or a specified number of objects to a specific part of the screen.

Each session took about 30 minutes to complete. A total of five blind subjects tried the auditory interface.

3.5.4 Conclusions

Even though all subjects were initially overwhelmed by the complexity of the sound environment, it did not take long for any of them to learn how to locate and move the objects around. None of the subjects were unable to get an overview of the auditory space, locate objects, or move objects around.

Navigation: Allow for individualisation of the display

When navigating a complex auditory environment it is important to provide the users with means of individualizing the display. This is important not only in terms of supporting different user needs and expectations, but also to support different tasks. For example the task of getting an overview is different from locating a specific object, the former requires a quick presentation of all objects with not too many details, while the latter requires detailed and precise information about a smaller set of objects. One of the subjects expressed the need specifically to be able to interactively change the volume differences between different parts of the display, and the tempo of the auditory display in order to separate overview from detailed examination.

Control: Provide different ways of accessing the information

One way of individualising the display is to provide different ways of accessing the information, as well as presenting the same information in multiple ways. In this application getting an overview was possible to achieve in two different ways, one passive and one active. The passive one was of course to utilize the overview presentation, the active was to rapidly move the pointer from quadrant to quadrant, listening if there were any objects located there.

Even though all subjects consistently used the active overview, moving the pointer from quadrant to quadrant, instead of the passive, they all agreed that the passive overview was important and that this was something that would be easier to use after getting used to it.

3.6 Metz – Tactile feedback devices featuring quick discrimination

The work of Metz focused on WP 2.2, in particular on directional information and external memory. To study this fields of research, we divided our work in three parts: the tactile feedback through vibrating devices, the force feedback through Phantom device and the and the tactile feedback through Braille display.

The first part (described here in Section 3.5) focused on the limit of use for standard vibrating devices such as Tactaid W32. To enhance such devices we proposed and tested a new specific device to guide user in a one dimension environment like games.

The second part (described in Section 3.6) was to study the force feedback of a Phantom to encode directional cues. To do this we proposed to study the directional discrimination and amplitude discrimination with a Phantom device. The result will be used in guiding and in external memory to code semantic about information.

The third part (described here in Section 3.7) is related to the previous one. We tried to see if tactile display with Braille cells can be used to give directional information to user. We studied several types of icons and tested all of them to find the better ones to use with the vtPlayer mouse.

3.6.1 Introduction

This work is a set of preliminary experiments, about the tactile perception of several kind of actuators [2.6]. The goal of these experiments is to find a set of additional modalities to give to users, in order to create hints when exploring a virtual environment. To restrict to a precise field for this study, we only wanted to guide people alongside a horizontal axis, telling them a distance to the left or the right. The navigation appears as a main topic in Task 2.2 of WP2. At the end, we wanted four signals: left-far, left-near, right-near and right-far.

When visually impaired people are dealing with computers, they immediately encounter problems when exploring their environment. A guidance system should help the visually impaired people in that way, by intelligently hinting them about the location of the important parts of the scene, as well as informing them of their nature.

A good example of what the application should be able to do is shown in the ComTouch design [2.4]. The ComTouch is a special phone fitted with skin actuators. During the normal communication, the caller can remotely activate the actuators of the called, thus extending the normal communication with additional custom short messages. That design implements secondary medium channel, the same kind of way we're intending to do. Now, this has to be adapted to automated, computer-based medium output, and that is what we're proposing to do.

Our study starts with some tests about the possibilities offered by various devices. This is a follow-up of work done by Brewster et al. [2.2] upon tactile icons: the Tactons. This work tries to create short messages for the user, composing simple basic tones into more complex ones, the basic tones being an alphabet. The messages created that way are giving information such as "Received an email" and can be derived into several different figures, such as "Received an important email" or "Received a mail from Francis" only by changing a few parameters in the tones.

But the Tactons have a duration which is not acceptable to guide somebody inside an environment. That is why we wanted to continue his work, by introducing different, shorter messages to pass on the information.

As we wanted to limit our field of research here, we wanted to create a system to give out hints about the position of a point onto a horizontal axis, telling the direction (left or right) and the distance (near or far) at the same time. So, our idea was to encode several relative positions using different kind of vibrations with an actuator, the Tactaid VBW32 (prototype 1). Also, all our tests are focused on immediate usage, without prior learning, since we want to get the most intuitive signals as possible.

3.6.2 Prototypes specification 1

The Tactaid [2.7] VBW32 is a small actuator, which can be used on the skin, and works as an audio output device. You can see it in figure 3.6.1. It's nominal frequency is 250Hz, and the best quality is obtained with sinusoid signals [2.3]. Initially, the device is used as a transducer plugged on a portable frequency compressor to help deaf people sensing sound directly on their skin.

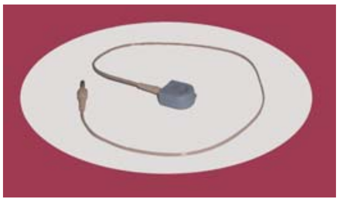


Figure 3.6.1: The Tactaid VBW32

We choose to create tactile tones by modulating the base signal, as described in [2.5], using amplitude modulations of low frequencies. Thus, we created four tones based on the main 250Hz one, by modulating it at 2, 5, 16 and 40Hz, which gives us a total of four derived tones. Of course, we also use the main unaltered tone of 250Hz, that we will further note "modulation 0".

We based our frequency choices on Brewster's work [2.1], but we extended it so to use lower frequencies. These lower frequencies were not suitable for him because the signals were used in a combination of several signals altogether, thus creating a small alphabet and words using that alphabet. Again, we wanted to create tiny signals to send to the user, and not composing the signals into new ones. So that's why we wanted to try them during our tests. Also, he conducted tests with the VBW32, but the results were not good enough compared to some other, more expensive, but more precise actuators.

3.6.3 Evaluation

Experiment methodology

We created two series of tests using the Tactaid. We did the tests in a noisy environment, because we wanted to see whether the users were able to discriminate the signals in such an environment.

The first test was simply giving randomly a tone out of the five available, and asking the user to say if it was the same, or a different one than the previous one. Each tone display was spaced by a half of second silence. We were interested by the accuracy of the answers, and by the timing as well, to see how quick the users were to recognize the tones. Each tester had to go through 40 tests.

The second test was a memory test. One random tone was outputted during one second. Then, each tone was outputted in a random order. The user had to stop the test whenever he thought the first tone is outputted again. The users had to go through 20 tests.

Participants (sighted or blind)

We did these tests with a panel of nine blind people, aged from 14 to 37.

Hypotheses

We didn't choose the tone to combine them but to be used alone. So, we were able to choose tones in low frequencies. For this reason, we expect that users will be able to discriminate the tones without any difficulties and in a good time.

Evaluation

The first test got about 7% of errors. Results are shown in table 3.6.1. The users spent about 2s distinguishing the tones, with the fastest ones spending 1.3s. The most problematic tones to distinguish for the users were the tones modulated at 0, 16 and 40Hz.

1	2	3	4	5	6	7	8	9
2.5	17.5	7.5	0	0	7.5	10	10	7.5

Table 3.6.1: Errors in the first test, in percentage, the first line being the index of the user.

You can see a comparison in table 3.6.2, where we give the percentage of errors between each pair of vibration, as well as the number of error. You can see that there was 36% of errors for the tone 5, but that occurs only 4 times, and that was only for the same user: he was persuaded the tones had to change, so he was confused that he got the same tone twice.

	2	5	16	40	0
2	8.9, 4	13, 7	0, 0	2.1, 1	1.9, 1
5		36, 4	6.7, 1	0, 0	0, 0
16			0, 0	81, 9	7.4, 2
40				0, 0	31, 9
0					5.5, 1

Table 3.6.2: The tone-per-tone errors. The first number is the percentage of errors, and the second is the number of errors.

For the second test, which results are shown on table 3.6.3, the users got an average of 24% of errors. We can note that since the errors rate decreased with time, the users might give better results with some training. The users spent around 2.4s to recognize the patterns, but the time gradually increased from 2 to 4 seconds, depending on the position of the tone to recognize among the five presented.

1	2	3	4	5	6	7	8	9
25	55	15	15	20	20	30	25	10

Table 3.6.3: Errors in the second test, in percentage, the first line being the index of the user.

Discussion

What is important to notice in the first experiment is that each user either did mistakes distinguishing 0 and 40, or 16 and 40, but not all the three altogether. That is, in average, individual people did 76% of their errors between two of the five vibrations, but these two vibrations are not the same among different people. This tends to indicate that each user have different "feelings" than the others, which means that if we want to use the Tactaid using these tones, we will have to decide with the users which vibrations to use in the set we created so to have the maximum efficiency in the recognition of the signals.

In all cases, the errors of the second experiment are of the same kind as the previous test, that is either errors between 0 and 40, or between 16 and 40.

We conducted a short, informal test, with 10 users, to get a first grasp about the usability of the tones as a left/right directional hint. We mapped four signals to the information left-far, left-near, right-near and right-far, and created a small test application in the shape of a pong game, where the relative position of the ball from the racket was encoded using these signals. The result was quite catastrophic, as the users couldn't be able to remember the signification of the signals at all. We then wanted to create a more direct representation of the distance and direction, thus leading to the next hardware.

Conclusion

The results of these tests show that it is somewhat possible to give information to the users through the tactile modality, with small skin actuators, such as the VBW32, leaving the other senses free for any other function. We can also notice that when the skin is not directly in motion, or when the motion is too rude, the users are not really able to discriminate anything apart of the roughness of the feedback. Also, having a feedback too rude is tiresome when being repeated too long. Moreover the link between the vibration and the associated semantic is not always trivial. That's for we tested a custom joystick featuring directional feedback (prototype 2).

3.6.4 Prototypes specification 2

This joystick was built specifically for this experiment to ease the understanding of the directional information. The point was to have two sources of vibrations, placed physically on the left and on the right of the hand, to build an immediate representation of the information we want to pass on. The distance can then simply be encoded using two different forces of vibration on the left and the right.

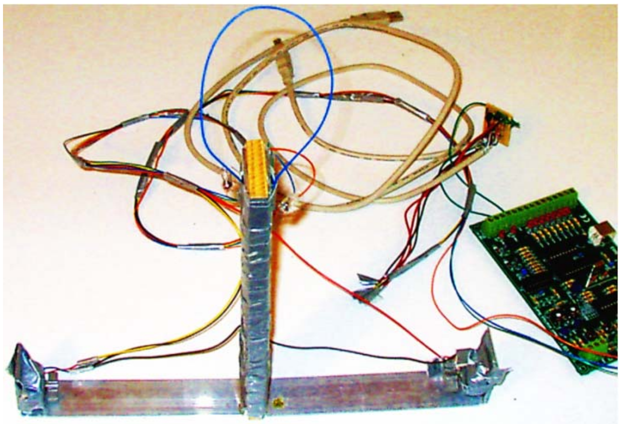


Figure 3.6.2: Our custom joystick

The device is built in the shape of a T, upside down. You can see it on figure 3.6.2. Two small motors are stuck on each extremity of the horizontal bar. These motors are taken from typical "force feedback" joystick: they are fitted with some eccentric piece of metal so that the motors are shaking while spinning.

The whole is linked to a USB interface, making it drivable from the computer. The software part is able to control precisely any voltage level on any of the two motors. However, in the final application, we only kept two levels for each motor, thus creating two signals per motor. At the end, the software had four different signals to send to the joystick: left-rough, left-smooth, right-rough and right-smooth, as we hoped to create left-far, left-near, right-near and right-far signals. Note that activating the two motors at the same time would not make sense for our simple guidance system, as it would then create a composition of basic signals.

User interactions

The user grasps it on the main vertical axis. Each motor is linked to an amplifier system which can control the voltage applied to them, thus controlling the rotation speed. This way, the roughness of the vibration changes depending on the voltage applied.

3.6.5 Evaluation

Experiment methodology

We did two series of tests using that joystick. Each series contained 60 tests. The first series was only to distinguish whenever the vibrations come from the left or the right, so only one kind of vibration was displayed. The second series was to also tell if the vibration was soft or hard, in addition of the direction. So, in that second test, the users had to distinguish the four vibrations in total.

Participants (sighted or blind)

The tests were done with 7 blindfolded people, aged from 20 to 47. The tests were conducted in a safe and quiet environment.

Hypotheses

We based this prototype on the hypothesis that one can sense the source of vibration when holding a joystick, without having the actuators on the skin directly.

Evaluation

For the first test, we got an average of 9.5% of error, which is not so bad for a direct left-right hint, but one very user did no error at all. As we were conducting the tests, we noticed that this user didn’t held the joystick like the others. While everybody held the joystick tightly as in the left of figure 3.6.3, that person hold it by pinching it, as you can see on the right of the figure 3.6.3.

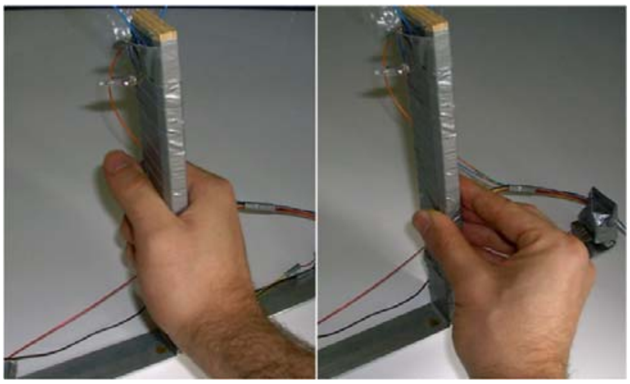


Figure 3.6.3: On the left, user holding the joystick tightly and on the right user pinching the joystick.

With the second series (table 3.6.4), the users made only 2.1% of errors discriminating the force of the vibration, while they did an average of 25.9% of errors. This jump in the errors might be explained by the new vibrations introduced in the second test, disturbing the users. Note that the user gently holding the joystick still did very few errors (5%).

User	1st test	2nd test	Force errors
1	13.3	25.0	1.6
2	0.0	5.0	0.0
3	23.3	21.6	1.6
4	5.0	31.6	8.3
5	15.0	38.3	0.0
6	5.0	40.0	1.6
7	5.0	20.0	1.6
Average	*9.5*	*25.9*	*2.1*

Table 3.6.4: Results of the tests with the joystick, in percentage. The force error rate is for the second test.

Discussion

In these tests, we didn’t do any particular test about the way the users were holding the joystick, but, since it seems it had quite an importance during the tests, we might go on with a new series of tests to see how exactly this might have an influence.

Also, among the various comment we got back, the users told us that they don’t sense the signals as being from the left or from the right, but as a different feeling inside the bones of the hand. So, each user created their own codification for "left" and "right" depending on the sensation they felt in their hand.

In all cases, they all agreed that the discrimination was very difficult, since the differences between the feelings were really tiny and thus difficult to tell. But the design and ergonomy of the joystick was bad since the prototype was built quite roughly, so maybe this had an influence over the problems our users had.

Conclusion

While we might conduct new tests with the joystick, in order to analyze the impact of the grasping in the recognition, all the users complained about the fact the joystick was shaking too much, being inconvenient after a while. So, the solution we will keep as a guidance modality for our users will be using the soft skin actuators. However, the poor recognition speed (more than 2s for some users) of the tones should make that kind of interaction impossible for time critical operations. This should be the topic of another study, by comparing the speed of recognition of auditive feedback with these tactile tones.

3.6.6 Conclusion

The tests showed that it is possible to have short signals sent to the user with good discrimination, using skin actuators, but that the signals have to be choose depending on the users.

3.7 Metz - Information display by haptic bumps

METZ have been investigating navigation around electronic circuits using haptic and tactile feedback. These have many of the same issues as navigating standard maps and METZ are looking at tools to help guide people around circuit diagrams.

The research described in this section concerns information display. This can be made by several channels, whether to give the user the choice of the channel which suits him/her, or to use several of them at the same time, or to prevent a channel already very used from being overloaded. It enables specifically replacing a failing channel. The visual and auditory channels are heavily used even though other channels like haptic, which gather together tactile and force feedback, are still not widely used. Some studies on information display have been made. We can especially quote the auditory icons of Gaver [3.1] : they are sound metaphors which able to associate a sound to an object or an action. For example, a file deletion can be notified using a paper crumpling sound. The drawback is the icons are chosen in an arbitrary way and the comprehension of the information needs pragmatic knowledge between the creator of the icon and the user. Another system has been created by Brewster [3.2]: the earcons. In that case, simple sounds aren't used, but rather notes. Several level codes are created to display hierarchical information. The rhythm changes at the first level only, each rhythm corresponding to a category. To differentiate codes of a same category, Brewster creates information of higher level by modifying the melody. At the next level it's the global tempo which changes. So we can link several information by comparing the rhythm, the melody and the tempo.

Haptics can be used to give the user some information. For example, Wall and Brewster [3.3] describe a system which allows the user to put bookmarks in the environment called beacons. Thanks to these bookmarks they can navigate from each recorded location to another: with a simple keystroke, the user is dragged to the bookmark's position. Their study exposes a navigation of bar charts. The user had to give the highest value between four given bars among twelve bars. The proportion of correct answers was 76% and the average time taken to answer a question was 50.92*s*. It would be interesting to add some codes or icons on the beacons to give them a semantic value. Some user tests could be done to let us know if adding information during the guidance can decrease the answer time and the error rate.

We can find two kinds of haptic icons in the literature. The first one has been created by MacLean and Enriquez [3.4]. They use a DC motor which delivers forces on a rotation axis. The signal parameters are magnitude (or force), shape (sinusoid, square, etc.) and frequency. They did some tests where users had to classify icons in categories. The results show that the only criterion commonly used by all the users is frequency. It should be interesting to create such kind of icons with a widely used device.

The other haptic icons are the Tactons created by Brewster and Brown [3.5]. These icons are a tactile transcription of earcons [3.2]: the codes are created in a hierarchical way. One criterion is used per level, one value of a criteria maps to a code of the level associated. Tactons use three parameters: rhythm, frequency and duration. For example, you can create a rhythm for file and another for directory, then a frequency for "open" and another for "close". And finally you create a duration for "read only" and another for "read and write". So you will be able to code "open file in read only" and to compare easily with "open directory". The first tests are not conclusive enough so other tests with other parameters are currently being processed.

3.7.1 Rationale. What problem are we trying to solve and why its important

Haptics is a good alternative channel to provide the user some information when visual and auditory channels are not suitable. Currently, force feedback messages display is less studied. We want to know if the principle of Tactons is extendable to force feedback and if yes, with what parameters. This is the goal of the PICOB system that concerns the experiment of haptic stickies by barcodes. Our goal is to find small haptic effects that could be used to present information to the user of a haptic pointing device.

3.7.2 Prototypes specification

The purpose of these experiments is to test the discrimination of several direction and amplitude bumps. It's the basis of our research on PICOB interaction technique since it combines haptic bumps and meaning. Before adding meaning to haptic bumps, we must test which bumps are discriminable according user interactions.

A widely used technique to prevent the user from being lost in the haptic space is to constraint him in the area he is supposed to explore. For instance, we often stick the user on a line: this could help the user to recognise a shape or a path. We designed some bumps we could put on a line to add information to it (bold line on the figure 3.7.1). So when the user moves along the axis, he will be dragged in a direction, according to a code. He will feel like if the line was bent.

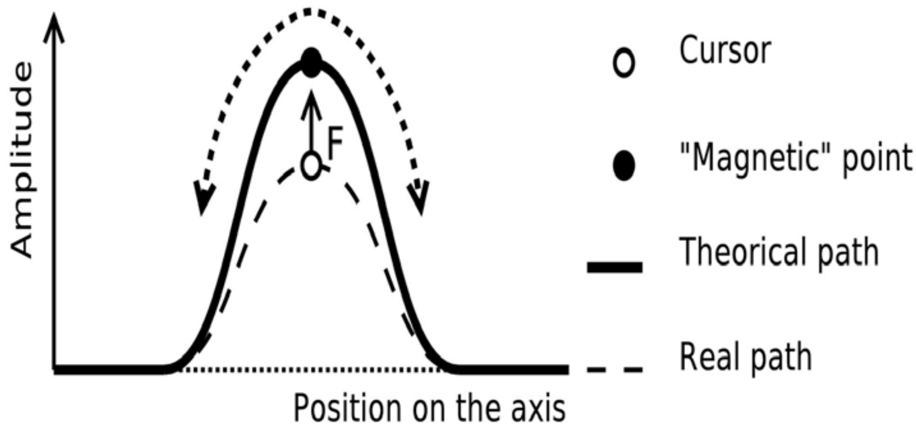


Figure 3.7.1: Bump felt by the user

It's impossible to directly control the position of the PHANToM device because it only renders forces. So we used a magnetic point to specify the theoretical position of the PHANToM: where it is supposed to be (• on the figure 3.7.1). Then the API renders a force towards this point to put the PHANToM (° on figure 3.7.1) as close as possible to this point. In the following, we will only consider the theoretical position. Two prototypes are proposed to investigate haptic bump discrimination:

- Automatic bump recognition where the user is guided along the path of the bump. It's like if the system takes the hand of the user to make him feel the path. The user's hand was completely dragged [3.6]. It combines the idea of force feedback icons of the haptic icons, and the possibility to create hierarchical codes like the tactons/earcons. The idea was to drag the user on some millimetres in six directions (upward, downward, forward, backward, leftward and rightward). We used two and three amplitudes in the same series.
- Free bump recognition where the user can follow the path of the bump as he wants [3.7]. He is just constrained along the path. We decided to experiment a similar system where the user is more active and should move along an axis to feel the bump.

3.7.3 Description of the interface and any relevant equipment

We used a PHANToM Desktop [3.8] (figure 3.7.2) in these experiments as the haptic pointing device. It's a six degrees of freedom device (three in translation and three in rotation) and with force feedback on the three degrees of translation. The program used in these tests was written using the Reachin API [3.9] with VRML and Python.

Figure 3.7.2: PHANToM haptic device

Haptic bumps tested in these prototypes are independent of the way to interpret them. However, the first application of them will be to use them in a navigation context : direction of the bumps will indicate the directions to follow.

3.7.4 User interactions

To display a message you must first find a way to code it, then a way to represent it. A well known example is morse code : it uses two digits to code alphanumeric characters. To display a message using this code you must associate a representation to each digit. A very used auditory representation is long beeps and short beeps, and for visual representation dashes and dots. To display the message "SOS" with the morse code you must use one of its representation. We get for example ••• --- •••. We can imagine a haptic representation, for example with upwards and downwards bumps. The coding would be the same and the message would be displayed ↓↓↓ ↑↑↑ ↓↓↓.

We are in a preliminary state of our research and among the representation types possible we have designed, we present the bumps in this document. The principle is simple : the goal is to move the user's hand back-and-forth about some millimeters. A bump is defined by three parameters : length, amplitude and direction. The figure 3.7.3 represents bumps in six directions : upward, rightward, backward, downward, leftward and forward.

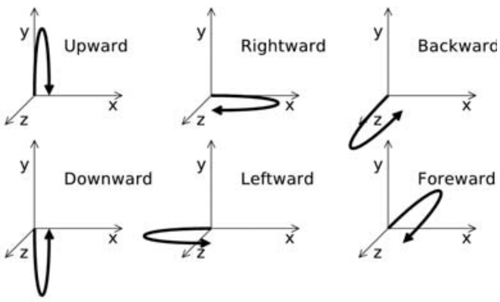


Figure 3.7.3: Bumps in six directions.

For automatic bumps recognition, the principle used to carry out these bumps is simple: the idea is to drag the cursor (○ on the figure 3.7.1) with a spring applying a force towards the theoretical position of the bump (● on the figure 3.7.1). As for free bump recognition, bumps were designed as shown on the figure 3.7.4: the bump was located at the right of the starting point. If the user moved to the left he was just constraint on an horizontal line. The bump was a sinusoid, and started 5*mm* after the starting point and ended 5*mm* after that, then there was a 2*mm* pause before stopping the bump.

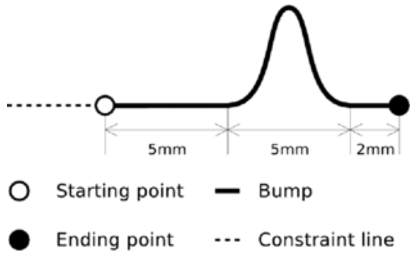


Figure 3.7.4: Bump design

All the experiments only use haptic feedback. There is no visual display.

3.7.5 Experiment methodology

The purpose of the experiments below is to study the discrimination of bumps of different directions and amplitudes. The goal of these tests is not to study training but an immediate usability. Users have done several series of bumps. Each series we presented 150 bumps to users. The series were gathered in sessions, knowing that all the users made the same sessions at the rate of one per day at most. After each session the participants were given a survey to collect their impressions.

For automatic bumps recognition experiments, a bump lasts $250ms$. The user had to recognize the direction or the amplitude according to the experiment. The duration of the bumps being fixed, discrimination according to this parameter was not tested: it will be the subject of another study. The duration and the amplitudes were selected after preliminary tests in order to have bumps a priori comfortable to use. Right after explaining the principle of the experiment to the user, the experimenter starts the bumps one after the other. The user says the direction (upward, downward, leftward, rightward, forward and backward) or the amplitude (1, 2, 3 for small, medium and big) which he felt and a quarter of second later the next bumps were started. Each experiment consisted in making one or more random series and the users processed all the same series in order to not favour anybody a priori.

As for free bump recognition, when the experimenter starts the bump, the system stores the cursor's position and sets the starting position at that location. Then the user has to move and feel the bump up to the stop position. After that, the user is not constraint anymore and says what he felt: the direction (upward, downward, forward or backward) and the amplitude (from 1 to 3, 1 being the smallest and 3 the biggest). The experimenter stores the answers, and the next bump starts. After each serie, the user's impressions were collected.

3.7.6 Participants (sighted or blind)

All participants were right handed. They were blindfolded to prevent from giving visual aids. For automatic bumps recognition experiments, six users were recruited for these tests: three researchers (two men and a women) and three male students. The researchers and one student were used to manipulate the PHANToM.. The users were between 23 and 47. As for free bump recognition, the users were between 23 and 37, one female and five male.

3.7.7 Automatic bump recognition - experiment 1

Experiments and procedure

In the first experiment we test direction discrimination. The bumps given are on the six directions : upwards, rightwards, backwards, downwards, leftwards and forwards (figure 3.7.3). Five series has been conducted, each using a different amplitude : $0.4cm$, $0.7cm$, $1cm$, $1.5cm$ and $2.25cm$.

Results and discussions

The errors are reported in the table 3.7.1: each row maps to a series for which the tested amplitude is described in the first column. The percentage of errors shown in the last column represents the percentage of erroneous answers among the total of all the users for the considered series.

Amplitude	User						Errors
(cm)	1	2	3	4	5	6	(%)
0.4	0	0	0	0	1	1	0.22%
0.7	0	0	0	0	0	0	0.00%
1	0	0	0	0	0	0	0.00%
1.5	0	0	1	0	0	0	0.11%
2.25	0	1	0	0	0	0	0.11%
total	0	1	1	0	1	1	0.09%

Table 3.7.1: Experiment 1 : errors in direction

Two users didn't make any mistake and the four others made an error among the 5×150 bumps. The number of errors is clearly negligible, therefore we can affirm that under these conditions we can discriminate bumps of six different directions. Only one user (not used to the PHANToM) acknowledges he sometime had difficulties to feel the differences between the directions and three other claim sometime had some hesitations. Two users thought they made more errors than they actually made. Two other users said they had the impression that the amplitude was not the same in different directions: a user had the impression that the right was stronger than up and down, whereas another user had the impression that up, down, left and right was stronger than forward and backward. Let us note that the amplitude of $2.25cm$ was considered to be too violent by the users; this is why it was not used anymore in the following experiments. The big bumps causes problems in catching the stylus: it should be hold more firmly.

3.7.8 Automatic bumps recognition-experiment 2

Experiments and procedure

The purpose of this experiment is to test the discrimination of three different amplitude bumps. The bumps given in this experiment were all directed to the top, and the amplitudes were $0.4cm$, $0.95cm$ and $1.5cm$. Only one series was carried out.

Results and discussion

The errors are shown in the table 3.7.2. The first three lines represent the errors by amplitude suggested and the last represents the total on the series. The last column represents the percentage of erroneous answers per amplitude suggested among the total of the users.

Amplitude	User						Errors
(cm)	1	2	3	4	5	6	(%)
0.4	0	1	0	0	1	1	1 %
0.95	3	2	4	5	2	6	7 %
1.5	3	10	7	10	1	2	11%
total	6	13	11	15	4	9	6 %

Table 3.7.2: Experiment 2 : errors in amplitude

The errors are more important than in the previous experiment. The users made between 4 and 15 errors out of the 150 impulses. On average, there is 6% of error, but the interesting point is that only 1% of the $0.4cm$ bumps were badly recognized, whereas with the two other amplitudes we obtain 7% and 11%. Moreover for the discrimination errors of the medium amplitude, the users always answered in favour of the big amplitude. For the other errors, on the small ones and big amplitudes, the answers of the users were in favour of the medium amplitude. Thus the users never made mistakes while answering "small amplitude". So, there is clearly a problem of discrimination between the medium amplitude and the big amplitude. This phenomenon is shown again in experiment 3.

3.7.9 Automatic bumps recognition-experiment 3

Experiments and procedure

What we want to test in this experiment is the simultaneous discrimination of direction and amplitude. For this purpose we propose bumps in the six directions, with two then three amplitudes. Three series were carried out: in the first there were only two amplitudes (0.4*cm* and 1.6*cm*). In the second there were three of them: 0.4*cm*, 0.95*cm* and 1.5*cm*. The same values than in the experiment 2 were used so that we could determine if the presence of several directions has an influence. The progression of these values is linear, we also tested a series with exponential value progression as Nesbitt [3.10] suggests it. This was the third series and thus the amplitudes were 0.4*cm*, 0.8*cm* and 1.6*cm*.

Results and discussion

The number of direction errors is still low: only two users did a mistake among the three series. This is why the values will not be detailed. We can conclude rather easily that using several amplitudes at the same time towards several directions does not disturb the discrimination of the directions.

For the errors of amplitude, with regard to the first series, half of the users didn't make any mistake and the others did only one among the 150 bumps. The discrimination of such impulse is thus clear. On the other hand, with three amplitudes it is more problematic.

The errors of amplitude discrimination for series 2 are summarized in the table 3.7.3. Alike the experiment 2 we separated the errors by amplitude given on each line and the last column represents the percentage of errors on the total of all the users for the amplitude of the line.

Amplitude	User						Errors
(cm)	1	2	3	4	5	6	(%)
0.4	0	1	3	5	0	0	3 %
0.95	10	10	19	4	5	2	19%
1.5	9	17	20	18	13	9	27%
total	19	28	42	27	18	11	16%

Table 3.7.3: Experiment 3, series 2: errors in amplitude

We get 16% of errors on average on all the series. 3% of the small impulses (0.4*cm*) are badly interpreted, 19% of the medium (0.95*cm*) and 27% of the big (1.5*cm*). If we compare these results with those of the experiment 2 we can notice that on average there is between two and three times more errors. It is clear that the various directions disturbed the discrimination of the amplitudes. This observation is corroborated with the feelings of the users collected after the tests: they had the impression to feel different amplitudes according to the direction. The users were disturbed because the training which was given to them was very quick.

You can consult the discrimination errors of amplitude of the third series in the table 3.7.4. In a general way it has to be noticed that there is a little less errors. There is always 3% of the small impulses which are badly recognized, but now there are respectively 11% and 19% of the averages and the big impulses which are badly interpreted.

Amplitude	User						Errors
(cm)	1	2	3	4	5	6	(%)
0.4	1	0	2	1	3	1	3 %
0.8	2	23	8	2	1	1	11%
1.6	7	24	13	5	3	1	19%
total	10	47	23	8	7	3	11%

Table 3.7.4: Experiment 3, series 3: errors in amplitude

We can notice there's three times less errors compared to the previous series, only one user made more mistakes. The percentage of small erroneous amplitudes does not change. On the other hand there is four times less errors for the medium amplitude and almost 40% less for the big amplitude. Thus, it would seem that the exponential progression of the amplitudes is more discriminatory than the linear progression. However, the amount of errors remains high (11% on average). That makes us believe that without any training the discrimination of bumps of three different amplitudes is not possible under normal conditions of use of the peripheral used.

3.7.10 Free bump recognition – experiment 1

Experimental procedure

The first step of our study is to test the direction discrimination. Four series had been made. In the first two ones there were two direction bumps (upward and downward). In the first series the amplitude was 0.4*cm* and 1.6*cm* in the second. In the last two series, four directions were used: upward, downward, forward and backward. The two series used 0.4*cm* and 1.6*cm* again.

Results and discussions

The errors of the series with 2 directions are reported in the table 3.7.5 and those of the series with 4 directions in the table 3.7.6. Each row corresponds to a series, the last line is the total.

Amplitude	Errors						
	Users						
(cm)	1	2	3	4	5	6	(%)
0.4	4	0	2	1	0	4	1.22%
1.6	0	5	6	1	0	4	1.78%
total	4	5	8	2	0	8	1.50%

Table 3.7.5: Experiment 1 with 2 directions: errors in direction

As we can see the users make very few errors (table 3.7.5). Three users made as much errors in the first series as in the second. The three others made almost all their errors in one series and none in the other. Only the first user rather preferred the second amplitude. So if we take the user's favourite amplitude we get only 0.77% of erroneous answers. All the users thought the second amplitude was very violent, and they had to hold the stylus stronger to prevent from making errors. Two users were very disturbed by that and made more errors with the bigger amplitude than with the smallest.

Amplitude	Errors						
	Users						
(cm)	1	2	3	4	5	6	(%)
0.4	0	1	3	3	1	2	1.11%
1.6	0	4	2	2	0	0	0.89%
Total	0	5	5	5	1	2	1.00%

Table 3.7.6: Experiment 1 with 4 directions: errors in direction

The amount of errors is less important than in the previous series whereas the task is supposed to be more difficult (table 3.7.6). You can notice that this time the users make more errors with the smallest amplitude than with the bigger amplitude. However, the users still prefer the smallest amplitude. We could explain the decrease of errors by a little learning, or by a better concentration because the task was more difficult. Some users had the feeling that some bumps of a series hadn't the same amplitude as others in the same series. Especially upward/downward and forward/backward didn't seems to have the same amplitude. We could explain that in two ways. The first hypothesis is that the PHANToM uses one motor for each axis, so there could be a difference of calibration. The second one is that forward and backwards are direction in the same axis than the user's arm, and upward and downwards are perpendicular to this axis. So the users have more natural resistance force against a forward/backward bump.

3.7.11 Free bump recognition – experiment 2

Experimental procedure

The second step aims to combine all the previous parameters by proposing bumps of several directions and amplitudes in the same series. Two series has been made: in the first one there were only two amplitudes (0.4*cm* and 1.2*cm*) and in the second one three amplitudes (0.4*cm*, 0.8*cm* and 1.6*cm*) were proposed. In both series the four previous directions are used. The user had to recognise the direction and the amplitude at the same time.

Results and discussions

Direction errors are reported in the tables 3.7.7 and 3.7.8. This time each table represent one series and each row shows the number of erroneous answers when the corresponding direction was given. The amplitude errors are in the tables 3.7.9 and 3.7.10, and the rows show the number of errors when the corresponding amplitude was given.

Direction	Errors						
	Users						
	1	2	3	4	5	6	(%)
upwards	0	1	3	1	0	0	2.98%
downwards	2	2	4	0	0	1	3.26%
backwards	3	0	1	2	0	0	2.33%
forwards	2	1	5	2	0	1	5.56%
total	7	3	13	5	0	2	3.33%

Table 3.7.7: Experiment 2 with 2 amplitudes: errors in direction

We get three times more errors than in the previous experiment (two last series). So using several amplitudes in the same series obviously disturbs the direction discrimination.

Direction	Errors						
	Users						
	1	2	3	4	5	6	(%)
upwards	2	2	0	4	1	1	4.07%
downwards	2	0	1	2	0	1	3.57%
backwards	1	0	0	1	0	1	1.61%
forwards	2	0	1	6	0	0	3.00%
total	7	2	2	13	1	3	3.11%

Table 3.7.8: Experiment 2 with 3 amplitudes: errors in direction

The error rate is quite the same than in the last series (table 3.7.8), so the number of different amplitudes doesn't matter with the direction discrimination. Thus we can conjecture the errors are caused by the fact of having other parameters to recognise at the same time.

Amplitude	Errors						
	Users						
(cm)	1	2	3	4	5	6	(%)
0.4	0	1	9	1	0	1	2.78%
1.2	3	10	15	1	6	4	8.33%
total	3	11	24	2	6	5	5.67%

Table 3.7.9: Experiment 2 with 2 amplitudes: errors in amplitude

As you can see the amplitude errors are higher than the direction errors. It is clear that the amplitude discrimination is a difficult task. An interesting point is that there are three times more errors when the strong amplitude was proposed than when the weak amplitude was proposed. Moreover: only one user made more than one error among the 150 bumps displayed when a weak bump was proposed (user 3, table 3.7.9).

Amplitude	Errors						
	Users						
(cm)	1	2	3	4	5	6	(%)
0.4	9	4	6	7	0	3	8.63%
0.8	10	4	12	9	4	12	18.09%
1.6	13	8	17	26	12	26	36.17%
total	31	16	35	42	15	41	20.00%

Table 3.7.10: Experiment 2 with 3 amplitudes: errors in amplitude

One bump among five is misunderstood by the users. It is clear that users have difficulties to discriminate three amplitudes. Many users make a lot of mistakes because they think relative. So they don't feel the same amplitude when the previous bump was weak, medium or strong. It could be explained by the fact that people don't hold the stylus with the same strength whether the bump was weak or strong.

Two users made an interesting remark. They said that the direction was easier to understand when moving slowly, and the amplitude was easier to understand while moving quickly. This could explain the difficulty of trying to recognise both simultaneously. One of those two users was the user 5 and is one of the users who made the less errors. Due to this remark he deduced that he has to read all the bumps with the same speed. The experimenter noted that the users that made the more errors was often changing their reading speed. This fact is important and should be experimented.

3.7.12 Conclusions

Automatic bumps recognition experiments show that information display by bumps of several directions and amplitudes is possible. The studies detailed in this document permit us to affirm that the discrimination of direction is easy, as well as discrimination of two amplitudes. However the discrimination of impulses of three different amplitudes is problematic. It would be interesting to study new values and especially if a suitable training allows this discrimination. Concerning the discrimination of two amplitudes it could be interesting to test the minimal difference of the values to have a discrimination without ambiguity.

By using six directions and two amplitudes we can use the principle of hierarchical codes of earcons and Tactons on two levels. Our future work on the different duration bump discrimination will perhaps allow us to create a third level. In forthcoming studies we will be interested in other alphabets.

The interaction technique for free bump recognition is a simple idea to give the user some information using an haptic pointing device. The users can recognise the direction quite efficiently, and have some difficulties while trying to recognise the amplitude at the same time. The users made fewer errors in the previous tests with completely dragged bumps, so we think that we can obtain similar results if we put the bumps in a context, as suggested by some users. Sometime they had some hesitations and it caused quite many errors, so the possibility to read several times the code could help them to understand better.

This point should be fixed when we will do tests of bumps sequences on a large axis. This experiment was only a preliminary test of immediate utilisation. We will do tests with visually impaired children, and we will tests a learning on these icons.

3.8 Metz - Static and dynamic tactile directional cues experiments with VTPlayer mouse

3.8.1 Introduction

Our goal in this study is to use the tactile sense to give direction information (part of results is submitted to EuroHaptics). Visually impaired people are used to Braille techniques to read information. The Braille cells technology allows to create dynamic information using Braille. In this paper we aim to find a set of icons to provide the user some directional information. Many other works concentrate about haptic representation of information: Gunnar Jansson [4.1], Eric Lecolinet [4.2], Gapenne & Ziat [4.6, 4.7]. The work described here is already published in [4.3, 4.4].

In particular one other set of work is relevant. In [4.5], Wall and Brewster have studied the graph recognition efficiency with tactile pin arrays. The VTPlayer mouse was used as pin arrays display, and Wingman Force Feedback mouse was used to compare the cutaneous technique with the kinaesthetic technique. Then a raised paper model was used to compare these two techniques with what the visually impaired people are used to use. The task was to recognize whether a line goes upwards or downwards when the user slides over it from left to right. The recognition threshold with VTPlayer is 5°, against for the force feedback mouse and for the raised paper. The authors explain the superiority of the raised paper by the combination of tactile and kinaesthetic sense that doesn't exists in the two other models. Another explanation is that with raised paper the user has the possibility to explore the scene with two hands. This study shows that the pin array technique is not adapted for precision tasks, but it's sufficient to recognize angles greater than 5°. Our goal is to design icons which represent eight directions so the angle difference is greater. The results below show that we could give this information with a simple 4×4 pattern on a pin array. So if we combine the graph exploration as Wall on one Braille cell, and use an icon to indicate the direction on the other cell: it could be possible to explore the graph easily.

3.8.2 Prototypes specification

The device used is a VTPlayer tactile mouse (figure 3.8.1): it's a simple mouse with two 4×4 Braille cells. In this study we use the left cell to create static and dynamic patterns, which we call "icons". The icons designed represents 8 directions: upwards, downwards leftwards and rightwards will be called "radial icons", and towards the four corners "diagonal icons".

Figure 3.8.1: VTPlayer tactile mouse

Several sets of icons have been designed to represent the directions. Some of them are static: they are just patterns that the user has to feel by palpating the cell. Other icons are dynamic: the patterns blink or move. The animation is just created by changing the pattern every certain amount of time. Each step, or pattern will be called "frame". Our goal in this study is to find some sets of icons easily discriminative.

In the test application, a square divided in 8 zones was displayed (figure 3.8.2). It was used to train user to feel the corresponding icon of each sub square and to answer when user felt an icon.

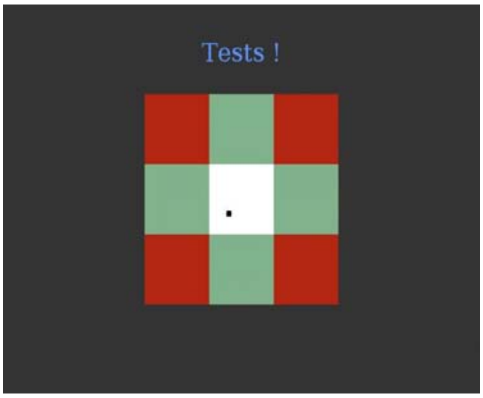


Figure 3.8.2: Screen test

3.8.3 Evaluation

Experiment methodology

This experiment was conducted to find out some interesting sets of icons. Many tries have been conducted to find sets of icons a priori easy to use. Then an experimental protocol has been established, and we started the tests. The results of this experiment led to the next experiments.

All the icons designed are symmetrical so that the user has the same kind of information whether he feels the right or left icon for example. In most case we tried to use the same number of pins for all the icons of a set so that the user feels the same area under his tip.

For all the dynamic icons of all the experiments, the frame duration was set to 100*ms*. After some preliminary tests it appears that with a shorter duration, the discrimination falls down and we think longer duration would raise the recognition time.

Before all the tests, the users could explore the icons and see the corresponding direction as long as they wanted to. Then a square divided in 8 zones was displayed (figure 3.8.2) and the first icon started. The icon is displayed on the left cell of the VTPlayer until the user click in the zone he thinks the icon corresponds to. Then he had to go back in the central zone to launch the following icon. The users did not have the right to look at the Braille cell. After the 100 icons, the user was told how many errors he made by the system, and he had to answer a survey. For visually impaired persons, the answer was exclusively done orally.

Participants

We used always nine or ten users per icons. They were between 24 and 48 years old, all are right-handed and used to deal with computers. They were all sighted people but not allowed to look to the Braille cell of course. The tests with visually impaired people are not yet available.

Hypotheses

We expect to find efficient icons to display directional cues according to Wall and Brewster work [4.4] which shows that Braille feedback can be useful for angle greater than 5°.

Evaluation

We tested more than 10 icons to find the better one. To ease the reader, we only present the best found icons both for static and dynamic.

In a static context, the best icon is the fourth shown on figure 3.8.3. We used four pins for orthogonal directions. For the diagonals, we used the corners, but we could not use the same number of pins than for the edges because to be symmetrical we had to get $2n+1$ pins: 1 for the corner, and n pins on each adjacent edge. We decided to use 5 pins instead of 3 thanks to the preliminary tests.

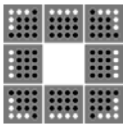


Figure 3.8.3: Static Icons 4

In a dynamic context, the best icon is the ninth shown on figure 3.8.4. The idea was to use wave metaphor. We used four frames for the orthogonal directions plus two blank frames and we used the full diagonals (always with two blank frames). So the diagonal icons have more frames than the horizontal and the vertical ones.

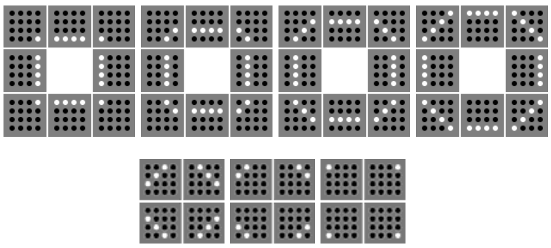


Figure 3.8.4: Dynamic Icons 9

Discussion

The number of erroneous answers and the answer times for some static icons are represented in the charts of the figure 3.8.5. The four bars for each user represent the number of errors and the answer times for the icons 1, 2, 3 (not presented in this document) and 4. The fourth icon set (figure 3.8.3) was very efficient because it uses the whole size of the cell to indicate the direction. We can also notice that this set of icons is the quickest recognised for all the users, and all the users preferred these ones to the others so we can conclude they are the best icons among the proposed ones.

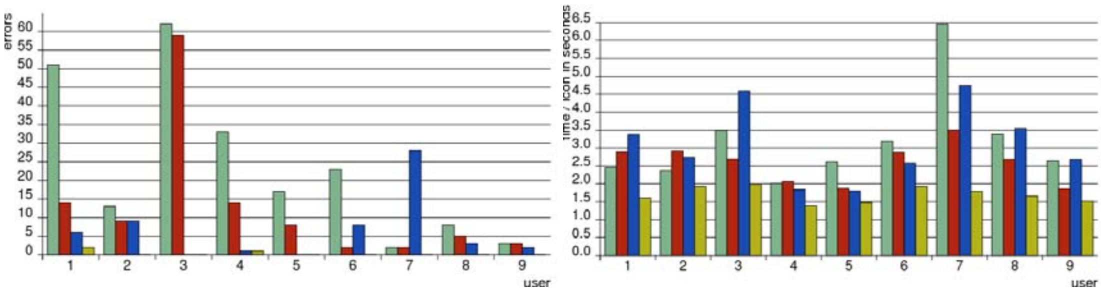


Figure 3.8.5: Results with Static Icons 4: errors and time

The number of erroneous answers and the answer times for some dynamic icons are represented in the charts of the figure 3.7.6. The four bars for each user represent the number of errors and the answer times for the icons 8, 9, 10 and 11 (only the 9 is presented in this document). The users did less errors with the icons 8 and 9 than with the icons 10 and 11. According to the recognition time, the icons 8 and 10 seem to be longer to discriminate: they take 20.9% more time to recognize than the 9 and 11. So it appears that if we have to choose a dynamic icon set, it would be the number 9, it is the best among all the dynamic icons proposed.

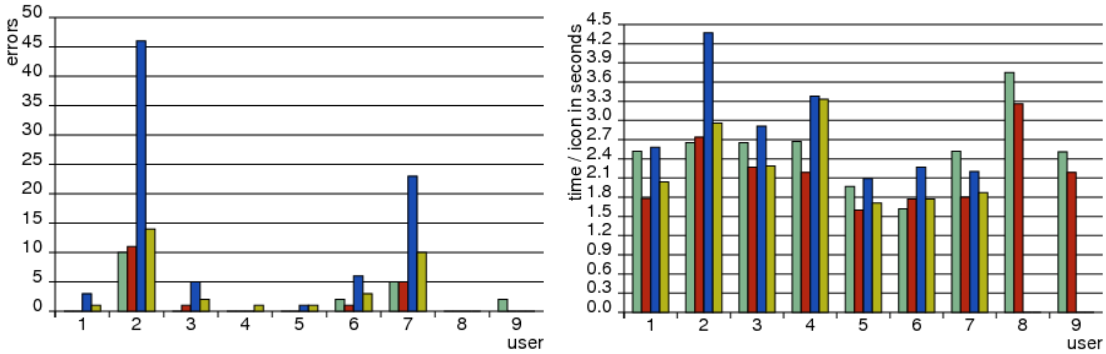


Figure 3.8.6: Results with Dynamic Icons 9: errors and time

Conclusion

Several icon sets have been tested. Some of them are static and other ones are dynamic. Most of the user prefer the static ones; their advantage is that we can easily palpate the cell since the pattern doesn't change. The better recognized icons are those with shapes very pronounced. For example if we display a line, it should be large and thick so that there is no ambiguity about the orientation. However the position of the shape on the pattern is sometimes hard to feel because of the bad ergonomy of the VTPlayer. So the better icons are the icons number 4 (figure 3.8.3) and the better dynamic icons are the icons 9 (figure 3.8.4). Since these tests have been conducted with sighted people, we can expect better or different results with visually impaired people.

3.8.4 Conclusion

All the studies presented here are helpful for the next step of MICOLE project and especially for WP4. Thanks to all the results and the running tests we are able to select the best interaction techniques to give directional cues and to code some information during exploration.

For the vibrating devices, the joystick prototype presented in 2.3 is able to help disabled people to play simple game with only movement in one dimension. We expect to enhance it by a better holding and a better architecture to enhance discrimination between the two vibration amplitudes.

For the force feedback device, we better know the discrimination of user about bumps, both for directional and amplitude point of view. This will be intensively used in electrical circuit to guide user for exploration and for component discrimination (sequence of bumps easy to read with the device).

For the tactile feedback, we know no more precisely the most important thing to display icons easy to understand with the vtPlayer mouse. We plan now to develop this work for the exploration and especially to explore if the tactile feedback can be sufficient for shape recognition as it can be done with a force feedback device. This is very important for low cost equipment.

3.9 Basic Interaction Techniques Discussion

The above section has described work on non-visual cueing to aid users in navigating and controlling a computer interface. Successful techniques have been identified for navigation in both single user and collaborative environments. These techniques can now be applied to other domains. Combinations of the successful techniques can be evaluated to provide interfaces that convey more information through multiple modalities.

4. GAMES AND ENTERTAINMENT

4.1 Introduction

Accessible games were considered important for the project from a number of different perspectives. Many of the challenges that need to be addressed to play a game successfully can be generalised to the challenges faced in designing any accessible interface. Games can be designed to incorporate a wide range of navigation, control, and memory problems that the user must overcome during the game. There is also the extremely important aspect of social inclusion that became apparent during the requirements capture stage of the project (see deliverables D2 and D8) that games can help addressed. Many blind and visually impaired children can feel excluded from break time activities or games and sports because vision plays such a large role in these activities. Designing activities that blind and sighted children can play together or compete against each other with equal chance of success will be an important step in addressing this problem. Finally, our ideas need to be evaluated with the user group to assess the success of the techniques developed. However, standard usability studies can be difficult to run with children. In order that the child will concentrate on the task and use the interface, motivation must be considered an important factor. Games can provide challenges to children that will encourage them to concentrate on the interface and motivate them by allowing them to attempt to better their previous scores.

The accessible game prototypes can be divided into the modalities that are used during the games. The modalities considered here are audio, tactile, force feedback and combinations of these.

The large majority of the accessible games available display information through audio only. Dedicated internet sites such as audiogames.net and kitchensinc.net provide links to many of these games that can be download and played through standard equipment. The advantage of audio games over other types of accessible game is the fact that only standard equipment in needed to play the game. The following section describes the audio game environments developed during the MICOLE project. There are few accessible computer based games that rely on tactile feedback although tactile feedback (in the form of vibration on a gamepad for example) is often used to enhance engagement in a game. For accessible applications, tactile feedback would more commonly be associated with accessible board or card games where Braille labels can be used to represent text used during the game. Force-feedback is less prevalent in games than tactile feedback mainly due to the comparatively high cost of the devices. Force feedback is most often incorporated into driving simulators or flight simulators to simulate road conditions or turbulence effects. There are few examples of force feedback being incorporated into accessible games.

Many of the prototypes developed for MICOLE have been using more than one modality of feedback to present the user with information. By presenting information to different channels, through combinations of audio, tactile and force feedback, there is the potential to increase the amount of information presented to the user. However, evaluation of systems using combinations of modalities is an important factor in ensuring that the increase in information presented to the user leads to improvements in performance. Presenting a user with information that conflicts with feedback from a different modality or overloading the user with feedback may lead to a decrease in performance and an interface that is difficult to use.

4.2 UTA - Game-Like Navigation within the Grid Augmented with Sounds of Animals (sound mapping and navigation)

4.2.1 Introduction

Special techniques have been developed for visually impaired people to support and facilitate human-computer interaction and access to information. Braille systems, tactile feedback and speech synthesis all make some aspects of the computer use easier for the blind, but none of these solutions comes without certain difficulties; they might require expensive hardware or/and special software or can be only used with textual information.

Nowadays, an ordinary personal computer (PC) system employs mouse as the primary (graphical) input device alongside the keyboard (command mode). Mouse can, however, be very inconvenient input method for blind users because of the lack of feedback. The user has to rely almost solely on visual feedback and the mouse requires the user to use his/her eye-hand-coordination to control the cursor. There is some amount of kinesthetic feedback involved in the moving of the mouse, but it reveals only the movement; it doesn't reveal anything about the relative position of the cursor on the screen. Sighted people can see not only the movements of the cursor immediately as the movement of the mouse happens, but also the location of the cursor on the screen even when the mouse is standing still.

In today's computer environments, Graphical User Interface (GUI) is the most common interface-type. GUIs are problematic for the blind using computers because the textual information on the screen is not easily retrievable [2]. This makes the use of Braille systems or speech synthesis complicated. Tactile and auditory feedbacks have been considered as alternative or complementing signals for output and imaging. Tactile feedback requires special devices, and the methods of using such a display technique are still under investigation. A pair of speakers is included in almost all modern PC packages. That makes the possibility of using auditory feedback more widespread.

Making use of spatial sound is one alternative which has been suggested as a solution to the problem of blind navigation. Bölker and Gorny have tried to solve the problem of blind navigation in GUIs with hearcons [2]. In their software prototype a hearcon, which was characterized by tone, volume, location and size, was associated with every item on the screen. In this approach, the user heard the topographical arrangement of the items on the screen, which made it possible for the user to find a certain item without a long inspection of the whole space. The reliability of recognition in different positions of the grid has also been evaluated. The authors found out a certain disparity between the reliabilities of different positions in the grid [3].

Parente and Bishop in [7] have also presented a system for blind exploring of spatial information. In addition to tactile feedback, their solution employs spatial auditory icons, which give information for the user by identifying the map item, indicating its direction and signalling its distance.

Restrictions in these above mentioned approaches include the limited number of sounds human auditory perception can process simultaneously and the difficulty for humans to sense the direction of a sound; most humans cannot distinguish more than five sounds simultaneously and a sound coming directly from forward direction cannot be distinguished from a sound from backward direction [6]. The spatial sound also requires the computer setup in use to include sophisticated surround sound system to make the playback of spatial sounds possible.

As an alternative to spatial sound, Kamel, Roth and Sinha have designed a virtual sonic grid [8]. In their study of auditory pattern perception by blind people, they showed that with the 9-cell virtual grid (3 rows by 3 columns) the subjects were able to faster locate queried positions than with physical tablet or spatial sound localization techniques. They also found out that easily recognized sound in the center of the grid reduces the navigation time. In the grid used, two different notes were played on every crossing of a border of grid cells. The authors concluded that spatial information should be important part of auditory interface design and a technique similar to the "landmark" technique used by cane-travellers could be employed to assist blind persons in identifying different areas of the user interface.

Sribunruangrit, Marque, Lenay and Gapenne have studied the use of reference points to provide help for spatial navigation [9]. They tested two kinds of approaches: in active mode the subjects assigned the reference points and in passive mode they were predefined. The authors noticed that the use of active and passive recognition points shortened exploration and recognition times of geometric forms.

As mentioned before, GUIs are generally unsuitable for blind use. This is true, at least, in the normal form filling and widget manipulation tasks. Yet, there might be some tasks that can be modified to make blind pointing and selection techniques possible. Most of the commercially available computer games (board and puzzle games) are impossible to use for the visually impaired players, but with certain modifications, some of them could be altered to make them accessible for blind children.

Research has been done to find out how to better develop games for the visually impaired. Audio games, which are the games relying on sound feedback, have been generated for blind audiences. Some of the games are modifications of existing commercial games, but as the popularity of sound games grows, there probably will be new genres specifically designed for auditory interfaces [5].

There is no reason why audio games should be designed solely for the visually impaired; sound makes possible to design game script and concepts that would not be possible with only graphical illustration. Even though sound liberates the player from the two dimensions of the screen, there might be many uses for blind navigation in game interfaces. Still, sounds and sonification as methods for interaction and conveying spatial information are not as well developed as image processing. When spatial understanding is needed in a sound game, additional speech cues or instructions are required [4].

In our study, a game-like grid navigation task with sound feedback was used to evaluate target acquisition under blind conditions. The subjects were involved in a pilot testing of two sound grids with different sound layouts and the data collected were then analyzed. In the Section 2 the test method is explained in details. In Section 3, the results of the study are presented with further discussion. The conclusions are finally summarized in Section 4.

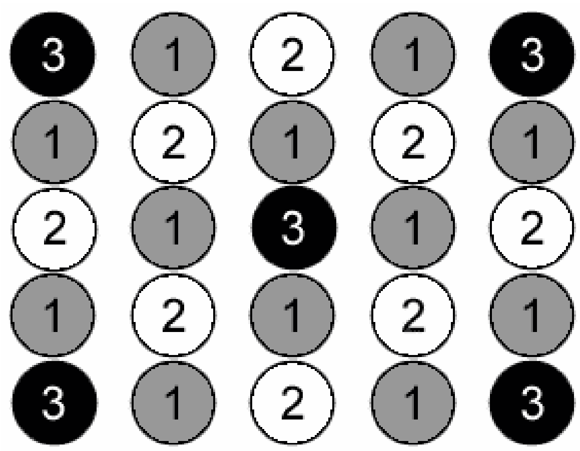


Figure 4.2.1: Sound layout of the grid augmented with 3 different sounds.

4.2.2 Method

Subjects

Four volunteers participated in the pilot testing. Age of the subjects varied from 22 to 50 years. Two of subjects were males and two were females. All of the subjects used computer and mouse on a daily basis. All had normal seeing and hearing abilities and none used a hearing aid.

Apparatus

A conventional desktop PC (ASUS P4B533) with Intel Pentium 4 processor, 512MB RAM, Trust Sound Expert audio controller, Trust optical mouse and Trust stereo headset were used in the experiment. The application was written in Microsoft Visual Basic 6.0 SP6 under Windows 2000. The original application was modified into two different versions to simplify the pilot testing. The only differences between these two programs were in the sonification techniques applied to support the blind navigation and target acquisition task. The layout of the grid augmented with 3 different sounds is shown in Figure 4.2.1. And 6 different sounds were distributed as shown in Figure 4.2.2.

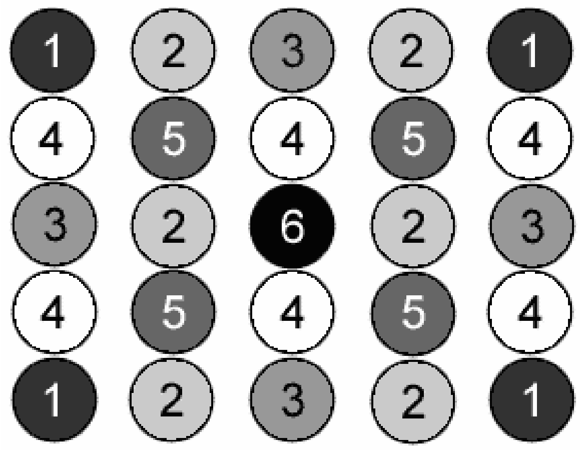


Figure 4.2.2: Sound layout of the grid augmented with 6 different sounds.

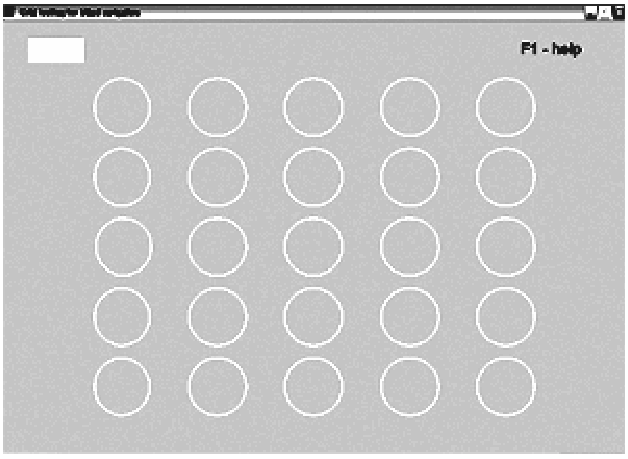


Figure 4.2.3: Locations of the target spots within the game field.

The software supports functionalities for storing the track of mouse movement (scanpath), the time spent, the distance travelled and the number of the spots passed for each of the tasks performed. These data could also be stored into files for further analysis. The application also included a Microsoft Agent interface, which was necessary for reading the tasks aloud for the blindfolded subjects. The agent then used Mikropuhe TTS synthesizer through SAPI-interface to make the instructions possible in a native language (Finnish) for the subjects.

The game-like navigation task was based on capturing 25 circular targets (spots) arranged in a square grid (5 rows by 5 columns). In the center of each of the cells was a round spot with a radius of 65pxls. Distances between center points of the spots were 156pxls vertically and 156 pxls horizontally. The spots (in opaque mode) and their locations on the screen during the testing are shown in Figure 4.2.3. Every time when the mouse cursor was moved to any of these spots, a wave file of an animal sound was played, so that the person could know that cursor had arrived into a spot. The durations of the animal sounds used varied from 0.58 seconds to 1.65 seconds. The subjects could also repeat the sound, as long as the cursor remained inside the spot, by pushing the spacebar button. There were no intentional differences in a volume, spatial properties or in any other parameters of the sounds. After the last task had been completed, there was a sound signal indicating the completion of the game.

The sounds used to augment the location of the spots in the grids were animal sounds, which were selected so that they could be easily recognized from one another. In particular, the sounds of dog, cow, cuckoo and cat were used. Of all sounds, animal sounds were selected because of their familiarity for all, children and adults. It was supposed that familiar sounds would make the recognition of the feedback cues easier and shorten the time required for the learning of the sonification technique. Animal sounds also made the game instructions more understandable for the subjects.

The instructions given by the Microsoft Agent character comprised of a target description that is the target spot to be found. The instructions were given in Finnish language, but followed the form of the example given below in English:

"Click the animal in the middle of the center row".

If the subject forgot the instructions or did not understand them on the first time, s/he could repeat the instructions by pushing a button on the keyboard. The instructions for the next task followed instantly after the target of the previous task was captured.

4.2.3 Procedure

The subjects were instructed how to capture the spots described in the tasks spoken by the Microsoft Agent. The subjects were also given five minutes before the test to familiarize themselves with the sounds and the navigation technique. At least some level of experience regarding the detection of the sound locations was necessary for them to clarify the features of the blind positioning of the cursor in the grid and to use navigational cues. When the subjects were ready with the trials, the cursor was placed near the central position of the screen and the test started.

During the test, the subjects received the tasks to locate a specific spot within the grid. To accomplish each trial, they had to employ both their knowledge of the positions and associated sounds in the grid and the audio feedback coming from the cursor passing into other spots. The spots to be located were selected randomly, and all of the targets were presented once per session. As the starting spot and target spot varied randomly, the routes to navigate were different for each subject and in each trial.

Each session consisted of 25 trials (tasks) to test the sound mapping. Every subject performed one session with each of the two sound mappings. Two subjects started the test with the grid with 6 sounds and two others with the grid with 3 sounds. To decrease stress factor there was a short break between sessions. After the pause, subjects had again five minutes to get to know the sounds of the second grid. Two sessions took approximately one hour for each of the subjects.

During the test, the data were collected automatically with the application. The actions of the subjects were observed with the objective of finding additional information that could not be calculated from the data gathered. After completing the test, the subjects were interviewed.

4.2.4 Results and Discussion

Two Sound Mappings

As described in the Section 2, the two sound mappings applied to the grid had only differences in the number and layout of the sounds. However, there were fundamental differences in the design ideologies of these two alternatives. The 25-cell grid augmented with 6 sounds consisted of four partly overlapping 9-cell sub-grids and therefore could be described as a hierarchical grid. The number of sounds was minimized to 6, while there were still enough sounds to make every spot almost unambiguous in each sub-grid. Another sound mapping was implemented to ultimately minimize the number of sounds to 3. The small amount of sounds, the sounds that are certainly easy to remember, comes with the disadvantage of their unambiguousness.

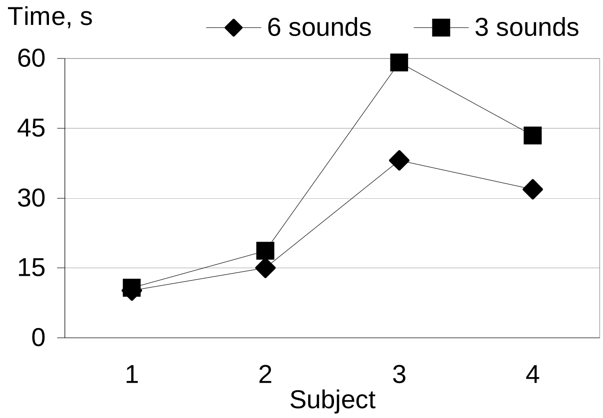


Figure 4.2.4: The overall averaged target acquisition time for 6- and 3-sound mappings.

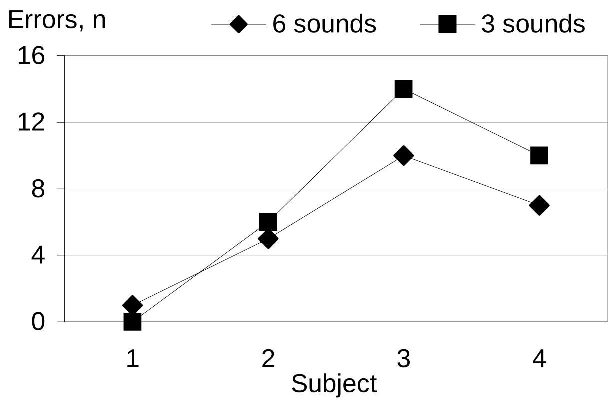


Figure 4.2.5: The overall averaged error rates in the target acquisition task with the use of 6- and 3-sound mappings.

Figure 4.2.4 shows the averaged target acquisition times for each subject during the test of different sound mappings and Figure 4.2.5 shows the corresponding averaged error rates. Both diagrams indicate that the navigation was faster when the grid was augmented with 6 sounds. Paired-samples t-test also showed the difference $t = 2.022$, $df = 3$, $p < 0.01$. The target acquisition times were shorter for all subjects when the grid was augmented with 6 sounds, and there was only one subject who had more errors in this session with 6 sounds ($t = 1.578$, $df = 3$, $p < 0.01$). These facts might result from the observation that it was easier for the subjects to confuse two spots with each other when multiple locations were marked with only 3 sounds. The differences between grids were also greater for subjects who were slower in finding the targets and who committed more errors. The reason for this might be that some persons require the extra navigational aid which could be provided by the differences in sound parameters (e.g., L-R balance) or through other modifications of the grid layout. For instance, non-linear distances between locations of the spots could enlarge kinesthetic feedback.

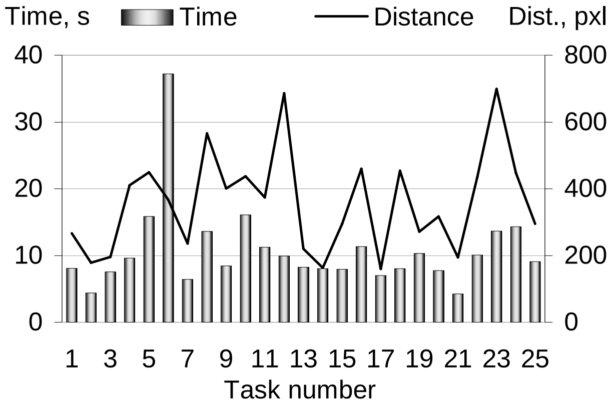


Figure 4.2.6: The target acquisition time and the distance to target, a case study of the subject A3.

When asked, most of the subjects reported that after trying only one grid they thought that the blind navigation with 3 sounds would be easier than with 6 sounds. That seemed due to the shorter learning time for three sounds. However, after completing both sessions, the subjects themselves noticed that they had more problems with the grid augmented with 6 sounds.

Task Difficulty

During the study, the factors, which had an impact on the task difficulty, have been explored as well. The most obvious hypothesis would be that the time of target acquisition depends on the distance between the current position of the cursor (the last captured spot) and the target spot. In Figure 4.2.6 we can see that there is no strong dependence between these parameters measured (corr. = 0.346) in the data sample of the subject A3. The results for other subjects were alike. The comparison of the same samples of the target acquisition times and shortest paths to target showed the same negative result (corr. = 0.233). The shortest path was calculated as the minimum number of spots needed to be passed to arrive at the target spot when moving only horizontally and vertically. However, the comparison of the target acquisition times and numbers of passed spots for the same subject A3 (Figure 4.2.7) indicated a strong positive correlation (corr. = 0.96).

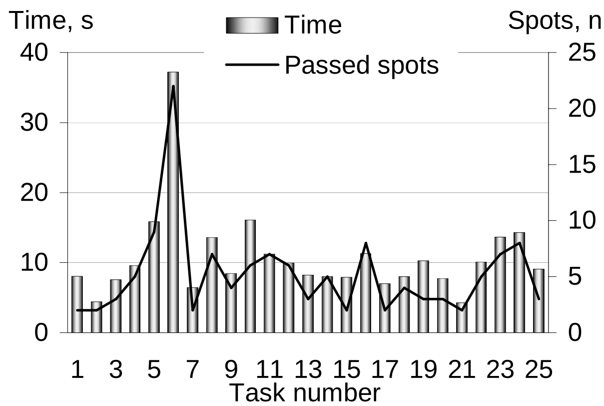


Figure 4.2.7: The target acquisition time and the number of spots passed, a case study of the subject A3.

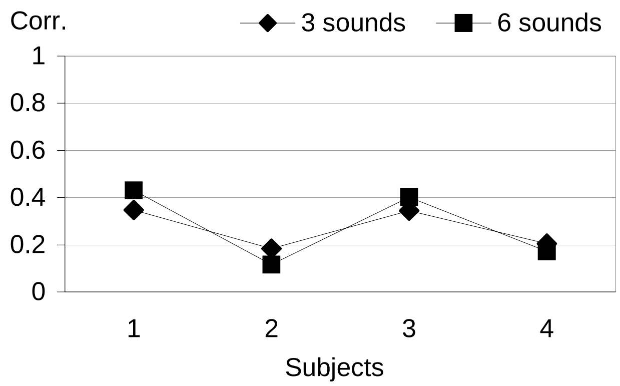


Figure 4.2.8: The correlation between the target acquisition time and the distance to target.

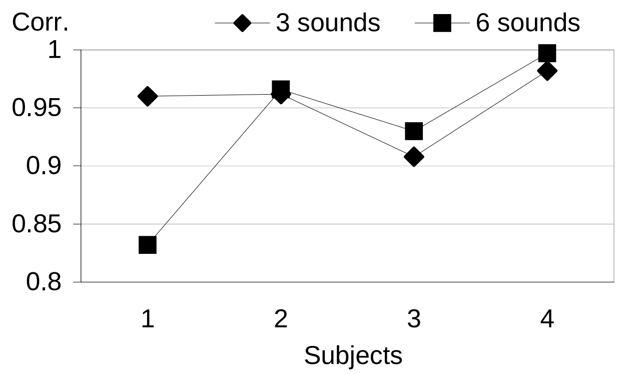


Figure 4.2.9: The correlation between the target acquisition time and the number of passed spots.

As we look at the correlations between target acquisition time and distance (Figure 4.2.8) and then between the time and passed spots (Figure 4.2.9) we can clearly conclude that the correlations were higher between time and distance for all subjects and with both sound mappings. All these results together indicate that the reasons for navigation problems lie somewhere else than in length of the scanpaths in different navigational tasks.

It was also analyzed how target acquisition times, errors, distances and numbers of passed spots in different tasks relate to the target position. Figure 4.2.10 shows matrices which demonstrate the averaged data. Distances between the last captured spot and the target spot were shortest in tasks when the target spot was located near the center of the grid. There is no surprise in this conclusion. However, the number of spots passed during the target acquisition was smallest in the tasks when the target was located in one of the corners or along the edges of the grid. The same holds true with the average time spent for navigation and errors committed during the tasks. The eight spots surrounding the center of the grid (Figure 4.2.1 and Figure 4.2.2) were generally the hardest group to detect and capture (Figure 4.2.10).

4.2.5 Navigational Landmarks

As was noted in the first section of this paper, a “landmark” technique could be used to assist blind persons in identifying different areas of the user interface. It was also mentioned that an easily recognized sound in the center of the grid reduces acquisition time [8]. Taking into consideration the observations revealed regarding the difficulty of finding different spots in the grid, it could be supposed that the corners of the grid could also be employed as navigational landmarks to facilitate navigation and reduce the time of wayfinding to target spot. Figure 4.2.10 shows that even though the distances to target were generally longer when the target was located in some of the corners of the grid, the average time of target acquisition was shorter and fewer errors were committed than in average.

	Both					3 sounds					6 sounds				
Avg. times, s	18	26	11	30	14	27	32	8	51	15	9	19	14	9	12
	26	46	29	29	16	12	45	30	21	18	41	48	27	37	14
	18	37	23	28	32	10	52	26	27	28	26	22	21	28	35
	30	65	36	34	32	41	112	54	48	7	18	18	18	19	57
	15	46	29	20	21	18	46	44	22	30	12	47	15	17	11
Errors, n	1	1	0	4	0	1	1	0	3	0	0	0	0	1	0
	2	5	2	3	0	0	3	1	1	0	2	2	1	2	0
	2	3	2	2	2	0	1	1	1	1	2	2	1	1	1
	3	4	2	4	2	3	3	2	2	1	0	1	0	2	1
	1	3	4	1	0	1	1	3	1	0	0	2	1	0	0
Avg. distances, pxl	340	477	301	283	576	348	526	257	378	558	333	428	345	188	595
	364	396	251	388	446	370	430	253	393	435	358	363	249	383	457
	322	253	303	240	490	348	245	373	198	423	297	261	233	282	557
	431	353	259	291	299	350	389	253	301	166	513	317	266	281	432
	433	300	423	445	468	373	271	490	418	587	493	330	357	473	350
Avg. number of passed spots, n	6,6	7,5	3,4	12,4	7,3	9,8	8,5	2,8	22	9,3	3,5	6,5	4	2,8	5,3
	8	13,8	14,9	7,9	6,4	4,8	12,8	10	8,3	8	11,3	14,8	19,8	7,5	4,8
	9,3	11,9	8,4	8,1	14,1	4,5	15,5	10,5	10	16,5	14	8,3	6,3	6,3	11,8
	11,1	28,1	19,9	15,5	11,6	15,5	50,2	34,5	23	2,3	6,8	6	5,3	8	21
	5,1	15,6	11,5	7	6,9	5,3	13,3	17,3	7,5	10	5	18	5,8	6,5	3,8

Figure 4.2.10: Overall data in a target acquisition task with the use of the grid augmented with 6- and 3-sounds.

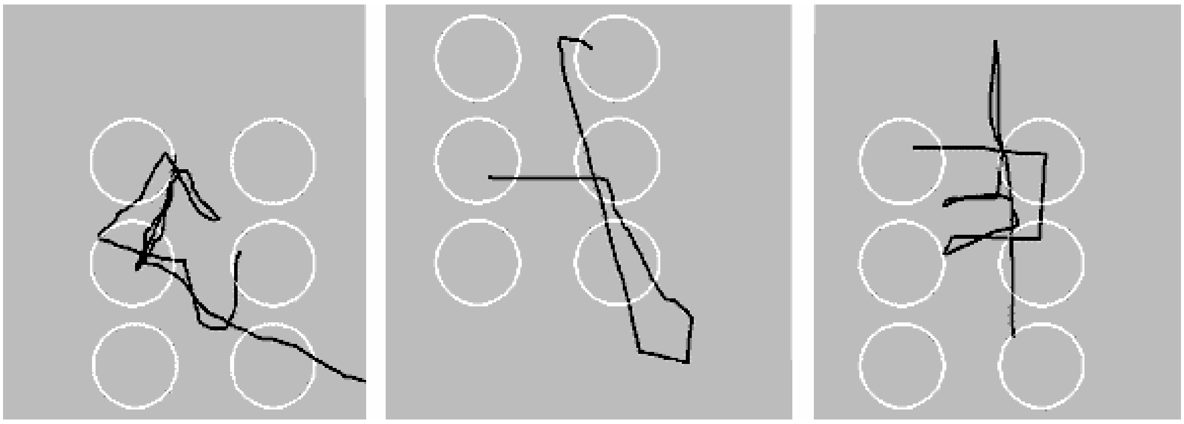


Figure 4.2.11: Scanpaths recorded during inspection of the game field indicating the use of the corners as an external memory aid in the target acquisition task.

The behavioural patterns (scanpaths) were also recorded during the tests. Figure 4.2.11 shows samples of scanpaths. The reason for extra-movements to some of the corners of the grid might be that the landmarks could be considered as external memory aids [1] for the subjects to formalize a mental image of the navigation route when they first found their way to target. Another reason might be that the sounds associated with the corners of the grid were more distinctive than other sounds.

Unintentional Deviation of the Cursor

When moving the cursor vertically right (the mouse is moved right forward), most of the subjects also unintentionally moved the cursor downwards (mouse moving backwards) as shown in Figure 4.2.12. This behavioural pattern resulted in a lack in accuracy and other navigational problems. These problems had an impact on cursor travelling between two spots of the grid and near the target spot. When the subject thought that the cursor is over the right target location, unintentional mouse movement could lead into an error in the task completion. Not all subjects experienced this problem as they applied different techniques to mouse control and blind navigation.

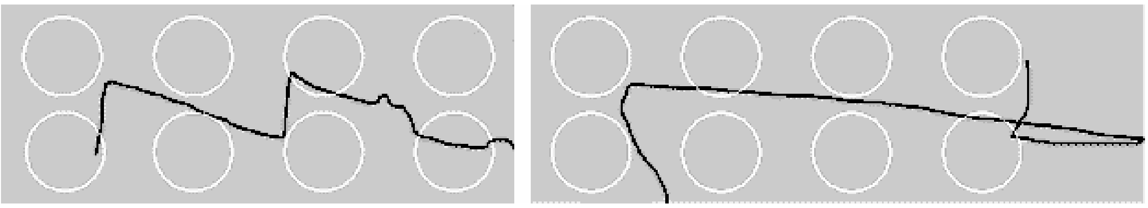


Figure 4.2.12. Scanpaths recorded during inspection of the game field indicating the unintentional downward movements of the cursor while trying to move it vertically to the right.

Lifting the mouse also caused orientation problems, because after the lift the subjects were not able to recover the knowledge of the previous location. Disorientation could be provoked with similar sounds associated with different target spots of the grid as well. This mixing up of sound and location was more probable to happen in conjunction with other problems discussed above. When the subjects mixed up two positions, they tried repeatedly to navigate into the target. The subjects were not able to recognize that they had committed an error even if they were in the opposite corner of the grid than they thought.

4.2.6 Limitations of the Pilot Study

It is impossible to define the level of distinctiveness in navigational sounds. Animal sounds were used and some of them might have been easier to recognize for the subjects than others. Because of this, the selected sounds might have affected the efficiency of the behavioural patterns or strategies which were employed in the pilot test. This problem would have been present even if MIDI sounds were selected as feedbacks. All sounds generated with MIDI synthesis are different in the sense of personal distinctiveness. The distinctiveness of a particular sound can be different for all persons, so it would have been impossible to totally remove this factor.

4.2.7 Future Work

Since the different distinctiveness of sounds cannot be totally removed, it would be useful to test both mappings with different sound layouts. If the results with different permutations would be the same, the reliability of the conclusions and generalizations would be higher. The sound parameters of the landmarks (beacons) should be also explored in more detail.

In their study, Eriksson and Gärdenfors stated that all sounds in audio interfaces should be adaptable to personal preferences [4]. It is also a possible to investigate if the results of this study would be applicable when the subjects could choose themselves the sounds and their positions in the grid. That would also make the distinctiveness of the sounds less important, because the users could realize their own preferences to place the sounds into the grid.

4.2.8 Conclusions

The study has shown that in grid navigation with sound feedback the mapping and number of the sounds influences the difficulty of navigation tasks. Optimization in the number of sounds is needed. Small number of sounds makes the learning time of the sonification technique shorter, but the use of more sounds provides more cues facilitating the target acquisition. Short learning time may result in the sensation of fast task completion even when not true. It was revealed that the mapping of 6 sounds provided more effective non-visual interaction and made the target acquisition time shorter by about 1.39 times and the number of errors smaller by about 32%. The type of the mapping also affects the navigation task by providing the user with different techniques for mental image construction of the external space (game field) and the cues map.

Different locations in the grid have different levels of difficulty when used as targets in navigation tasks. Some locations are preferred as landmarks over other locations. The results can be used when designing sound mapping for blind interaction with different applications, for instance, wayfinding systems, mobile games and other software for visually impaired people.

4.2.9 Guidelines

To build user-friendly interface for visually impaired users there is a need to carefully balance between performance of interaction and perceptive and cognitive abilities of the person.

Mapping (with any cues) should rely on

- a restricted memory capacity, that is, an external memory aid should be inherent property of the signals (primary feedbacks) and pointing behaviour patterns (motor/kinaesthetic memory)
- cross-modal interaction (coordination and integration) should be considered as a basis in designing the basic structures, components and their relationships to be efficiently managed by the user
- memory (brain) plasticity, that is, being simplified to a basic structure (3 by 3) and amodal directions might be flexible and adaptive as well, in use. (“dynamical grid”, dynamical cues…)

It is reasonable to assume that advanced interface design for visually impaired users might rely on a higher level of cognitive processing and natural way of perceptual cooperation and integration of the notions, concepts and models.

Cross-modal (amodal) information, signals and components will have a significant impact on designing advanced user interfaces in the near future.

Consequently, we are going to continue development of the algorithms and adaptive models to support blind interaction and user-device integration.

4.3 FORTH - Prototype development of a dual collaborative Pong game

4.3.1 Introduction

This study is carried out by monitoring non-visual interaction with a Pong game prototype, specifically developed for this purpose. Briefly, Pong is a 2D arcade game, played by two players, or alternatively played by one player, where the computer, or game console, simulates the second player. The objective of this work is to design and evaluate some multimodal navigation tools for this game, in order that children, who face severe sensory impairments, will be able to interact with it. To achieve this objective, haptic devices and 3D audio environment are used. Although ideally, impaired people should be able to experience the data as fluently as their unimpaired counterparts, this is not entirely possible. Despite that, impaired people should be able to interact with the application without countering obstacles and difficulties.

Someone can ask why it is so important for a blind child to be able to play the Pong game. The role of entertainment for pedagogical purposes is well known in the education domain, especially for sensory impaired children who do not have many opportunities to enjoy themselves. In addition, this kind of games plays a significant role in challenging and sharpening basic kinesthetic skills, short-term strategic thinking and decision making.

While there has been a lot of research and development towards universal access, it is only recently there the need for accessible entertainment has been widely recognized, with the formation of the Game Accessibility Special Interest Group (GA-SIG, 2004) of Independent Game Developers Association (IGDA), defining game accessibility as "the ability to play a game even when functioning under limiting conditions. Limiting conditions can be functional limitations, or disabilities - such as blindness, deafness, or mobility limitations". More recently, there is a serious trend for introducing games for training and learning (known as game-base learning, Prensky, 2000) in order to take advantage of the unparalleled motivation and engagement that computer games can offer to learners of all ages. Although this fact, the existing accessible Pong games have a lot of disadvantages. These games make use only of stereo sound (2 channels) and this has a great impact to blind children, because we have observed that they are not able to locate the exact position of game objects. Furthermore, some of these games make simple use of force-feedback interface, as a consequence this interface does not help players.

4.3.2 Prototypes Specification

In this context, we have to investigate some alternative methods to present information (concerning the position and the velocity of the ball, the position of paddles, etc.) for visually impaired players. For this purpose, an auditory and a haptic (force-feedback) interface are used. These two modalities have to be efficiently and effectively combined.

Auditory interface

For this purpose, an auditory media space is developed (approximately 2W x 1.5H meters), supporting spatial audio, consisting in the final version of 24 loudspeakers (4 rows, 6 loudspeakers each, with 24 separate audio channels – this means that a 24-channel sound card is also needed). The prototype of the auditory lattice is illustrated in figure 4.3.1 - a special purpose wood-made set-up is under construction. This grid is currently limited to 9 loudspeakers that fill 3-row by 3-column matrix behind the screen.

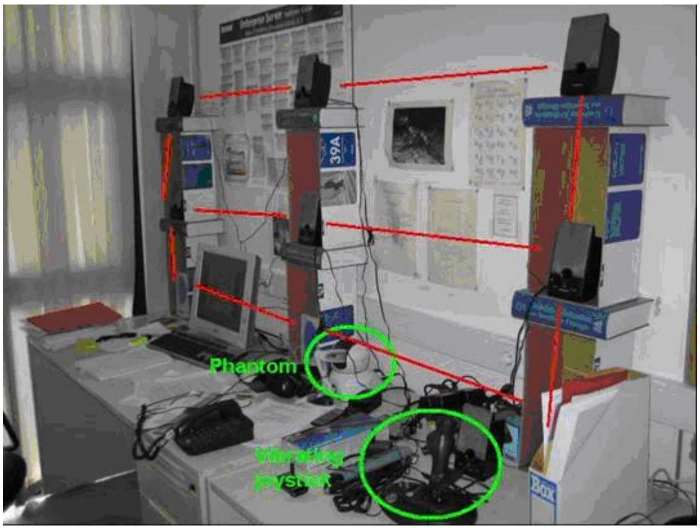


Figure 4.3.1: The auditory wall, as it has been prototypically set-up for the Pong media-space game; a special purpose projection screen will be put in front of the wall, so that spatial audio can augment the large visual display.

The display is split into 24 regions and each speaker is responsible for one region (therefore, there are 24 speakers which comprise the multi-channel auditory media space) (see figure 4.3.2). Actually, the dimensions of the grid (regarding, the number of rows and / or the number of columns) are configurable, so they can fit to the available equipment (number of loudspeakers, sound card type). Each game object (paddles, ball, etc) is located in exactly one of these regions each time. Moreover, every game object is associated with one sound. The ball has its own distinctive sound, which is a loop of electronic music. Upon playback, the location of the ball is reproduced in the auditory space, which is a virtual vertical plane positioned in a small distance in front of the user. The choice of the sound sample used for representing the ball is very important, because this sound sample is heard continuously and the user should concentrate on this sound in order to track the location of the ball and not disturbed by that. Moreover, the space where the ball moves has an upper and lower border. When the ball bounces on these borders a wooden bounce sound is reproduced at the corresponding location in the auditory space. In contrast, when the ball bounces on either of the two paddles, a metal sound is reproduced at the corresponding location in the auditory space. When a paddle fails to hit the ball a 'glass-breaking' sound is heard. Finally, when the user paddle reaches the upper or lower border, a respective sound is reproduced, to notice the user. It is noteworthy that all the above sounds are configurable (through a configuration text file), so anyone can change them according to his preferences. All the messages (score announcements, player moods, game state –pause, resume - etc.) that are represented on the GX display as text are converted to speech messages in the auditory display. These have been recorded through a conventional microphone, and passed through special effects (i.e. pitch shifting and flanging effect) in order to make them more impressive.

The above sounds are reproduced in the auditory space in the following way: For the game objects (paddles and ball) according to their position, the appropriate loudspeakers are enabled in the appropriate volume (figure 4.3.2). Loudspeakers are enabled so that they provide sufficient information about the position and mainly about the velocity (as vector) of the game objects. It must be noticed that at least two loudspeakers (each one in different volume) are enabled for every object. As illustrated in figure 4.3.2 (the direction of the ball is indicated by the green arrow), the volume of loudspeaker 1 is, let's say, 70% and the volume of loudspeaker 2 is 30%. As the ball is moving towards region 2, the previous ratio changes (the volume of loudspeaker 1 decreases and the volume of loudspeaker 2 increases). When the ball leaves the region 1, the loudspeaker 1 will be disabled. In this way, the auditory display can provide the appropriate information concerning the velocity vector of the game objects to the player. Initially, the sounds were reproduced as follows: simply, the sound was reproduced only from the respective loudspeaker of the region which the game object lay. But after an ad hoc evaluation which was carried out in August 2005, some serious problems revealed. The main difficulty which users had, was that they were not able to locate the position of the ball because they did not have any evidence about its velocity vector. For this reason, was decided that a redesign of the 3D audio environment was absolutely necessary. For the speech messages, all loudspeakers reproduce them in a standard volume.

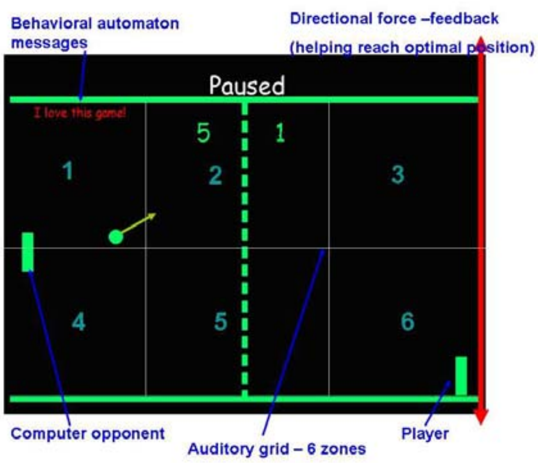


Figure 4.3.2: Snapshot of the basic screen (traditional profile). For simplicity, it is used an auditory grid with only six regions (zones)

Haptic (force-feedback) interface

The vibration feedback controller which is used, is the "Logitech RumblePad 2". The vibration feedback provides additional hints to the user in collaboration with the 3D sound environment. These hints concern:

- The ideal position of user paddle in order to hit the ball. The amount of force depends on two parameters: firstly, the distance between the ball and user paddle and secondly, the distance between the current position of the paddle and the ideal position of the paddle (the ideal position is the position which the paddle must have in order to hit the ball). As far as the first parameter is concerned the force fluctuates in the following way: the closer is the ball to the user paddle, the greater is the force which is applied (figure 4.3.2). This is to ensure that the player perceives the distance between the ball and his paddle and takes the appropriate actions (to move his paddle and hit the ball). If the user does not move his paddle, the force is getting greater and greater in order to warn him that he will lose the game. As far as the second parameter is concerned the force fluctuates in the following way: the greater is the distance between the current position and the ideal position of the user paddle, the greater is the force which is applied. In this manner, the player perceives the distance between the current position and the ideal and consequently determines how much he will move the paddle. However, it is crucial for the user to have a clear view of the game (i.e. the positions of the game objects). This means that he must be able to distinguish, for a given force, these two different situations: i) the current position of the paddle is far away from the ideal but the ball is also far away from the paddle, ii) the current position of the paddle is close enough to the ideal, but the ball is also close to the user paddle. This is accomplished with the help of the 3D audio environment (for that reason the two modalities -auditory and a haptic (force-feedback) interface- have to be combined and cooperate effectively). Hence, the user can distinguish the above two situations because the 3D audio environment gives him the information about the position of the ball. If the ball is close to the user paddle, then the player knows that he has to move the paddle slightly (in the direction of the force) in order to not lose the game. Otherwise, he knows that the position of his paddle is far away from the ideal, so he has to move the paddle quickly (in the direction of the force).

- The user paddle reaches the borders of the game space. This indicates that the player can not understand and analyze the information that the auditory and haptic interface provide (probably, he is moving the paddle in a random way and the paddle hits the upper or lower border). However, with that hint, the user can locate the position of his paddle.

- The user paddle hits the ball. This indicates that the player accomplishes his “mission” successfully.

4.3.3 Conclusions

Guidelines

- Once there is a need for design tools to allow visually impaired people navigate the information which is presented to them, then the use of an auditory display is suggested. However, one should consider how complicated and expensive the setup is (large number of loudspeakers, advanced audio card, etc.). Alternatively, an HRTF-based auditory display can be used instead (it simulates the presence of a sound-emitting object in any position within the listener’s environment), which requires only a pair of headphones but the main drawback of that approach is that the 3D auditory environment around the listener, which is reproduced on the headphones, appears to be moving when the listener’s head moves.

- Once there is a need for presenting information to visually impaired children, then the use of force-feedback is suggested. The main advantage is that a vibration feedback controller does not cost much. On the other hand, it is possible some children to not be familiarized with this device and have several difficulties at the beginning.

Future evaluations

When the implementation of the 3D sound environment is completed, an evaluation process will be arranged in order to ensure that impaired users are able to interact with the application without facing difficulties and without much of effort. If the output of that evaluation shows that some of the above problems remain, a redesign of an alternative audio interpolation algorithm will be investigated and implemented. In addition, a different grid topology will be investigated (for example, 4 rows, 6 loudspeakers each). Currently, the auditory media space is flat. It would be interesting to test what happens, if the auditory wall has a parabolic shape. Moreover, the position of the player’s head (in regard to auditory wall) must be investigated.

4.4 UGLAS - Two-Handed Navigation in a Haptic Virtual maze Environment

4.4.1 Introduction

Users rely heavily on visual feedback when interacting with a computer. However, computer users with no or very little vision must rely on other modalities to access the same information. Screen readers have proved to be a successful solution for accessing the textual information required to interact with a computer. However, this information is generally accessible only in a linear manner (from the top left corner of the screen) and non-text information such as pictures and diagrams are not easily displayed in this manner. The goal of this work is to examine techniques to enable users to navigate computer interfaces and explore information non-visually in a non-linear manner. To achieve this, a two-handed focus-context interaction paradigm is adopted. Users can navigate a cursor in a 2D space and receive force-feedback by moving a device with their dominant hand. They also receive contextual information through their non-dominant hand. The contextual information in this case will be directional information displayed on a small pin array.

Similar bi-manual techniques have previously proved successful for accessing information non-visually. The Optacon [1] is one commercially available example. Visually impaired users could access printed material by moving a camera over a page with one hand while receiving a vibrotactile representation of the image under the camera presented to the other hand. Recently, Wall and Brewster [5] developed a system for browsing a bar chart with a graphics tablet and stylus for navigation. The fixed frame of reference offered by the tablet allowed users to employ their proprioceptive sense to maintain an idea of where they were within the environment. In the non-dominant hand a direct tactile analogue of the graphics was presented to the users' finger tips allowing them to browse the data through a small tactile window centred around the current cursor position.

Tactile cueing has previously been studied, for example, by van Erp and van Veen [4], who use vibrotactile cues spatially distributed around a user's torso presented through a tactile vest. Here, they use tactile patterns to indicate to astronauts their orientation with respect to the International Space Station. A recent study conducted by Martin *et al.* [3] examines the discriminability of different forms of cues presented to a user's fingertip through a raised pin tactile array. They examine the success of presenting a set of 8 different directional messages through different patterns of tactile cue. Different forms of static, dynamic, and 'blinking' (cycling between the pattern and an empty array) patterns are studied with the best performance noted with the static cues.

For this experiment a selection of two of the sets of cues developed by Martin *et al.* [3] are examined. The goal of this study is to test performance in a more complex navigation task when users must integrate cues presented to different hands to navigate a virtual environment. These cues are presented using force feedback and tactile feedback.

4.4.2 The Maze Environment

The Maze Game

A game environment was developed to evaluate this two-handed interaction technique. A screen shot of the application is shown in Figure 4.4.1. The black squares represent walls, the white squares represent corridors. The goal of the maze is to navigate the man through the maze within the time limit while avoiding the obstacles (carnivorous plants) and reaching the exit (shown by the door in Figure 4.4.1).

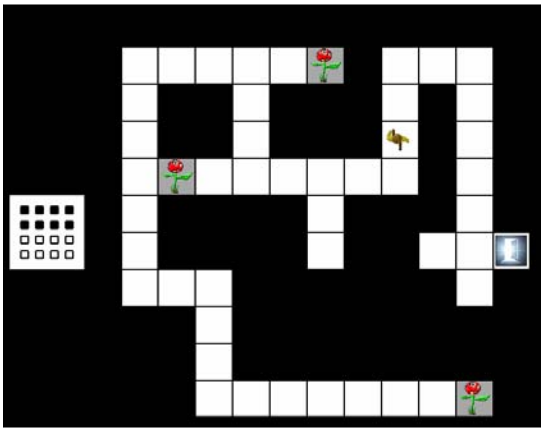


Figure 3.4.1: The maze application. The user must navigate the man through the maze to the door while avoiding the plants

4.4.3 Interactions

A user moves the sprite through the maze by moving the Phantom device with their dominant hand. The maze is set in the vertical plane. Users can move freely in the x and y plane but are tightly constrained in the z direction allowing for two degrees of freedom of movement only. The application will allow users to freely navigate the corridor while using a spring force to constrain the user to the path while pressing against a wall. The absolute position of the Phantom effector is directly related to the user's position in the maze allowing for absolute position judgments. Colours for the maze have deliberately been chosen to be high contrast to provide users with low vision to view the application.

Guidance in the form of directional information is provided to the user's non-dominant hand through tactile cues from the VT Player mouse. The user places fingertips on the tactile arrays of the mouse and is provided with information about the direction they must travel in to reach the exit. Different design of cue were evaluated, with the cues and the results described in section 3.

Obstacles

The obstacles in the maze are represented by carnivorous plants. The user must avoid these as a collision results in the loss of one of 3 lives. The location of the plants are displayed to the user through audio. There is a continuously looped "chomping" noise to alert the user of a nearby plant. Audio may be panned to either the left channel, right channel or displayed equally through both depending on the direction the user must travel in to reach the plant. As the user moves closer to the plant, the volume of the warning sound increases. A collision with a plant is displayed through audio and force feedback. The audio chomping signal changes to alert the user. A force effect is played so the user is aware that they were attacked by a plant (this can be felt as a buzz). Speech is used to convey the number of lives the user has left.

Timing Information

Audio is used to display the timing information. The user will hear a series of ticks with the length of time between the ticks indicating the amount of time left. As the ticks become closer and closer together, there is less and less time to complete the maze. A warning clock sound indicates that the user's time is nearly finished with 3 seconds left.

Basic Game Administration

There are a number of other tasks that must be performed such that the user can use the game with no visual feedback. Firstly, instructions on the goal of the game and how to start the game are displayed through audio. At the end of each game, a Phantom force effect pulls the user back to the starting position for the next game. This force constrains the user to the start position until the game is started by clicking the Phantom button. A random number generator is used to randomly select a maze.

Displaying the Results

At the end of a game, speech is used to alert the user to the success or failure. The user's path travelled during is game is displayed visually (as shown as the cyan line in Figure 4.4.2).

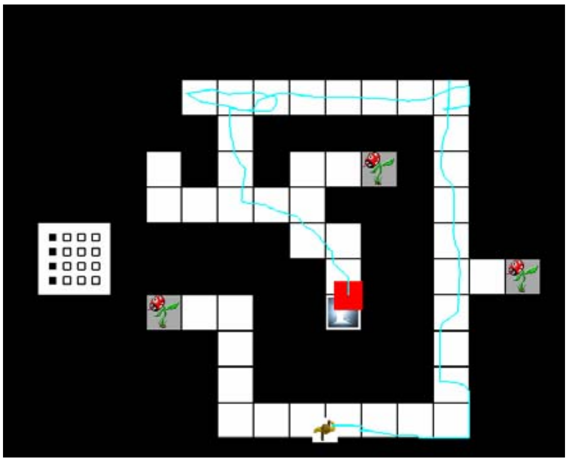


Figure 4.4.2: A screenshot of what the user is shown at the end of the game. The blue line indicates the path taken by the user during the game. The red square indicates the position of the user when the game finished.

4.4.4 Evaluation

The task chosen for the evaluation was for the user to navigate a maze using only their haptic sense. Since the evaluation was based around this interaction mechanism, the in-game obstacles were removed. A maze environment was chosen to evaluate these techniques as it provides a constrained environment with a clearly defined goal. The user must navigate from the start position to the exit. An ideal path can therefore be defined that allows an easily measurable error from this path. Also, the difficulty of a maze can be altered by adding or removing junctions. A visual representation of one maze used in the study is shown in Figure 4.4.3. All of the mazes for this study were similarly set in a 12 x 12 grid of squares.

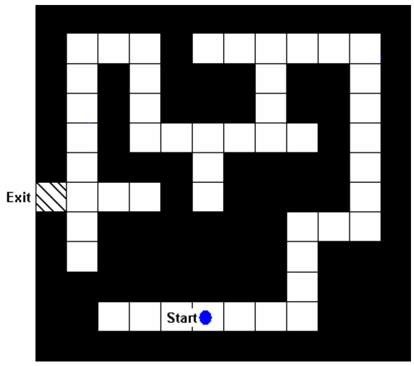


Figure 4.4.3: An example maze used in the study. The white areas represent corridors and the black areas walls. The start and end positions of the maze are marked. Lines delineating the maze squares are shown visually here across the corridors.

Navigation

To navigate the maze, the user interacts with a PHANTOM OMNI force-feedback device (from SensAble Technologies) using their dominant hand. This device offers high fidelity feedback while still being relatively cheap. The device has a small wrist movement sized workspace (160mm x 120mm x 70mm) and is relatively easy to overpower, which are both important safety concerns when the device arm can move independently and users cannot see the arm. Although this device allows 3D interactions, for the maze environment users are constrained by the device to 2D interactions in the vertical plane only. Users are always constrained to the corridors of the maze and can feel the maze walls (represented as stiff springs).

Tactile Cues

An initial version of the maze attempted to present a direct tactile representation of a small area around the user's cursor (described in [2]) using a VirTouch VTPlayer tactile mouse. Here, the area of the maze around the user was displayed through a tactile pin array (4 vertical x 8 horizontal) pins with pin-up representing a wall and pin-down a corridor (like a tactile map). Each pin represented one square on the maze centred around the user's cursor position. A pilot study with four blind participants was conducted to test the usability of this system as a navigation aid, the results of which suggested that this was an unsuccessful method of presenting the information. All four users found the amount and the complexity of the information confusing. Each pin on the display represented a piece of information and the large number and high density of pins as well as their rapidly changing state as the user moved made the task too difficult. One user succinctly summed up the sensation as 'a tactile mess'.

It was therefore important to develop a navigation technique that reduced the complexity of information presented to the user's non-dominant hand. Instead of a visual analogy, coded tactile representations were developed to aid user navigation. The information presented to the user was reduced to four tactile cues that provided the user the direction to the maze exit. These cues (presented on a 4x4 raised pin display) indicated to users that to get to the exit, they must move up, down, left or right. Two forms of these cues were developed: static and dynamic.

Static cues form a tactile pattern on the display with the pattern indicating the direction to move in. The four patterns are chosen to be similar to those developed in [3]. These patterns are shown in Figure 4.4.4. Each pattern is represented by a line of raised pins on the display. The position and orientation of the pins indicates the direction the user must move in to reach the exit. If the raised pins are felt at the top of the display, the user must move up, and similarly for the other three directions. The pattern displayed remains the same until the user is required to change direction.

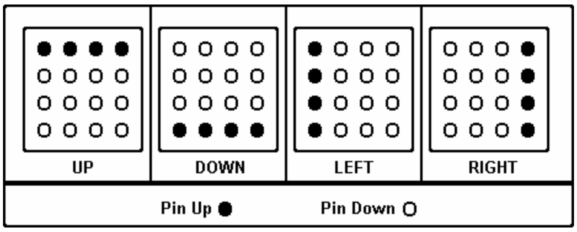


Figure 4.4.4: The four static cues used for the study.

The second set of cues (dynamic cues) use tactile flow to indicate direction. These offer the potential to be more expressive than the static cues as the rate of change of pins and changing patterns can now be altered to provide more information to the user. However, they may also be more difficult for the user to interpret [3]. A series of patterns is played to the user for each of the 4 dynamic cue messages. These patterns are shown in figure 4.4.5. For each direction message, the user is played a series of five patterns where the direction of flow of the raised pins indicates the direction in which the user must move to reach the goal. In each case, the first and final patterns are left with no raised pins to allow the user to more easily separate the cues. Unlike in the static condition, the state of the display is constantly changing even when the user remains stationary. In the event of a required change in direction, the appropriate tactile cue is played from the start (always starting with an empty array). The rate of change of the display was chosen empirically at 100ms per update.

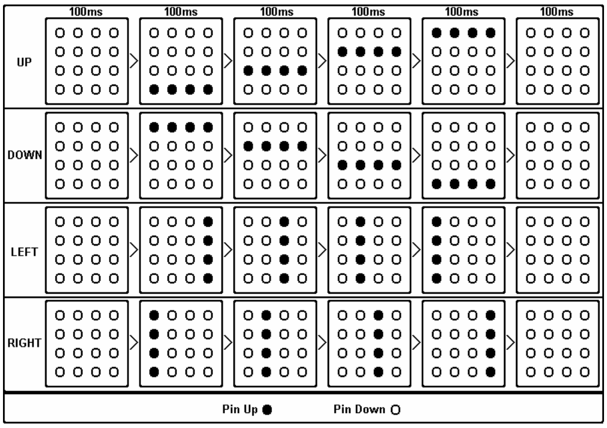


Figure 4.4.5: The four dynamic tactile cues used in the study. Each row represents a series of patterns played to the user (at a rate of 10 patterns a second) to indicate a direction.

4.4.5 Experiment

An experiment was conducted to examine the performance of visually impaired users on this system.

Methodology

There were two conditions for the experiment: static or dynamic cues. Users were set the task to navigate to the maze exit within 50 seconds with audio cues alerting users of the amount of time that they had remaining. A within-subjects design was used such that all participants performed both conditions in a counterbalanced order. Ten participants from the Royal National College for the Blind in Hereford (UK) took part in the study. Participants had a range of visual impairments from congenital blindness to some residual sight remaining. In all instances, instructions for the experiment were provided verbally. To ensure the complexity of the mazes was kept constant, the mazes in one condition were mirror images of the mazes in the other condition. There were 8 mazes in each condition making 160 trials in total during the experiment.

Training

At the start of the experimental session, the user was initially presented with a physical representation of a maze (built using LEGO blocks) and the equivalent computer representation using the PHANTOM only. This allowed the users to familiarize themselves with both the concept of the maze environment and the PHANTOM device by exploring both simultaneously. Before each condition users were familiarized with the 4 appropriate cues for the condition, then presented with three mazes using the appropriate tactile cues for navigation and asked to navigate to the goal.

Hypotheses

1. Participants will successfully complete more mazes within the given time frame in the static condition

2. Participants will perform faster in the static condition

3. Participants will travel less distance when completing a maze in the static condition. This will be measured by examining the excess path length as proportion of the ideal path length (both measured in squares traversed) for successfully completed mazes only.

4.4.6 Results

Data collected from 15 mazes were unusable in the analysis. The most common reason for this was the user applying excessive force and overpowering the device, and thus pushing through walls. When data was discarded from a maze, the mirror image data from the other condition for the same participant was also discarded to maintain data that could be compared over both conditions. There were a total of 65 paired mazes from each condition that provided data that were usable in the results. Participants in total completed 58 in the static condition compared to 47 in the dynamic condition. The paired difference in performance for each participant was analysed using a non-parametric Wilcoxon Signed Rank Test and a significant difference was found ($W = 33.0$, $p<0.05$) supporting hypothesis 1.

Data for hypothesis 2 were analysed using a paired T-test. Times for unfinished mazes were set at the timeout value of 50 seconds for the analysis. Mean time in seconds for each maze was 23.1 (stdev = 9.12) in the static condition compared to 34.4 (stdev = 10.26) in the dynamic condition. This difference is significant ($T_9=2.62$, $p<0.03$) supporting hypothesis 2.

An Anderson-Darling test demonstrated that the path length data was not normally distributed. A non-parametric Wilcoxon Signed Rank Test on the difference in path length for each user was therefore used to test significance. When completing a maze, the mean excess number of squares traversed was 0.93 (stdev = 0.86) times the ideal path length in the static condition compared to 1.09 (stdev = 1.03) times the ideal path length in the dynamic condition. This difference is not significant ($W = 31.0$, $p = 0.76$). We cannot therefore support hypothesis 3 with the current data.

4.4.7 Observational results

Of the 10 participants that took part in the study, all but one expressed a preference for the static cues over the dynamic cues. One potential reason for this could be due to the fact that all had previous experience with Braille (which is another static coded tactile representation) and the sensation of moving pins conveying information is a novel experience. Two users had trouble with the two-handed nature of the task. One user preferred to concentrate on the feedback from the PHANTOM and only used the tactile array while holding the PHANTOM stationary. The other required convincing to keep a hand on the tactile array and stated they rarely used the feedback from it.

Horizontal movement in the vertical plane can be difficult when no visual feedback is provided. Figure 4.4.6 shows an example of one participant attempting to move right with no visual feedback and no supporting force feedback. The user's cursor has a tendency to move diagonally down and right possibly due to the effect of gravity.

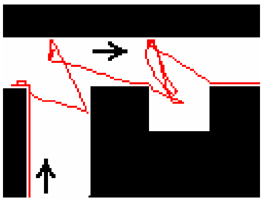


Figure 4.4.6: A cursor trace recorded during the experiment. The user recognises the cue to move right, but finds it difficult to move horizontally without visual feedback.

4.4.8 Discussion and Conclusions

The above results suggest that most users could successfully use the two-handed technique to navigate the maze environment. Users performed better and faster using the static patterns as was suggested by [3]. However, even in the dynamic condition, users still completed over 70% of the mazes successfully with little training. There was no difference in path length detected, although this is mainly due to the high level of variability in the data.

Guidelines

The following guidelines have been drawn from experience with the evaluated maze environments.

- Direct translation of a visual to a tactile representation will not necessarily result in usable tactile feedback.
- Visually impaired users can successfully integrate force feedback cues and tactile cues presented to different hands.

- Static tactile cues provide better performance than dynamic tactile cues when working in a two-handed navigation task.

Future Work

The data gathered in this study will now be further analysed to look for differences between conditions to examine, for example, reaction times to change direction at junctions in the different conditions or differences in the success of perceiving each cue within a condition. One area of future work will be to encode more information in either moving or blinking patterns. For example, the distance to the next turning position could be encoded in the rate of change of the pattern.

This study used a virtual maze environment but techniques here can be generalised. Future work will involve using combinations of force and tactile feedback with the addition of auditory feedback in different computer environments to allow user to browse and navigate data non-visually.

4.5 ULUND – The tactile Labyrinth game

4.5.1 Introduction

Although some games exist for visually impaired persons, the number of games available is very limited compared to the number of games available for a sighted person. Furthermore games is a way of testing different interface designs and interaction techniques in a more entertaining way.

The present work is concerned with a labyrinth game, and it fits best within 2.2 (Multimodal control and navigation).

4.5.2 Prototypes specification, labyrinth game

Apart from using the ReachIn API, we have also investigated the use of OpenHaptics in combination with ODE (open dynamics engine) and 3D sounds (direct3Dsound) to produce audio-haptic kind of environments. One such environment designed for MICOLE is a labyrinth game. The visual interface of the game can be seen in Figure 4.5.1 below.

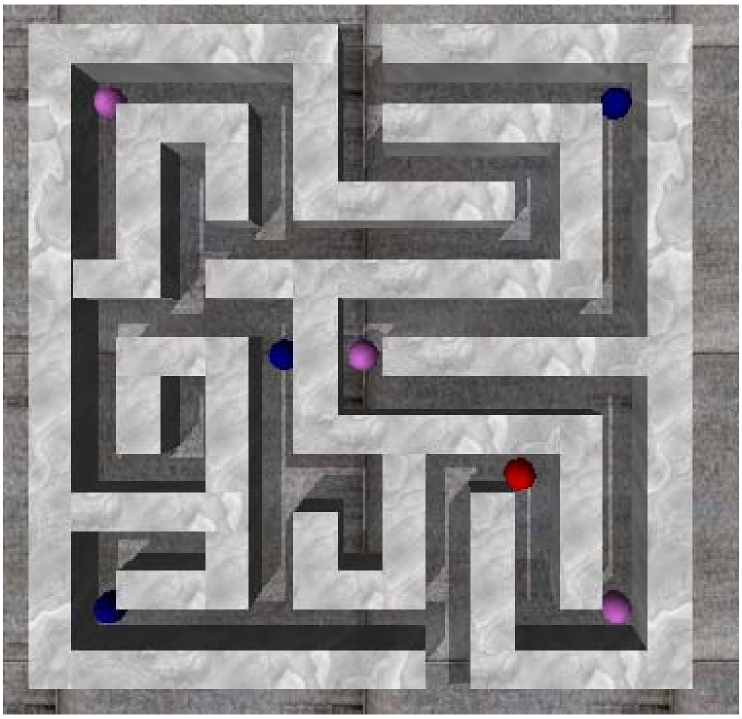


Figure 4.5.1: A labyrinth game (vertical version).

The red ball is the cursor, and the aim of the game is to collect the purple balls and avoid the blue ones by jumping over them. The blue and purple balls emit different sounds (the strength of the sound depends on how close you are to the ball), and the user receives audio feedback when he/she touches them (which makes them disappear). The cursor ball produces contact sounds on collisions with the walls. The labyrinth exists in two versions – one vertical (as on the screen) and one horizontal (see Figure 4.5.2). It is impossible to jump over the walls in the labyrinth.

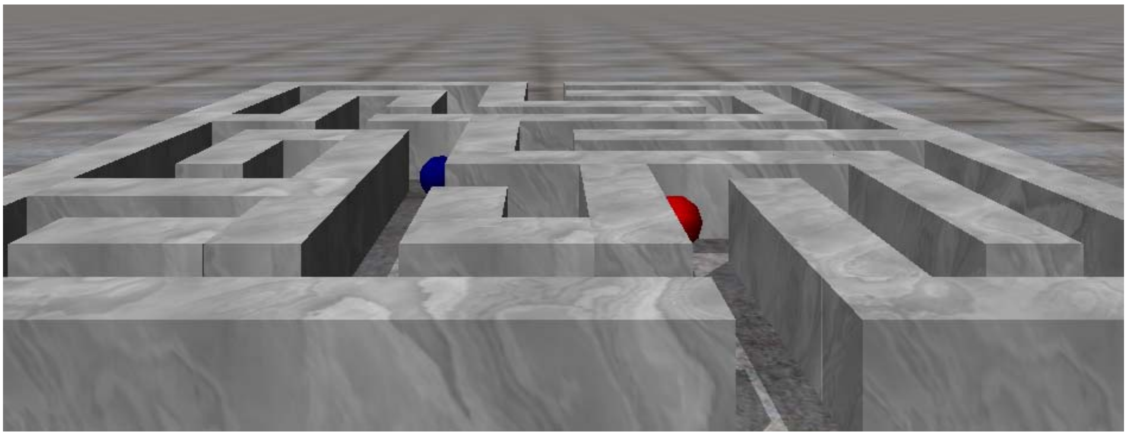


Figure 4.5.2: Horizontal version of the labyrinth.

The reason for having these two orientations was that it allowed to test user preferences with regards to orientation.

4.5.3 Evaluation

This game, with the two different orientations, was evaluated by four (4) members of the LUB. The evaluation was done informally – the users were just asked to try and comment on the application.

Hypotheses

- Horizontal orientation would be preferred due to the more comfortable arm position
- A maze game is a good type of game for our user group

Evaluation

The users tended to prefer the vertical orientation of the maze, although some said that it was hard to say in general. Still one comment was that differences in position was more easily felt in the vertical orientation. A big problem turned out to be the fact that the labyrinth had exits, which caused the users to fall out all the time. In the discussion after the test one user expressed the wish for things “eating you” inside the labyrinth – more action was obviously needed – but in general a positive attitude towards this type of game was expressed.

This environment was also tested with a group of sighted users (17 persons) who had never tried the PHANToM before (demo session to show our work). Several of the persons in this group had initial problems with feeling any haptic illusion in general, and some of these users commented that the labyrinth was good because it constrained you.

Discussion

The choice of orientation is still an issue. Even though our users seemed to prefer the vertical orientation, the arm position needed tends to be tiring, and preferences for long time use may differ. Another argument for horizontal orientation is that for some environments this allows for “hardware” restriction of violent user movements – the user will simply be restricted by the surface of the table.

Labyrinth type games seem to be appreciated, although more action is needed. We are currently working on a pac-man type game which we hope will meet these requirements.

Another obvious observation is that labyrinths for blind/visually impaired users should not have exits.

The sighted user reactions indicate that this type of environment may be a good way to get familiar with the PHANToM, particularly for persons who have initial difficulties with feeling the haptics illusion (possibly this also includes persons with motorical problems).

4.5.4 Conclusions

This small test shows that vertical orientation may at times be preferred, but one has to keep the effects of long time use in mind. The general recommendation has to be that the suitable orientation for each environment needs to be determined by testing.

Labyrinth games seem appreciated, although one needs to consider the "idea of the game".

Another obvious recommendation is that a labyrinth like this should not have exits. This is essentially the same consideration as the recommendation to use a limiting box – the user should not be able to "fall out" of the environment. The limiting box of course has another motivation: it allows the user to separate objects from environment limitations (if now limiting box is used the PHANToM physical limitations may be felt as objects).

There is also an indication that this type of restricted environment is a good starting point when people are introduced to haptics – particularly if you have problems feeling the haptic illusion.

4.6 ULUND - Navigational Tests

4.6.1 Introduction

With one point haptic interaction in a non visual setting it is easy to miss objects, or get lost in haptic space [1]. Some navigational tools have been suggested, such as "magnets", "crosses" (allowing the user to feel if he or she is aligned with an object) or a "ball" (to feel things from a distance) [2]. Particularly the attractive force has been used, and found to be helpful in many circumstances eg [3], [4] and is provided as a standard tool in the current OpenHaptics software from SensAble. For graph exploration Roberts et al [5] and more recently Pokluda and Sochor [6] have presented different versions of guided tours, while Wall and Brewster [7] have tested the use of external memory aids, so called "beacons" which the users could place on a surface and which then could be activated to drag the user back to this particular place. Text labels have been used extensively to help users obtain an overview of for example maps [8] or traffic environments [9].

Other ways suggested to help the user with navigation/learning is so called fixtures (automatic guiding constraints), which has been used for tele-operation, shared control tasks, tracking and training often in a medical context [10], or to have the user cancel forces generated by the haptic device [11].

If we look at the combination of audio and haptic feedback, we see that for the 3D (VR) type environments there is still not much work done on designs involving both these modalities. In the following we will look closer at different implementations of a set navigational tools utilizing 3D audio together with haptics, and discuss results from two exploratory pilot studies of such tools performed at Certec, Lund University during the spring of 2005 (these results have been presented in Audio haptic navigational tools for non-visual environments, Charlotte Magnusson, First ENACTIVE Workshop, Pisa, March 21-22, 2005 and Audio haptic tools for navigation in non visual environments, Charlotte Magnusson, Kirsten Rassmus-Gröhn, ENACTIVE'05, 2nd International Conference on Enactive Interfaces, Genoa, November 17-18, 2005). We will also report on the results from a more extensive test performed during the autumn of 2005 (to be published).

This work fits into both 2.1 and 2.2, since it addresses a type of tools that involve multimodal representations of spatial/navigational information (2.1 Multimodal representation and perception) at the same time as it investigates tools for navigation (2.2 Multimodal control and navigation).

4.6.2 Pilot test 1

Navigation and selection tasks in VR typically rely heavily on vision [12]. Even so, general descriptions and taxonomies are to some extent applicable also to the task of finding objects in a non visual environment.

Travel can be active or passive and the user may perform physical movements in the real world or remain stationary (and only move in the virtual environment). The user needs to specify how and where to move and to receive relevant feedback from the virtual world about what is happening. Generally speaking, to find a specific object the user has to:

- find which object to go for
- go to the object (actively or passively)

To investigate further how this can be accomplished in a non-visual environment, we decided to implement a virtual environment where we could provide different ways of finding which object to go for as well as different ways of helping the user in the task of getting there. We attempted to make the functions implemented rely on different principles to cover a large portion of the possible design space for this kind of environments.

Implementation

A virtual world containing ten spheres with radius 0.01 m was implemented (Figure 4.6.1). The size of the spheres was chosen to be small enough to make them hard to find without search tools, but large enough to be obvious once encountered. Each object was assigned a sound to distinguish it to other sounds. In the test task that utilizes the search and find tools, the user heard a reference sound, and the task was to find the sphere in the room that had the same sound attached to it. Four different ways of selecting a target as well together with four different ways of helping the user navigating to the target were also designed and implemented.

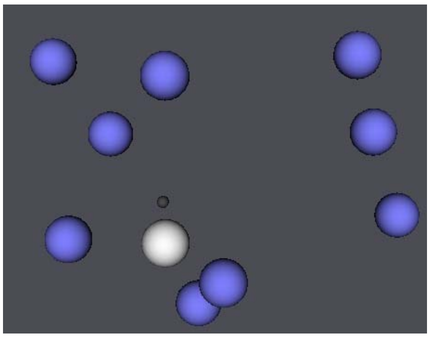


Figure 4.6.1: A visual representation of the haptic environment. The spheres are randomly distributed, and in the testing mode they are invisible. The white sphere indicates the target for the navigational task.

For the selection task the following tool implementations were made:

1. Free exploration, with spheres emitting 3D sounds. The 3D sound was restricted so that only the closest sphere was heard (this closest sphere was then also the current selection). The user could also press a button to hear all sounds at the same time. This implementation was inspired by an attempt to replace visual feedback with audio feedback in an ordinary mouse/pointing device selection. In theory the user could obtain some kind of general overview by pressing the button to get all sounds simultaneously, while the other mode allowed the user to focus on the closest object undisturbed by sounds from other objects.
2. Stepping through all objects in sequence. This function was inspired by the tab-type function in an ordinary windows interface. It is also a common interaction mode in e.g screen readers.
3. Free exploration, but the selection was made by clicking the button on the PHANToM device. When the button was pressed the closest sphere was selected, and the sound of this sphere could be heard.

This version was inspired by the same ideas as number 1, but the user had to make an active choice to get the sound feedback (hopefully generating less unwanted sound feedback).

4. Map selection. A 2-d haptic map was implemented at the bottom of the environment (ball positions were indicated by half sphere shaped depressions). The user selected an object by locating it on the map. This selection was inspired by the fact that the use of a map restricts the selection to a 2D space which should (in theory) be an easier task.

For the task of navigating to the object the following tool implementations were made:

a. 3D radial audio sound source placed at the object location. The “ears of the user” were placed at the PHANToM stylus position (partly inspired by the camera-in-hand VR technique [12]), and thus the user could explore the 3D soundscape by moving the stylus around. This design ties in with the selection functions 1 and 3 and was motivated by the same type of considerations.

b. Radial force field attracting the user to the target. This force was activated by pressing the button on the PHANToM stylus. This tool has been suggested before [3], [4], but was also motivated by the fact that it would form a haptic correspondence to the 3D radial audio sound feedback. Thus a gravity well type of attractive force was used, to get the same type of distance dependence in both modalities.

c. Cross-like search tool enabling the user to search for the object in one dimension at a time (Figure 4.6.2). This tool had been suggested already in [2]. This type of tool allowed the user to actively explore the search space, while providing a way of “sensing from a distance” as well as a restriction of the search space.

d. Sound beams in the z-direction. When inside the beam (which is found below the sphere and limited by the sphere radius) the user could hear the sound. Outside the beam no sound is heard. The sound beam did not use 3D sound. This design was inspired by an attempt to restrict the search to two dimensions, and the design was used together with the map selection which was based on the same basic assumption that a 2D search should be an easier task.

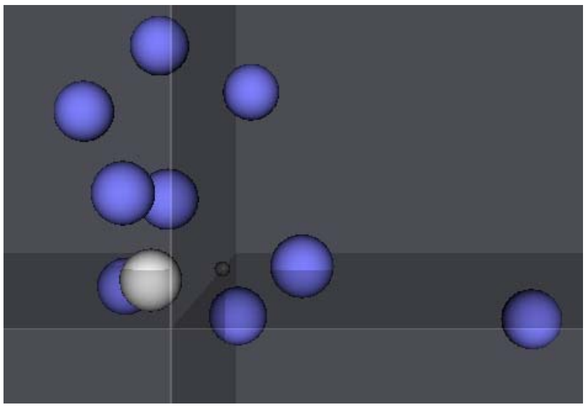


Figure 4.6.2: The cross like search tool. The search planes stop when they hit the selected ball, which makes it possible to first find the target in the left-right direction, then to locate it in the up-down direction and finally to follow the intersection of the two search planes towards the goal.

Since this was a pilot test, we did not explore all possible combinations. Instead the select and navigation tasks were combined in four applications as follows in table 4.6.1:

Test application	Select	Navigation
1	1	a) b)
2	2	a) b)
3	3 (2)	a) c)
4	4	b) d)

Table 4.6.1: The button selection implementation was replaced by the tab type selection (2) after the first tests had showed it very difficult for the users to handle.

Technical detail

For the haptics, The PHANToM Omni together with ReachIn API was used. For the sound feedback Zalman ZM-RS6F 5.1 Surround Headphones together with Direct3DSound was used. For the 3D sound the virtual listener was always assumed to be facing forwards within the virtual environment. This was motivated by the consideration that the user would actually be sitting in this way in front of the computer. A rolloff factor of 0.8 together with a minimum distance of 0.01 m and a maximum distance of 100 m was used. To get more distinct directional information from the audio feedback, the sound field was scaled with a factor 10 with respect to the haptic virtual world.

The haptic world consisted of ten spheres of radius 0.01 m. The spheres used the standard frictional surface implementation provided by the ReachIn API.

The gravity well type attractive force was based on the ForceModel3DOF in the ReachinAPI, and the force returned was $-0.1\hat{e}_r/r^2$ N ($\hat{e}_r$ radial direction outwards from the target). To avoid excessive vibrations at the object surface, the force was set to zero 0.004 m above the surface of a sphere.

The cross like search tool (Figure 4.6.2) was implemented as two planes. Each plane would stop half-way into the spheres and generate a spring type force $-500\delta r$ N along the normal of the plane. The reason for stopping some distance in was that this allowed the user to feel part of the object through the plane. The intended usage was that a user would locate the object with both planes generating an intersection between the planes which could then be followed towards the object.

4.6.3 Pilot Test 2

To look a little more in detail both on the spatial experience and task dependence we designed a second test based on a more spatial task, a memory game. The tool designs were improved using the feedback from the previous test. In this test the users should find pairs of similar objects (similarity indicated by sound) with the help of different types of navigational tools. A recall task was also included where the users were asked to point out which spheres belonged to which sounds.

Implementation

The memory game consisted of ten invisible but touchable spheres randomly distributed in the workspace (see Figure 4.6.3). Each sphere was assigned a sound (five sounds all in all) and the task was to find pairs – that is to press two spheres with the same sound directly after each other. The sounds used were animal sounds (frog, horse, coyote, cock and hawk). The sounds were chosen to be easy to discriminate from one another, to avoid the pitch perception problems that occurred in the previous test.

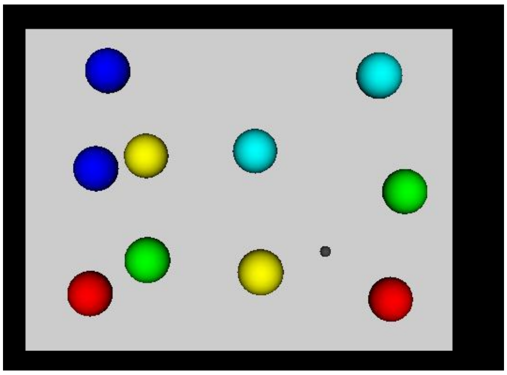


Figure 4.6.3: The layout of the memory game with the spheres shown visually. The same colour indicates the same sound.

Since the previous test had indicated that tool designs involving haptics may influence the spatial experience, we now divided the tool designs into sound based designs and designs based on haptic feedback. The four sound designs were based on three dimensional sound, combined with an "ears in hand" interaction technique. As before the avatar was always assumed to be facing forwards in the virtual world, just as the user would be sitting in front of the computer. The following four sound based designs were used:

a. Free exploration, with spheres emitting 3D sounds. All sounds were playing at the same time to increase the amount of possible overview. Free exploration had been seen to work in the previous test, and thus it was included also here – although with the addition of allowing all sounds to play simultaneously. The sphere closest to the PHANToM tip would be the current selection.
b. The user could tab through the objects to select which one to go for, and only the sound source of that object would then be playing while the user tried to locate the selected object. This design was the favourite from the previous test.
c. Free exploration, with spheres emitting 3D sounds. Only the sphere closest to the PHANToM stylus would be heard (this sphere was also the current selection). This alternative had been seen to work quite well in the previous test.
d. Each sphere has a cylindrical sound beam extending along the z-axis (depth) of the workspace. The strength of the sound depends on the distance of the object (not constant as in the previous pilot test). When inside a sound beam the object producing the beam was selected. Outside the sound beams all sound sources were silent (no selection). This design reduces the search task from a three dimensional to a two dimensional task.

In all these sound designs the listener position was attached to the tip of the PHANToM stylus ("ears in hand").

The implemented designs based on haptic feedback were activated by pressing a button on the PHANToM stylus. To get a tool that allowed more active exploration on the part of the user, but still provided a clear direction, a linear fixture was added to the list of tools tested. Since the map was unpopular in the previous test, and the same effect could essentially be provided by audio only, we did not include that design in this test series. Thus, the following three haptic designs were tested:

1. Linear fixture. The movement of the tip of the PHANToM stylus was constrained to a line pointing towards the selected object (cf. [10]). Since the users did not like their hand being forced in the

previous test, the linear fixture was introduced to provide a directional force based tool which still required the users to move actively themselves.

2. A radial force that attracted the tip of the PHANToM stylus to the object. The force was constant over distance to pull the hand of the user more gently than in the previous pilot test.
3. A search tool made of crossing planes enabling the user to search for the object in one dimension at a time. The implementation was the same as in the previous pilot test (Figure 4.6.2).

Technical detail

For the haptics, The PHANToM Omni together with ReachIn API was used. For the sound feedback Zalman ZM-RS6F 5.1 Surround Headphones together with Direct3DSound was used. To make it possible to have all sounds playing simultaneously (as in design a above) we had to play around quite a bit with the sound parameters. The following set was the one finally used:

- Scaling factor (from haptic size to audio size): 1000
- Rolloff: The maximum value allowed by Direct3DSound (10.0)
- Minimum distance: 0.01 m
- Maximum distance: 1000 m

The haptic world was enclosed by a limiting box of 0.2*0.15*0.06 m. In non-visual environments such a box prevents the user from trying to extend the PHANToM arm outside the workspace allowed by the constraints imposed by the physical design of the device, and also provides useful reference points [2]. A limiting box had not been implemented in the first pilot test (and there was actually no indication of problems due to this), but since the memory game implementation was intended to be tested later also by persons with visual impairments a limiting box was added. To separate the limiting box from the spheres inside it, the surface of the limiting box was made slippery (no friction) while the spheres used the standard frictional surface implementation provided by the ReachIn API. As in the previous test the spheres had a radius of 0.01 m.

For the attractive force, a constant force of $-1.0\hat{e}_r$ N was used, to avoid the hard pulling produced by the gravity well type force used in the previous test.

The linear fixture was implemented as a spring force attracting the PHANToM tip to a line towards the target. No force was applied along the line – i.e the user had to move actively to reach the target. The force used to attach the PHANToM tip to the line was $-200.0\ \rho\ \hat{e}_\rho$ where ρ is the perpendicular distance from the line.

4.6.4 Evaluation - Pilot test 1

Test setup

In this test, the user was instructed to press the space bar on the keyboard to play a reference sound (the sound associated with the target sphere). The first press also activated the time measurement. The task was to find the sphere with the correct sound, and the user was allowed to press the space bar as many times she or she wanted. Sphere locations as well as the sound assigned to the target sphere were randomly generated.

The user was presented with the applications in a sequence. For the applications 1,2 and 4 the user first did one test using only auditory feedback for the navigation and after that a second test also using the attractive force field. For application 3 only one test was done with both audio and search tool available. Finally the user was asked for the favorite tool combination. Due to time constraints only the first user performed each test five times – in the following tests each test was completed three times.

Since some users that tested it appeared to have problems with the button type selection (3) and one user found it almost impossible to use (which in consequence made it impossible for this user to test the search tool) the last test was done with a tab type selection in the later tests. The problems the users encountered were mainly due to the fact that it turned out to be hard to keep pressing the PHANToM button to get the continuous sound feedback needed to locate the objects. And if you let go of the button and then pressed it again you may be closer to another object, and this object would then be selected for the sound feedback, causing confusion.

The time to complete, as well as the stylus movements were logged automatically by the program.

Results

Five sighted adult users tested the above implementations (one woman and four men, ages between 28 and 52). As expected the time to find the targets varied a lot. On the average the use of the attractive force was seen to speed up the process of reaching the goal (this is in agreement with [4] and also with [3] since the user was only attracted to the selected target), but due to the test design and the low number of test persons no definite conclusions could be drawn from the data on this point. A major, and somewhat unexpected problem was the problems with pitch recognition experienced by several users. According to [13] humans are good at distinguishing also small changes in pitch. The bell type sounds used were selected to be in a frequency range below 1kHz where humans have good ability to hear directions [13], and the pitch interval between sounds was at least two whole tones. Since the aim of the test was not to test pitch perception users with problems received help from the test leader on this point.

The major result from this study turned out to be the user preference information. The user preferences are summed up in table 4.6.2 below:

User	Preferences
1	Prefers to select by free exploration (1). Prefers to locate objects with free exploration and 3D audio feedback (a). Comments that this feels like the most natural mode although this user states that the force might be useful in some circumstances.
2	Prefers the “tab” type selection (2). Prefers to locate objects with free exploration and 3D audio feedback (a). Comments that restrictive forces destroy the spatial experience.
3	Prefers the “tab” type selection (2). Prefers to use the attractive force (almost too easy – feels a little like cheating) (b)
4	Prefers the “tab” type selection (2). Says that for gaming 3D sound (a) is best, but for speed the force (b) is probably better. But comments that when you move about freely you get a spatial experience and you learn where the objects are.
5	Prefers the “tab” type selection (2). Prefers to use the attractive force (b) – simple and fast!

Table 4.6.2: User preferences.

As can be seen all users but one preferred the tab type selection (2). For the navigational task the picture is less clear – both a and b are reasonably popular. As can be seen by the comments in Table 4.6.2 (reinforced by comments/observations made during the tests) the presence of constraining or attractive forces seemed exert a negative influence on the spatial experience. To restrict the search space by allowing the user to search in one or two dimensions at a time was seen not to be particularly appreciated – instead the users preferred either to explore the full three dimensions with the help of sound or to be dragged to the target directly.

The gravity well type of force ($\sim 1/r^2$) turned out to be problematic since it jerked the hand of the users too hard. This caused the user to loose track of his/her position is space, and was seen to influence the spatial experience negatively. In the implementation of (1) the users had as an option to allow all spheres to play their sounds simultaneously, but none of the test persons preferred to use this.

The “ears in hand” interaction technique (a) used was shown to be fruitful (as was the discrete version used in [9] where the user had to click the button on the PHANToM stylus to move the ears), but it was not clear how size was perceived. In the present application the sound is scaled with a factor 10 to get more distinct stereo, but all users perceived the sound as emanating from the spheres at the correct locations. This may be due to the fact that even though there is a scaling the sound will still be loudest close to the sounding object. It must be pointed out that we did not allow for any turning of the ears – it remains to study how an environment that allows for this is perceived. The sound beam implementation (d) showed the importance of 3D sound. Without the distance information users had no idea of how close they were the object, or if they were approaching it or going away.

4.6.5 Evaluation - Pilot test 2

Test users

Ten sighted adults performed the test. Their ages and gender is summarised in the table 4.6.3 below.

ID	Age	Gender (F/M)
1	37	F
2	40	M
3	41	F
4	38	F
5	36	M
6	31	M
7	21	M
8	54	M
9	44	M
10	72	M

Table 4.6.3: The test users.

Test setup

The test was divided into three sections. First the user had to play the memory game with four different sound designs, comment on them and select a sound favourite. After that, using the favourite sound design, the user tested three different force feedback based search tools, commented on them and selected a search tool favourite. Finally the user played a fixed memory game (same object positions) using the favourite sound design three times and after that a second fixed memory game (different from the first) using the favourite sound design and haptic search tool three times. This final test included a recall task where the user after having played the game three times was shown the objects visually (and haptically) and asked to identify them.

Results

Ten users performed this test. As always, user preferences turned out to be quite varied. The preferences for the first part of the test are summarised in table 4.6.4 below.

ID	Preference for audio	Preference for haptics
1	c) closest playing	1 or 3 – decides on 3) search planes
2	a) all sounds playing	2) attractive force
3	c) closest playing	1) linear fixture
4	a) all sounds playing	1 or 2 – decides on 2) attractive force

5	c) closest playing	1) linear fixture
6	d) sound beams	2) attractive force
7	c) closest playing	2) attractive force
8	c) closest playing	2) attractive force
9	d) sound beams	2) attractive force
10	a) all sounds playing	3) search planes

Table 4.6.4: User design preferences

In contrast with the previous pilot test, nobody preferred the sound design b) tab + one sound at a time. The attractive force design in this test was the most popular haptic design. The constant force used in this test did not force the user so hard, and none of the users above commented negatively on that. Some users now even thought the force could have been a bit stronger. One user also pointed out that since the force was quite weak, you needed to use a light and relaxed grip on the stylus, which tended to be hard since you had to keep pressing the button on the PHANToM stylus to get the attractive force feedback. A common comment for the linear fixture and the search planes was that it was hard to feel the difference between the tool feedback and the forces generated by actually touching a sphere.

Nine out of ten users were faster when using a haptically based tool in addition to the favourite sound tool design (see table 4.6.5). To check that this was not due to the memory designs used in the two tests we did a follow up test where one person tried both setups five times each. For this test only the sound tool was used. The average time to complete the variant used for the sound tool test turned out to be 90% of the time to complete the variant used in the sound and haptic tool test. This indicates that, if anything, the memory design difference should produce the opposite type of results (faster results without the haptic tool).

ID	Time 1.1 (s)	Time 1.2 (s)	Time 1.3 (s)	Average 1	Nr of recall	Time 2.1 (s)	Time 2.2 (s)	Time 2.3 (s)	Average 2	Nr of recall	Av(2) /Av(1)
1	94	138	253	162	1	161	71	106	113	0	0.7
2	332	315	165	271	3	198	73	178	150	5	0.6
3	320	191	303	271	5	109	146	119	125	2	0.5
4	215	123	132	157	5	211	165	119	165	5	1.0
5	256	162	288	235	3	66	88	101	85	0	0.4
6	255	355	228	279	5	252	224	85	187	5	0.7
7	186	213	77	159	4	67	75	72	71	4	0.4
8	540	202	201	314	3	137	124	65	109	1	0.4
9	178	127	116	140	1	213	53	93	120	5	0.8
10	344	412	211	322	0	357	219	195	257	0	0.8

Table 4.6.5: Summarised results of the learning/recall task.

The result for the recall task was not conclusive (see table 4.6.5), and the question of if and how haptic tool designs influence spatial recall needs to be further investigated. Still, several users commented on the fact that recall was somehow harder for the second task and one user made the interesting comment that with only the audio he got “images in his mind”, which was not the case for the combined condition. Another user commented that he used a different strategy with the haptic search tool compared to using only sound. With the haptic tool (in his case the attractive force) he just let the force drag him to the target and did not bother to remember positions

The “ears in hand” interaction technique was found to be easy and intuitive for all the users in this test. This interaction technique was also later informally tested by five visually impaired children. Four of these children used the “ears in hand” technique intuitively without much prior explanation.

4.6.6 Pilot test conclusion

With the above tool designs, the presence of a haptic search tool shortened task completion times. Two different types of attractive forces were tested, and it turned out that the users preferred a constant force (which the user could resist) to a gravity well type force (which forced the hand of the user). It is important to note that the used combination of audio and haptic feedback makes it possible for the users to use tools like an attractive force or a fixture more effectively. Instead of having distracting forces coming from all objects [3], forces are now only activated for one object at a time (on the basis on the sound information). These pilot tests furthermore point to a possible conflict between speed/tool use and remembrance/spatial understanding. Although this needs to be investigated further, these preliminary results imply that care needs to be taken in the design of navigational tools if spatial understanding is important in the environment at hand. The usefulness of different tools is not task independent – in the first test “tabbing through objects” was well liked (in this test the task was to find one specific object), while in the second nobody liked this interaction technique (here the task was to play a spatial memory game).

The “ears in hand” interaction technique that has been used is shown to be fruitful, but it is not yet clear how size is perceived. We have not allowed for any turning of the ears – it remains to study how an environment that allows for this is perceived.

Finally it must be pointed out that the “ears in hand” technique is intimately tied to the active exploratory actions performed with the hand. To get this input passively does not produce the same type of spatial experience (this was shown very clearly at a seminar where a screen dump video was played).

4.6.7 Navigational test

To further test the tools most popular in the pilot tests, as well as investigate possible influences on the spatial perception by different navigational tools a more extensive test was performed during the autumn of 2005. In this test audio feedback (using the ears in hand metaphor) together with haptic feedback in the shape of either a constant attractive force or a linear fixture was investigated. To test possible effects on spatial memory a task of locating three targets and then reproducing their positions was chosen.

Implementation

The targets to be located were small boxes. The size of the side of the cubic box was set to 5 mm to make it practically impossible to find objects by chance. Two different types of objects were included in the environment and to find out the identity of an object, the user had to press the PHANToM stylus against the side of the cube. This press/click type action generated the playing of either a frog sound or a ping sound. The navigational tools were designed in such a way that they always pointed to the object closest in space. Three different navigational tools were implemented:

- 3D audio using the ears in hand metaphor. In contrast with the previous tests this audio feedback did not contain any information about the nature of the object. The sound used for navigational feedback was a short musical loop. The fact that a looped sound was used enabled users to hear borders between areas close to different objects since the loop would restart each time the object the sound led to changed.
- Linear fixture. This tool was designed essentially the same way as in Pilot Test 2, except that it used a stronger force attracting the user to the line ($-400\ \rho\ \hat{e}_\rho$ vs $-200\ \rho\ \hat{e}_\rho$) and that it was toggled on/off by a keyboard press.
- Constant radial force. This force was weaker than in the previous test ($-0.5\ \hat{e}_r$ N vs $-1.0\ \hat{e}_r$ N) to allow the user to easily resist the pull. This way it was easy to move about within the environment without being disturbed by the force. When guidance was wanted the user just relaxed his or her grip on the PHANToM stylus and was then moved towards the target object by the attractive force. Also this force was toggled on/off by pressing a key on the keyboard.

These tools were all tested separately, but the two haptic tools were also tested in combination with audio feedback.

During the first part of the test the task was to find all three objects in the environment and to count the number of “frogs”. No visual feedback was available; i.e the objects were invisible and the PHANToM pointer was not shown graphically on the screen. Figure 4.6.4 shows a visual representation of this environment.

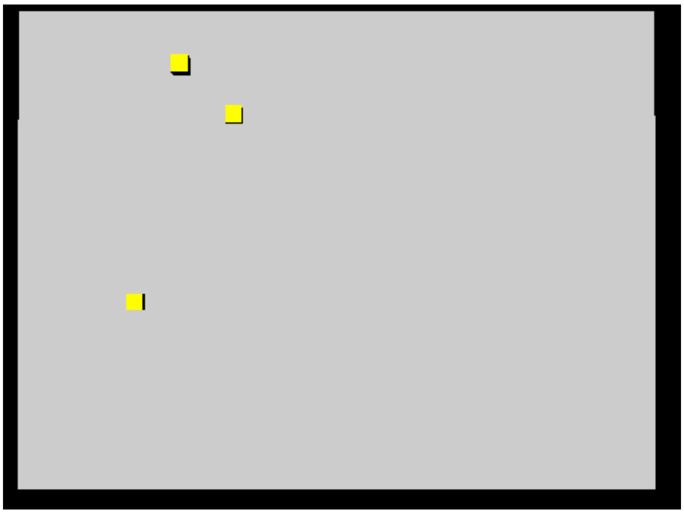


Figure 4.6.4. A visual representation of the test environment. To identify an object as a “frog“ or a “ping” the user had to move the PHANToM pointer to the object and press it. This pressing action generated the playing of the sound file identifying the object.

When the user felt confident that all objects had been found, he or she told the test leader that this was the case, and the test person then entered the second part of the test. In this section of the test the user was instructed to put the PHANToM pointer at the remembered position of each object and click the button on the PHANToM stylus. This would place an object at this position. The type of object could be changed by pressing a key on the keyboard. This enabled the user to build a model of the test environment encountered in the first part of the test.

Finally, when the user was satisfied with object positions and types, the result was shown visually on the screen as is shown in Figure 4.6.5.

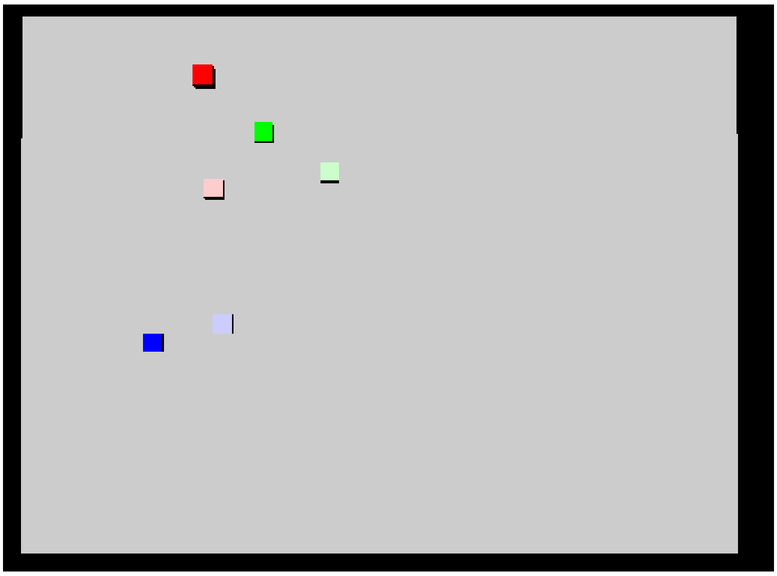


Figure 4.6.5. The visually displayed test result. The intensely coloured boxes are the originals, while the positions assigned by the user is shown in a paler shade. The computer assigned the object pairing by minimizing the total difference in distance between test object positions and assigned object positions.

Technical detail

For the haptics, The PHANToM premium together with ReachIn API was used. For the sound feedback Zalman ZM-RS6F 5.1 Surround Headphones together with Direct3DSound was used. The following set of sound parameters was used:

- Scaling factor (from haptic size to audio size): 100
- Rolloff: 1.0
- Minimum distance: scaling factor *0.0025 m
- Maximum distance: scaling factor *200.0 m

The haptic world was enclosed by a limiting box of 0.2*0.15*0.08 m. The cubic boxes had a side of 0.005 m. For the attractive force, a constant force of $-0.5\hat{e}_r$ N was used, to make the force easy to resist. The linear fixture was implemented as a spring force attracting the PHANToM tip to a line towards the target. No force was applied along the line – i.e the user had to move actively to reach the target. The force used to attach the PHANToM tip to the line was $-400.0\ \rho\ \hat{e}_\rho$ where ρ is the perpendicular distance from the line.

Test users

Eleven sighted persons and one visually impaired person performed the test. Their ages and gender is summarised in the table 4.6.6 below.

ID	**Age**	**Gender (F/M)**	**PHANToM experience**
1	37	F	Expert
2	44	M	A bit (more than a few times)

3	58	M	Never used
4	25	F	Never used
5	51	M	Few times
6	53	M	Few times
7	49	F	Few times
8	30	F	Never used
9	43	F	Expert
10	40	M	Expert
11	29	M	Few times
12	35	M	Never used

Table 4.6.6: The test users.

Test setup

This test consisted of two phases. In phase one the user was asked to locate and identify the three objects found in the environment. In phase two the user was asked to build a copy of the environment encountered in phase one. Each test person did this test task three times for each navigational tool combination (audio only, fixture only, force only, fixture + audio and force + audio). To avoid learning effects the order of the test tasks was varied. The users received no visual feedback from the environment (neither from objects nor PHANToM pointer) except after the test when they were allowed to see how well they had managed to reproduce the initial, phase one, environment. After the test each user was asked about preferences, and was encouraged to comment on the experience and the different navigational tools.

The test program logged PHANToM position, object positions, object types as well as toggle actions (fixture and force tool), object presses, elapsed time and the time at which different events occurred.

Results

As for the user preferences these are summarized in table 4.6.7. The attractive force was a clear winner, while it was unclear whether the 3D sound helped.

User nr	Preferred navigational tool	Comments
1	Force only	The strength of the force is just right. The audio feedback is confused with the sound tags of the objects (harder to remember them)
2	Force (with or without sound)	Possibly without sound better, since the sound may be disturbing
3	Fixture with sound	The line is more fun – you get to do something by yourself (the force is automatic)
4	Force only	The sound is not necessary
5	Fixture with sound	Easiest
6	Force with sound	Better to use two senses
7	Force with sound	Easiest
8	Force with sound	Much faster. The sound helped you to feel sure.

9	Force (with or without sound)	The fixture with sound somehow helped with the relative positions, but in a complex environment I believe the force will be better.
10	Force only	Force more intuitive. But the fixtures were good too once you learned to use them. The force works just as well without sound
11	Force only	The sound is distracting (harder to remember the object sounds).
12	Force with sound	But this depends on the application – I often neglected the sound.

Table 4.6.7: Preferred navigational tool

As regards to the time to complete the attractive force also did well. A summary of the results for the different navigational tools is given in table 4.6.8.

Navigational tool	Average time to complete (s)	Standard deviation	Fully correct answers	Correct nr of frogs	Average distance (m)	Standard deviation (distance)
Sound	388	206	22	26	0,044	0,031
Fixture	133	87	24	26	0,046	0,032
Force	104	97	31	34	0,038	0,027
Fixture with sound	107	118	23	28	0,041	0,026
Force with sound	83	68	30	32	0,040	0,026

Table 4.6.8: Results for different navigational tools.

Further statistical analysis (paired, two-tailed t-test) showed neither any significant effects on the distance (distance between assigned positions and the actual positions) nor on the average number of assignment errors (assigning the objects as frogs or non-frogs). There is a weak tendency ($p<0.1$) for the positions to be more accurate (smaller distance) when the force (without sound) is used compared to when the fixture (without sound) is used, but for the object assignments nothing could be stated even as such a weak tendency. The only really significant effects were seen in the speed to locate the targets, where the sound only tool was significantly ($p<0.01$) slower than all other tools. There was also a tendency ($p<0.05$) for force with sound to be faster than the fixture (without sound). There was furthermore a weak tendency ($p<0.1$) for also the force (without sound) to be faster than the fixture (without sound).

If we look at the average number of object presses per second we get the pattern seen in table 4.6.9.

Tool	Fixture	Sound	Force	Fixture with sound	Force with sound
Average	0,1782	0,0327	0,1822	0,1608	0,2058
Standard deviation	0,0963	0,0291	0,1017	0,0737	0,1117

Table 4.6.9: Number of object presses/second for different navigational tools.

The number of object presses/second for the sound only tool was significantly lower ($p<0.01$) than for all other tools or tool combinations. There is a tendency ($p<0.05$) that force with sound generated more object presses than fixture with sound, but no other tendencies (not even weak ones) were seen.

If we turn to the user comments these can be found in table 4.6.10. The comments are grouped after subject, and each row in the table is a different user.

Comments
The sound is somewhat confusing – one tends to confuse it with the object identification sounds. The navigational sound actually makes you somehow forget the object sounds.
The navigational sound somehow made it harder to remember the object identification sounds.
The 3D property of the sound is not so good – it is more like stereo + feedback from your moves (the volume/stereo changes as you move).
The 3D sound had good stereo, but up/down and back/front is hard. The sound also make the object identification sounds harder to remember.
It is harder to remember the object identities (frog or ping) than to remember the positions.
I would like object specific navigational sounds.
That the sound loop restarts every time you cross the border to an area close to a new object is really good clue.
The borders where the sound loop restarts are really important! They tell you that you are approaching a new object.
I tried to listen for the restart of the sound loop – this tells you it is a new object. Had to visit the objects several times to know where they were. Thought hearing was more demanding – the object positions were somehow easier to remember.
The sound makes you aware of the room – this could be used for theoretical training of spatial ability (visually impaired user)
With the sound you really notice the space of the room – I did not notice it that much before. It is really first now that I understand how to move my hand.
The sound gets better if you close your eyes.

Table 4.6.10: User comments

Discussion

The results of this test confirms the usefulness of the constant, weak, radial attractive force (on its own or with 3D audio). For the fixture, which also was seen to be useful, the sound was more important since it provided directional feedback. As for the spatial memory there is really no significant difference between the tools. In previous tests we had seen a tendency to remember the environment better if you spent longer time in it, but here it seemed as if spending a long time in the environment did not help. What did make a difference was the number of times you could "check back" or rehearse the object positions, something which was much easier with the attractive force than if you relied on the audio feedback only. Still, the user comments indicate that the 3D sound (ears in hand) enhances the spatial understanding – it seems as if this sound feedback may heighten the sense of immersion (we cannot say anything definite on this point though, since immersion was not tested for). A factor that may influence the result was that in this test we used the same navigational sound for all objects. We chose this design because we wanted to force the users to actually locate the targets, but one of the advantages of sound is of course that it can be heard from a distance. This test also points to the fact that navigational feedback may interfere with the actual task although this most likely depends on design as well as modality.

An accidental artefact in the design was the restarting of the audio loop at the borders between spaces close to different objects. This artefact turned out to be really useful, and implies that in the case when the same navigational sound is used this type of borders should be possible to hear.

4.6.8 Conclusion

A weak constant attractive force has been showed to be useful. This force should be weak enough to allow the user to resist it, while at the same time being strong enough to attract the user to the target once the grip is released. The results from this test highlight the importance of being able to "check back" – to be able to easily go back to objects in the environment to check their properties and positions. 3D sound feedback with the ears of the listener attached to the PHANToM position ("ears in hand") is a type of feedback which may help users to get an understanding of a spatial environment and which possibly also increases the sense of immersion within the environment (this, however was not tested). This type of audio is also a tool for navigation, but in this kind of environment (with few, small objects) it is less effective. User comments (as well as results from the pilot tests) show that if possible it is useful if the sound feedback allows object identification from a distance. The borders between different object spaces provide important information, and it is useful if f.ex the sound feedback gives this type of information. In the case of sound identification from a distance this is provided automatically, since the sound will change as the object changes, but in the case of a general navigation sound this is something that needs to be considered. Depending on the type of environment and the type of task the use of fixtures is another possibility to guide the user towards a target – this type of interaction may also illustrate a path. To do this with an attractive force a sequence of targets has to be used, but path following has not been tested within this series of tests.

4.7 ULUND - Virtual haptic-audio line drawing

4.7.1 Introduction

The application described in detail below is a virtual haptic-audio drawing application for low vision and non-vision users with an import function to get access to ready-made graphics. It is and will be developed in close collaboration with a user reference group of 5 blind/low vision school children. The objective of the prototype application is twofold. During the early development stages, it will be used as a research vehicle to investigate user interaction techniques and do basic research on navigation strategies and helping tools. Later, the prototype will be tailor-made for use in schoolwork and the final application should be possible to use in different school subjects.

Getting access to 2D graphics is still a large problem for users that are severely visually impaired. There are many issues to address, e.g. how to provide an overview, to what extent users are able to interpret a combination of lines or line segments into a complex image, how to design the lines to get appropriate haptic feedback, what hardware to use etc. Moreover, to create graphics, a severely visually impaired user must get appropriate tools. The development of virtual haptic devices and the research on auditory displays has made it possible to create such a tool, but many problems remain to be solved.

The investigations based on this prototype address the questions in the WP 2 task 2.2.1, about basic navigation and interaction.

Throughout this report the concepts "virtual haptics" and "haptics" will refer to force-feedback haptics.

4.7.2 Some relevant literature

Phantom-based haptic line graphics for blind persons

Calle Sjöström, Henrik Danielsson, Charlotte Magnusson, Kirsten Rassmus-Gröhn

Visual Impairment Research pp 13-32 Vol 5. No 1. 2003

Non-Visual Haptic Interaction Design - Guidelines and Applications

Calle Sjöström

PhD Thesis, ISBN 91-628-5412-7, Certec, LTH, Sweden

http://www.certec.lth.se/doc/hapticinteraction/

Haptic drawing program

Christin Hansson

Masters Thesis 2003

http://www.certec.lth.se/doc/hapticdrawingprogram/ (abstract)

In short, the suggested improvements for further development of a line-drawing application in this thesis are:

- Use sound for feedback on e.g. color
- Bigger drawing area
- Pre-defined shapes (circle, rectangle etc)
- Separated control panels for different functions
- Horizontal drawing area rather than tilted
- Better textures
- Smoother lines
- Better line update

Drawing & the Blind – Pictures to Touch

John M. Kennedy

Yale University Press, 1993

Art Beyond Sight

E.S Axel, N.S Levent

AFB Press, 2003

A Resource Guide to Art, Creativity and Visual Impairment.

The Integrated Communication 2 Draw (IC2D)

Hesham M. Kamel

Ph.D. dissertation, Electrical Engineering and Computer Sciences Department, University of California, Berkeley, CA., May 2003.

http://guir.berkeley.edu/projects/ic2d/pubs/hmk-dissertation.pdf

The dissertation describes the design, implementation, and evaluation of a dynamic drawing and animation tool for the blind, called the Integrated Communication 2 Draw (IC2D) that uses a combination of a simple grid-based navigational interface, keyboard input and auditory feedback in a 2D graphics environment.

4.7.3 Prototypes specification

Interface and equipment

This prototype is an application for making black & white drawings and tries to incorporate improvements suggested by the work in previous masters work (see above). The application consists of a room with a virtual paper sheet, which a user can draw a relief on. When the PHANToM pen is in touch with the virtual paper the user can draw on it while pressing the PHANToM switch. The haptic image is produced as positive or negative relief depending on which alternative is selected. The relief height (depth) is 4 mm. The drawing can be seen on the screen as a grayscale image – a positive relief is seen as black, and a negative relief is seen as white. The paper color is grey.

When the user draws, the haptically touchable relief is updated every time the user releases the switch on the pen. It is (so far) a problem to let the user feel the exact line that is drawn, since this causes instability in the PHANToM, but this way the user can still feel most of the drawing while adding new parts to the image.

A png import function has been developed. The files imported must be grayscale and a multiple of 256*256 pixels. A complete grayscale is actually translated into different relief heights, which makes it possible to import any grayscale image and get some haptic information from it. Images not adapted to haptic/tactile reading for blind users are very hard to understand, however, the grayscale can be used e.g. to smooth out relief lines.

The Reachin 4 beta software is used to control the haptic device, which is either a PHANToM OMNI or a PHANToM Premium. The sound control is based on the FMod API.

Basic navigation and interaction issues

- Optimization of the work area with respect to:
    - Ergonomics
    - Sound feedback mapping
    - Virtual paper size and shape
    - Size of limiting box
- Design of relief
    - Depth
    - Positive versus negative
    - Smoothness
- Placement of user input interaction controls
    - Virtual buttons
    - Keyboard buttons
    - Other input
- Design of position and mode feedback sound

4.7.4 User interactions – 3 gradually developed prototype versions

Prototype application – version 0.1 (haptic only)

In the first version of the application the virtual environment consisted of a sheet of virtual paper that was oriented in the x-z-plane (horizontal). The virtual paper was furthermore placed about 1 cm above the real tabletop of the desk that the PHANToM was placed on. This was a safety precaution to prevent a user from perhaps breaking the hardware if too much force was used to draw.

Draw mode

With the version 0.1 a user could, with the PHANToM pen, produce lines with negative or positive relief. The user used the PHANToM pen as a normal pen, pressed the switch on the pen, and when in contact with the paper this produced the relief chosen. The relief setting could be changed by the test leader.

Feel mode

By not pressing the PHANToM switch, the user could use the PHANToM pen to experience a drawing.

Prototype application – version 0.2 (haptic only)

The application was almost the same as the above described, with one change. In the virtual environment there was added a virtual button to change drawing modes. The user could change between positive and negative relief either by pressing this button or by pressing a real button on the keyboard (space bar). The virtual button was placed along the left side of the drawing, and toggled its color to display the relief type.

Prototype application – version 0.3 (haptic-audio)

The application underwent some greater changes that affected navigation and control. The goal has been to make practical use of both haptics and sound, and this prototype makes use of both, although the flexibility of the drawing program still is limited. Sound information has also been a high-priority wish from the reference group. So far, the sound adds information to the user about:

- Application mode (drawing, feeling or "flying")
- PHANToM pen position (vertical)
- Contact with limiting box

For the positioning, a pitch and pan analogy is planned. So far, the pitch is implemented, not the panning. When the cursor moves in the virtual room, the pitch of a position tone is changed, brighter upwards, and mellower downwards. The mode information is conveyed by the volume and timbre of the tone. In free space, a pure sine wave is used. When the user is in contact with the virtual drawing paper (not pressing the PHANToM switch) the volume is louder. And when the user is drawing (and thus pressing the PHANToM switch) the tone is changed to a saw-tooth wave.

To make the pitch analogy intuitive, the virtual paper had to be flipped to a vertical position, and the virtual paper was furthermore inscribed in a limiting box. The walls of the limiting box produce contact sounds when touched. Another reason for flipping the virtual paper was that the paper size inscribed in a limiting box was possible to be made larger in the vertical position.

Also, based on the results from the previous user trials, the virtual button for mode shifts was omitted.

Screenshots

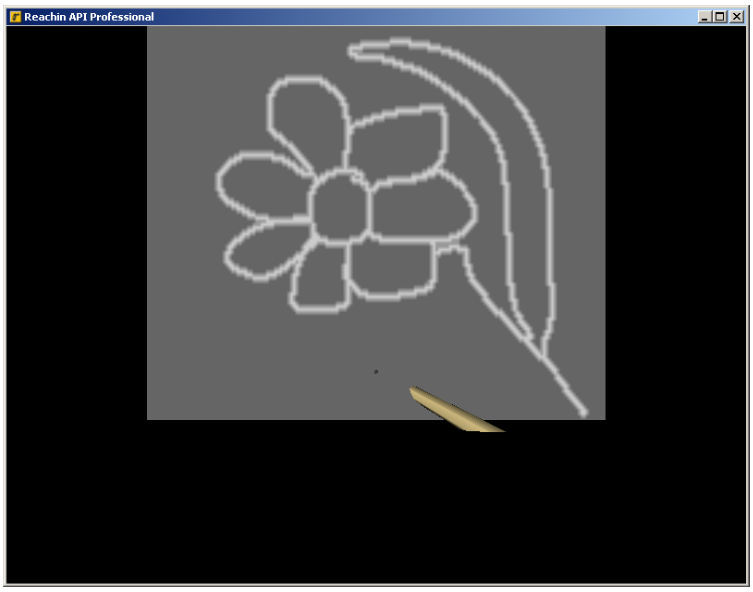


Figure 4.7.1: Screenshot of application prototype version 0.3 with drawing in negative relief.

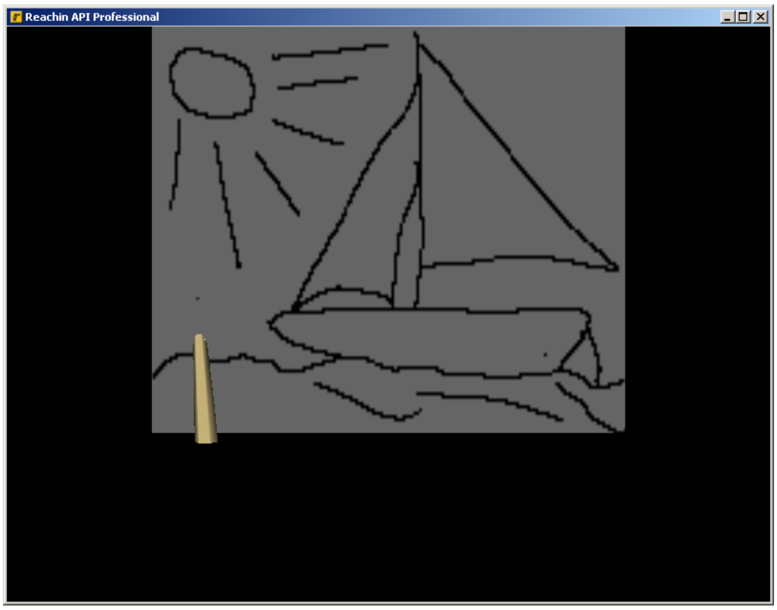


Figure 4.7.2: Screenshot of application prototype version 0.3 with drawing in positive relief.

4.7.5 Evaluations

Experiment overview and methodology

The gradually emerging application prototypes have been tested in informal tests during summer and fall 2005 with a reference group that participate in MICOLE work. Design work has been iterative and the users have been presented with new features and changes in the prototype at every meeting. All three evaluations have been qualitative. The first two evaluations were of an informal nature, with few and loosely formulated test tasks. Instead an open discussion took place in which children and their parents or other close relations and the researchers discussed topics triggered by the prototypes tested. The third evaluation also incorporated some formal test tasks.

Participants – research persons

The Lund User Board (LUB) of the MICOLE project has tested all prototype versions, although not all participants of the LUB have tested all versions. The LUB consists of five (5) children, aged 10 to 16. Two (2) of the participants are blind from birth, and three (3) participants have various forms of low vision. All of them read Braille and are integrated in normal schools in southern Sweden.

Hypotheses, evaluations and discussions

Since the application has been gradually developed, hypotheses have changed during the work, and evaluation has been made for each prototype version.

4.7.6 Evaluation - Version 0.1 – drawing and feeling positive and negative relief

For this test the application served as a discussion vehicle, about preference for positive versus negative relief and the overall feasibility of a haptic drawing tool. The PHANToM OMNI was used for the test, and the screen faced the user, making it possible for some of the users to use their residual vision to solve tasks.

Hypotheses:

- The users will be able to draw lines
- The users will be able to feel a drawn lines
- There will be a consensus on the preferred relief type

Evaluation

Five (5) children from the LUB tested this application informally. The users were asked to draw lines and to feel them, in two modes of the prototype – with negative relief and positive relief. All users seemed to enjoy the program, and found it easy both to draw and feel the lines. Four users preferred the negative relief (white) while one stated that positive relief (black) was easier to feel. The users with some residual vision focused quite much on the visual representation, despite being encouraged to rely more on the haptic representation. The users focusing on the visual representation seemed to take longer to complete tasks than blind users.

Discussion

Since the users could feel the lines the relief depth seems appropriate.

The heavy overweight of preference for the negative relief may depend on the type of drawing produced in the tests. A user commented: “Both types of relief should be available”, although the user did not state why this was to prefer. Also, the overweight for the negative relief may actually depend on screen contrast; negative relief produces white lines on gray background, whereas positive relief produces black lines on gray background. Nevertheless, it seems like an interesting flexibility to keep the possibility to change line relief.

Concerning the result about the focus on visual information (for users with low vision), the application should make it possible to optimize colors on the screen to enable users to make the most out of their residual vision if they prefer to use it.

4.7.7 Evaluation - Version 0.2 – changing relief mode

For this test the application served as a discussion vehicle about preference for virtual buttons as opposed to keyboard buttons and the overall feasibility of a haptic drawing tool. The PHANToM Premium was used for the test.

Hypotheses:

- The users will prefer keyboard buttons over virtual ones to switch between relief types
- The users will be able to draw and feel lines with the application

Evaluation

Four (4) children from the LUB tested this application informally. All of them were familiar with the application, but not all were familiar with the specific device (PHANToM Premium). The users were asked to draw lines, to feel them and to change the relief type with either the virtual button or the keyboard button.

The change of devices caused trouble in two ways. The Premium pen is narrow and does not have an "ergonomic grip" making it more obvious how to hold it (as opposed to the OMNI). Since visually impaired children don't use a pen grip very often, this caused some of the children to hold the pen very awkwardly, and it was not easy to correct their grip. Second, the smaller switch was unintuitive and sometimes got stuck in a pressed position if the user rotated the pen a certain way. This all seemed to make the difference between children with good versus poor fine motor skills even larger than in the previous test with the OMNI.

The evaluation question about the preferred way to use buttons – virtual or keyboard – did not get an immediate solution, instead it led to a discussion. Most of the test users did manage to solve the tasks, although the virtual button was seen to be impossible to use for the blind users. The virtual button in the prototype tested was placed in such a way that users accidentally touched it while drawing. Users with residual vision were helped by the visual representation on this point.

Furthermore, users asked for a way to change the relief on the drawing afterwards also. The mode shift that was implemented enabled the user to change mode on the pen rather than changing the relief on the drawing.

During the discussion afterwards, suggestions for using a drawing tool to learn and enhance drawing were brought forward. There were both pedagogical and encouraging reasons for this according to parents. One example could be a geometry learning drawing tool for schoolwork; another example could be a drawing program that helped the pupils to produce nice-looking drawings in art class.

Discussion

The trouble with the device usability was quite larger than anticipated. However, there is still reason to believe that the other results are valid since these discussion results did not really depend on the device as such.

The question about preference for virtual or keyboard buttons led to a discussion about the cognitive work load that blind or visually impaired children must face, in that they need to remember lots of shortcuts on the keyboard already. In that aspect it may be preferred to use virtual buttons or the like, provided that information about the function of the button is possible to receive upon request. However, this also brought up the question about how a user can be able to push virtual buttons, and in the same time be able to travel back to the exact spot where they left the drawing before.

It is not really clear what the users were asking for when users also wished to change the relief on a line after drawing it, but considering the flexibility of some visual drawing programs it might even be interesting to examine how one could change the relief of lines, segments, objects (depending on the complexity of the representation) whenever they choose.

4.7.8 Evaluation - Version 0.3 – sound enhanced navigation

Sound was added and the work area was flipped (from horizontal to vertical). The test was a small pilot study with a few formal tasks. The PHANToM Premium was used for the test, and the screen was faced away from the user (i.e. with only haptic and audio feedback).

Hypotheses:

- The users will be able to handle the vertical work area
- The users will understand and make use of the sound feedback
- The users will be able to use the application to draw a simple specified shape
- The users will be able to use the application to correctly identify simple shapes and Arabic numbers.

Evaluation

Three (3) children from the LUB have so far made a pilot test on this prototype. Two of the users are visually impaired and one is blind. After a verbal introduction to the new features of the application, the users were asked to explore the different mode sounds when drawing and feeling the image, and when exploring the free space in front of the haptic paper. The users were also asked about their ability to recognize printed Arabic numbers. Then, the users were asked to draw a shape (a rectangle) and an Arabic number (one they were free to choose themselves). The following test was to feel ready-made graphics – 2 Arabic numbers, and two simple 2D geometric shapes. All graphics were put in a 512*512 pixel file and with negative relief (groove). The Arabic numbers were based on the font *Letter Gothic Standard* and between 3 and 6 cm high. The reason for choosing the font was that it is a slim font where the narrow line thickness produces a good relief. The shapes were a triangle, a circle and a square, with the whole shape in negative relief (not only the boundary of the shape). To make the relief edge smoother, Gaussian noise with a 1-pixel radius was added to the numbers – see also the pictures below.

Figure 4.7.3: Sample test material; Arabic number and simple shape in negative relief (with 8 mm depth).

The three test users were able to use the application as intended, and the different task results for the users seem to match personal differences in fine motor skills and the ability to remember images. See table 4.7.1 below.

	User 1	User 2	User 3
Visual impairment	Blind	Partially sighted (low vision)	Partially sighted (low vision)
PHANToM user rating	Expert – has used PHANToM many times.	Has used the PHANToM 3 * 10 minutes	Has used the PHANToM 3 * 10 minutes
Estimated fine motor skill*	Medium	Very good	Poor
User's own estimation of shape knowledge of printed Arabic numbers	Poor	Good	Good

Draws square	Yes Is very accurate and manages to connect the end line segment to the starting point.	Yes Uses the wall to get a straight reference line to begin with.	Not really
Draws number	“2” – poor	“3” - good	--
Recognizes numbers	“7” and “5” Not really Has problems recognizing and cannot name them properly	“2” and “9” Yes Recognizes “2” fast, spends more time on “9”	“5” and “8” Yes Very fast on “5”, mistakes the “8” for a “3” to start with
Recognizes shapes	Circle / Triangle Yes. Recognizes circle fast, takes somewhat longer with the triangle	Circle / Triangle Yes. Scans the inside area of the shape, takes a while before recognizing.	Square / Triangle Yes. Very fast to recognize both – keeps the investigation to the edges of the shape

Table 4.7.1: Results from pilot test.

* The fine motor skills are just an estimation about the inter-individual rating done by the researchers who are only laymen concerning such estimations.

Some results need a clarification. User 1 who estimated the own knowledge of printed numbers to be quite poor is had greater trouble with those tasks, if we look only on task completion. The number drawing task resulted in a picture that is similar to the left one in Figure 4.7.4. And the recognition task was also seen to be harder for the blind user. The first number - “7” - was incorrectly interpreted as “1”. The second number - “5” – was described as “looking like an ‘S’” when the test leader asked for a description of the shape when the user hadn’t managed to name it in quite a while. User 3 failed in the drawing tasks. This user seems to have some fine motor problems and also looses interest in task very quickly. When asked to draw a square, the user never stopped when the square was completed – see right picture in figure 4. This user was not asked to draw a number.

Figure 4.7.4: Reproduction of the drawing of the number “2” by User 1 (left). Reproduction of the drawing of a square by User 3 (right).

During the test session some qualitative observations were also collected. It seemed that some of the users were helped by the difference in sound character to know which program mode they were in. This helped especially one user who previously had had big problems releasing the switch to feel the painting. The sounds, however artificial, did not disturb the users very much, although one musically trained user seemed not to be very happy with them. That same user also indicated the similarity of the sound with the aiming sound used for target shooting for blind users. Another user expressed great enjoyment with the sound and spent quite much time playing with it.

No problem was found during the test that was related to the vertical work area.

4.7.9 Discussion & Conclusions

The Arabic number recognition task was found to be too hard for User 1. Since this user is blind, there is a big difference between this user and the other two who are partially sighted. The partially sighted users have learned printed numbers (using their magnification techniques) so they are familiar with the shapes in a higher degree than the blind user.

After the test, the relatives (parents and siblings of test persons) gathered in the test room to discuss the test tasks and their relevance. One parent expressed hesitations concerning the use of a drawing application for blind and low vision users. This brought up the possible need for better motivation and description about possible scenarios for the end application. There is a need both for thinking through the goal and putting it on paper and then communicating it to the test persons and their parents.

The vertical work area did not pose any immediate problems, but there are ergonomic issues to consider. It might be stressful for the arm and hand to draw in a vertical position. One way to overcome the problem with a small horizontal work area could be to place the hardware (the PHANToM) in a flipped position. This would, however, perhaps make the pitch analogy unintuitive – but it might be worth to examine.

The pilot investigation did not incorporate any controlled test where the usability of the sound was tested; this will be made in a coming test.

Conclusions

- Both positive and negative relief is possible to feel and to work with.
- Drawing lines with a haptic drawing tool is not too easy, but not too difficult either.
- Both vertical and horizontal virtual paper will work in the short run – but what about ergonomics?
- Simple shapes can be recognized when they are kept in a specific context.
- The sound feedback was used to get information about the program mode.
- Using PHANToM Premium is not a really good idea. The PHANToM OMNI will probably be used in coming tests, or perhaps another approach with a new pen and switch on the PHANToM Premium.
- Using keyboard to control application tools may give users too much memory workload.

Planned prototype changes

- Adding pan to sound.
- Developing a scenario for a school subject.
- Implementing other sound designs.
- Designing tools to help draw simple shapes.
- Implement tool to save and recall positions.
- Zoom and scroll.

Future evaluations

- Controlled test where the usability of the position sound is going to be tested.
- Further qualitative tests in collaboration with the reference group.

4.8 UTA - The Directional-Predictive Sounds in a Game Application

4.8.1 Introduction

World Wide Web and game industry are progressively increasing fields for sound applications. Moreover, the game is universal medium for simulation and testing novel metaphors and techniques with a wide contingent of potential users. The blind people are the strong sound experts and, therefore, audio technologies and games (not the sound tricks) oriented on the blind audience would be favourable for all [19, 21, 22].

After the basic research we carried out the further investigation in behavioural patterns which could support and facilitate the use of the DPS for efficient inspection primarily within the game field, and learning how and when is suitable to apply one or another gesturing in dependence on discovered features of the external objects. We have assumed that sound feedback learning and experience should progress through the game from the concrete level to more abstract (cognitive) level. Gradual improvement on hearing of the feedbacks, coordinated with motor activity through haptics, should finally form the model of personal behavioural strategy for outdoor navigation and environment exploration in the absence of visual cues.

Sonification was not determined only as the modulation of acoustic parameters in accordance to some data value, but the function of information content. Sound signals support navigation of blind people both indoors and outdoors. To provide a natural and intuitive analysis of the sounds we hear, Yoshikazu Seki has developed a special training system for obstacle detection based on sound field perception [16].

Unfortunately, white cane training using mobility tools with respect to the particular audio-haptic techniques for blind navigation and the indirect inspection of the external objects is acquired individually. Simulation of the white cane through ultrasonic, laser and IR navigation devices (locators) still leaves the question open: which parameters should be sonified for the blind person to deliver as much useful information as possible and to decrease the noise and distraction. For instance, should it be the continued sonification of the distance to a target or the discrete sounds which warn about the change of the distance and in dependence on speed of the person motion? Thus, the task-oriented model for the interaction sonification is still a challenge for development.

Due to a narrow haptic (tactile-kinesthetic) perceptual field which is directly involved in interaction through white cane, a blind person could get much more information when a special strategy and the system of feedback cues are employed. Concerning the usage of the locators for blind navigation [1], we think that the feedback cues should be strictly coordinated both with exploratory movements and parameters being sonified.

In the Hidden Graphs application discussed next in the paper we carried out research into simulation and testing suitable behavioural strategies for non-visual interaction and grasping the hidden graphical images. The goal was to optimize the model of the "sonification dialogue" through basic behavioural patterns (BBP) coordinated to capture radius and directional-predictive sound signals (DPS). The player was required to improve the personal model of the behavioural strategy to discover the hidden graph features. The experience acquired within simulated conditions could be applied to train blind children.

4.8.2 Hidden Graphs

The Hidden Graphs game was developed as a multimodal game for the blind and visually impaired people. The goal of the game is a blind inspection of the hidden graphs to capture as many features as possible of the virtual graphical image. The graph does not exist as a drawing and the interaction occurs with the data array. Thus, the player has to explore a "visually empty" game field.

The game has four levels of difficulty, and each level consists of two phases. The first phase allows the preliminary inspection of the game field. The player has to scan a game field by using a stylus-type input device. To support non-visual interaction in each position of the stylus player receives information regarding a single point (pixel) being inspected through sound parameters. The size of the game field is 250 by 250 pixels and hidden object comprises only of about 250 pixels that is, 0.4% of the total number of possible locations. The player has to choose a right behavioural strategy which could allow encoding and integration of the feedback signals and to re-build the mental model of the image based on discrete sound cues and locations which were inspected.

As scanpaths concerning the graph during a non-visual inspection could not be predictable, it is quite difficult to complete the game and evaluate the result based on the data collected in the first phase. Therefore, in the second phase the player has to confirm the detected positions and their sequence suggested. A repetition is also beneficial to fix hidden tracks and optimize kinaesthetic behaviour (gestures).

Employing only three different sounds supports the gameplay. The sound feedbacks do not sonify the parameters of the pixels belonging to the virtual graph, but they are to present the relative distance between a stylus position and the nearest point on the graph. In particular, by changing the distance regarding the graph player manages the sound cues. Thus, the task-oriented sonification model is used to guide the player through grasping the graph. Two major concepts were applied in this model: capture radius and directional-predictive sound signals.

The second goal, which has been pursued, is the study of the basic behavioural patterns used when inspecting the non-visual graphs and learning how and when it is suitable to apply one or another gesturing in dependence on the discovered features and sound feedbacks. Learning and experience should progress through the game from the concrete level to more abstract level. Cognitive integration across hearing and haptics should finally form a personal model of a behavioural audio-kinaesthetic strategy.

As in the basic research, the capture radius (Rc) used during the graph inspection is defined as a range of pixels that the game application considers that the player has reached the target point located on or near the graph curve.

The levels of difficulty affect the player performance and are established in accordance with the different sizes of the capture radius. The levels of the capture radius were 20, 15, 10 and 5 pixels. 20 pixels was the starting level of the game. Directional-predictive sound signals were used in relation to the player gestures with the capture radius. The centre of the capture radius was associated with the nearest point of the graph regarding the stylus location (Figure 3.24).

4.8.3 Directional Predictive Sounds

Directional-predictive sound signals (DPS) used in the game, had the same parameters as described in the subsection 2.2. The model implies that directional-predictive sounds will guide player actions to help in navigation and grasping of hidden graphs. Each of those sounds has their own unique denotation as a capturing cue during the game playing [1], [15]. Player hears the crossing sound (CS) when entering or moving inside the capture radius. Capture radius depends on the game level as discussed in the previous section 4.1.

In the case the player has left the capture radius, s/he will hear the backward sound (BS). Normal procedure at this occasion is that the player moves back towards the location where s/he last heard the crossing sound. During the return towards the graph, the player hears the towards sound (TS). Still, there is no need to activate BS or TS sounds when a stylus location is far from the graph. Therefore, the distance by four times more than Rc was taken as a threshold value after which sound feedback was not supported at all. In other words, when the Rc is equal to 20 pixels the BS and TS are supported within the range of 20-80 pixels.

4.8.4 Basic Behavioural Patterns

Other components of the task-oriented interaction model were the basic behavioural patterns (BBP), which were explored in the game as the possible guideline to facilitate shaping the personal behavioural strategy in discovering the features of the hidden graphs. As it was supposed, BBPs should promote attaining the game goal more effectively to demand less cognitive efforts.

The behavioural strategy of the player could be built up as a combination of the basic behavioural patterns. Through learning and acquiring experience in the coordination of sound and kinaesthetic feedbacks, a personal behavioural strategy would finally be formed. To formalize the testing procedure, three behavioural strategies based on the basic behavioural patterns were proposed for the players. They were as follows:

- In the first behavioural strategy, to discover the graph, the player has to employ spiral and straight-line gestures as the basic behavioural patterns. The player could change the scale, direction or speed of the gestures during an exploration of the game field in relation to the directional- predictive sound signals.
- 'S'-shape and straight-line gestures were applied as the basic behavioural patterns for the graph capturing in the second behavioural strategy. The player could change the scale, direction or speed of those gestures in relation to the DPS signals.

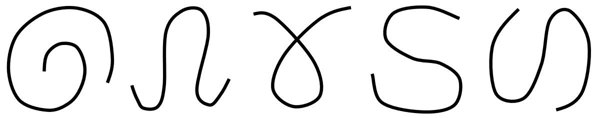
The third behavioural strategy was presented as combination of the first and second strategy. Behavioural patterns followed the same rule format.

4.8.5 Evaluation of the Game

The five two-dimensional arrays were plotted and stored for testing. The subjects were asked to discover the graphs, which were never presented through graphical images. Visualization of the arrays used for testing is shown in the Figure 4.8.1.

Follow the basic findings, all the graphs were created with the discreteness index 8 to decrease the number of the array elements (pixels). That is, when Rc was equal to 20 pixels in the first level of the game, crossing sound would be activated sequentially in two locations of the stylus movements within Rc at inspection the hidden graph in any direction.

To avoid a dependence on the input device resolution the size of the game field was specified in relative units. Thus, the game field had a size of 250 by 250 relative units (still later mentioned as pixels).



289 253 227 237 206

Figure 4.8.1: Visualization of the hidden graphs and the number of pixels to be inspected in each array.

Participants

Eight (another) students (unpaid volunteers) participated in the evaluation of the game Hidden Graphs. They were four females and four males, right-handed persons with normal vision and hearing. The ages of the subjects ranged from 20 to 35 years. All used computers on a daily basis, reporting 6 to 8 hours of usage per day. None of the subjects had prior experience in playing the Hidden Graphs game and were not hired in previous testing DPS.

Apparatus

The Hidden Graphs game was written in Microsoft Visual Basic 6.0 under Windows 2000. Hardware used in the game testing included the AceCad AceCat Flair USB graphics tablet with active area is of 127 mm by 96 mm and a standard DELL laptop (Intel Celeron Processor 1.4GHz/1Mb) with two external speakers. As only the sound bursts were used, there were no particular requirements for sound equipment.

The following parameters measured were stored in the log file for further analysis:

- the number of loaded array (graph);
- the amount of points to be inspected;
- the capture radius (game level);
- the time spent;
- an average distance to the graph and standard deviation;
- the number of directional-predictive sound signals (CS, BS and TS);
- the amount of points which were captured during the inspection phase and the confirmation phase accordingly.

Procedure

The evaluation took place in the usability laboratory at the University of Tampere. The subjects were blindfolded (wore mask) throughout the test to avoid visual prediction and approximation of the detected locations and scanpaths concerning touch tablet features.

Three separate test sessions for each subject were scheduled in different days, due to high attention level and test duration of about 60 minutes. Test sessions were carried through without a break, in order to maintain the pace and familiarity with the strategies which were being evaluated. Each subject played 40 games in each session. Thus, each of 5 graphs was inspected 8 times in a random order using 3 different strategies. Each game involved playing at the preliminary inspection phase and confirmation phase.

The subjects were instructed concerning the features of the game and testing procedure. Participants were then allowed to familiarize themselves with the procedure and play a “warm-up” game.

Results and Discussion

The data was collected on a total of 960 games from 8 players. During the test we had to restrict the number of games per session. Therefore, all the game levels had different relative frequency of appearing. Over 70% of the games were played in level 2 and 3, where capture radius was set as 15 and 10 pixels. The first and fourth levels were played with almost equal probability of about 15%, with capture radius of 20 and 5 pixels accordingly.

Starting position of the stylus for the graph capture was free and did not make a difference in the performance. However, lifting the stylus would cause confusion for the player regarding the graph location and the direction of segments which were inspected.

The major consideration of the study was to discover if the game could be efficiently played by following the interaction model augmented with directional-predictive sound signals in relation to the capture radius and by applying different behavioural patterns.

The results revealed that the average number of toward sounds was repeatedly less than the backward sounds (Figure 4.8.2). The player followed the directional-predictive sound signals until s/he would lose the track (outside capture radius) and backward sounds would stop the player movement. Therefore, the player would back track stylus in the inverse direction, and soon after toward sound, stylus would cross the graph (crossing sound will follow immediately). Consequently, the crossing sound was noticeably more frequent than toward or backward sounds as shown in Figure 4.8.2. The similar tendency was found at the confirmation phase for all the subjects when different behavioural strategies were applied (Figure 4.8.3).

The Figure 3.2.6 shows the ratio between the average number of crossing sounds and backward sounds used during an exploration of the hidden graphs at the inspection and confirmation phase (corr. = 0.9956). As it is supposed that at the confirmation phase the player has to track the graph discovered during the inspection phase, the ratio value (CS to BS or CS to TS) is higher and follows to the capture radius that defines the difficulty level of the game.

When the smaller capture radius (5 or 10 pixels) was used, the difference in the ratio values was decreased and vice versa. Within each behavioural pattern, directional-predictive sounds associated strongly to movement and to each other, resulting in high correlation. Overall, the ratio between the number of crossing sounds and backward sounds varied at confirmation phase in dependence on some features of the graph and the behavioural strategy used (Figure 4.8.4).

Due to a close position of the segments in graph 1 and 3 (Figure 4.8.1) the numbers of pixels captured within those graphs were the largest. We can suppose that the player had larger probability to discover the points that were positioned closer to each other, even by accidental gestures. However, a fixed value of capture radius constrains accuracy and the cognitive performance in grasping continuity of the invisible track. It means that the capture radius ought to be adaptive regarding to both the player behaviour and the graph features being explored.

Composite strategy seemed the most successful for capturing graph 1 and the strategy 2; S’-shape and straight-line gestures appeared to be the most efficient for the graph 3, but not for the other graphs. Especially, the strategy 2 “fell through” in discovering graph 4 comparing to the other graphs. The performance with the strategy 1, spiral and straight-line gestures, appeared to be similar for all the graphs, except for the graph 4 (Figure 4.8.4).

All in all, the behavioural strategies suffered from low performance when the graph 4 was explored. The possible reason is that the shape of the graph 4, in particular the segments in horizontal direction having a small curvature.

While the players were blindfolded, they explored the game field by making basic behavioural patterns most in the diagonal directions, as these movements could be easily

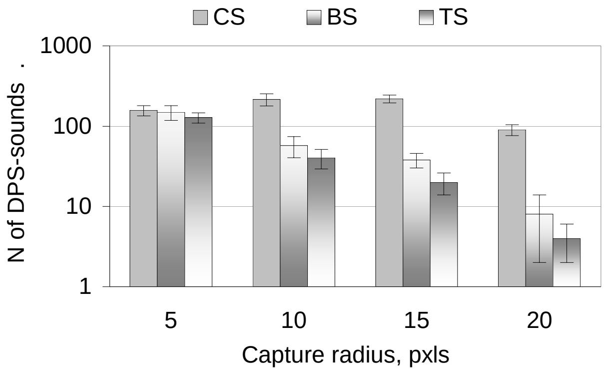


Figure 4.8.2. The average number of DPS used during the inspection phase at different game levels.

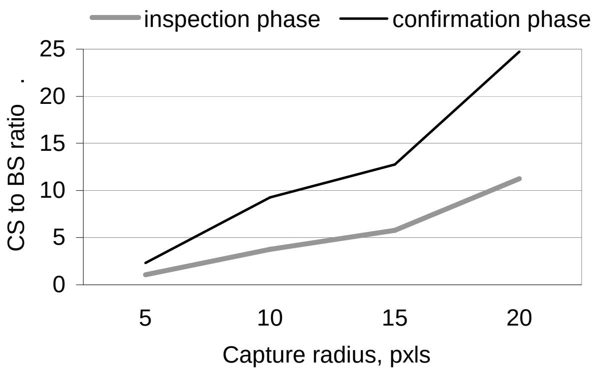


Figure 4.8.3. The ratio between the average number of CS and BS during the inspection and confirmation phase.

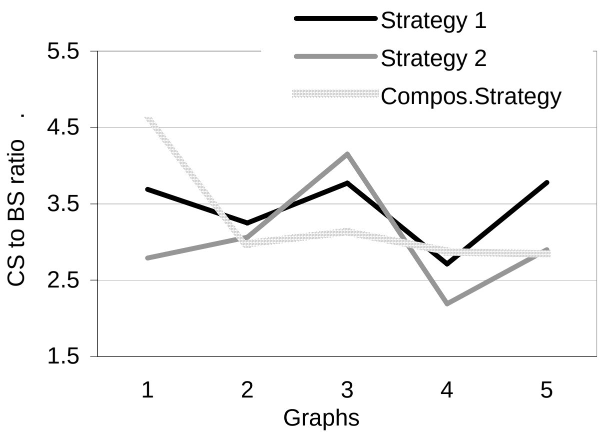


Figure 4.8.4. The average ratio of CS to BS at the three behavioural strategies applied to discover five hidden graphs in the confirmation phase.

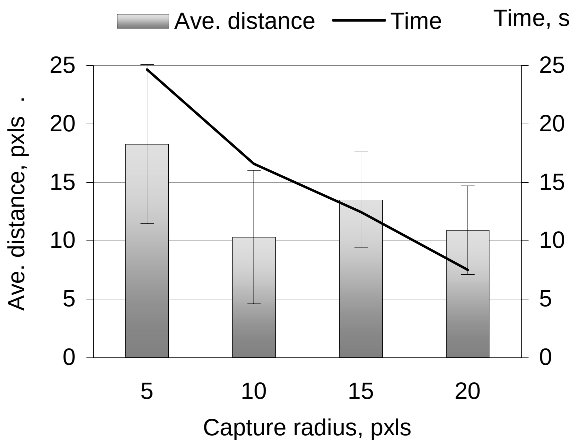


Figure 4.8.5: The average distances to the graph with standard deviation and the time spent at the confirmation phase averaged over all the cases and strategies regarding the game level (capture radius): 71/5, 165/10, 176/15, 68/20.

coordinated to the hand position which was almost static. The diagonal gestures have maximal variations as reported in [12]. We did not perform special analysis for scanpaths of the player, but the graph 4 has a lower probability to be crossed by diagonal gestures.

The efficiency of the first strategy applied to five graphs explored was very similar. Smaller the capture radius was, longer it would take the player to complete an inspection and confirmation phase. This would lead the player to explore more locations before grasping the virtual object, the whole graph or a separate segment.

Next, we supposed that all hidden graphs were equally accessible with the use of directional-predictive sounds. The Figure 4.8.5 illustrates the average distances to the graph (stylus deviation) and the duration time spent at the confirmation phase (game phase after the preliminary inspection) The averaged data were taken from all the recorded cases and the strategies were applied in respect to the game levels (capture radius).

The average distances and standard deviation showed that when the capture radius was more or equal to 10 pixels, it was commensurable with the discreteness index 8 pixels. This index was used to create the arrays of the hidden graphs and allowed the players efficiently coordinate sonification through directional-predictive signals and gestural techniques (kinaesthetic feedbacks). When the capture radius was less than 8 pixels, the probability to lose crossing sounds was higher. The navigation was supported via balance between background and toward sounds, within a range of four times capture radius. The stylus movements could extend outside this range as well.

Nevertheless, when the behavioural strategy 2 was employed, the standard deviation (9.67 pxls) on the average distance to graph (16.34 pxls) within any game level was higher than with other gestural techniques. The composite behavioural strategy 3 seemed to result in the best performance when a smaller capture radius (5 or 10 pixels) was used.

4.8.6 Conclusions

In the case of interaction with touchscreen, there are many different possibilities of delivering feedback coordinated with exploratory movements of the stylus or finger. In the presented basic research, we have investigated the potential of using directional-predictive sounds (DPS) to support non-visual inspection of the graphs through sonification and kinesthetic perception. The sound signals were not connected or proportional to visual parameters of the graphic image or an absolute position of the stylus, but they were used to communicate the user the appropriate movement direction. That is, sound cues directed and optimized the behavioural activity. The user does not need to process or extract information from the new array of alternative feedback signals about the array which is being explored. However, s/he has to understand the direct prompt ("which direction is the best?") and to move forward. Such a way of employing sonification showed efficiency and can support natural and intuitive interaction in a much greater degree than conditional mappings used before. The use of DPS signals facilitates multimodal integration of alternative feedback.

The statistical analysis of the basic results collected from eight blindfolded subjects suggests that sonification of the stylus movements during non-visual inspection of hidden graphs based on directional-predictive sounds is reliable and robust enough to be possibly used in mobile devices, such as PDAs. A significant difference was found in the performance of the subjects under two sonification conditions: when they used the *crossing sound* alone and three sounds to signify different movements concerning the graph.

The deviation of the stylus from the graph inspected had always a smaller mean and it was less than one capture radius. The scanpaths were as much as 24-40% shorter in length and the task completion times decreased by 20-25% on average.

The Hidden Graphs game was developed as a multimodal game for the blind and visually impaired people. The goal of the study was to optimize the model of the "sonification dialogue" with a player through basic behavioural patterns (BBP) coordinated to the capture radius (Rc) and directional-predictive sound signals (DPS) to facilitate shaping the personal behavioural strategy in discovering the hidden graphs.

Three behavioural strategies were employed as a combination of basic behavioural patterns in the proposed game scenario. Directional-predictive sound signals led player actions in grasping the features of the non-visual objects. Each of those sounds had their own unique denotation as a capturing cue during the game. The task-oriented sonification technique and parameters of the interaction model were designed to augment and coordinate kinaesthetic information. The idea was to facilitate cross-modal integration and interaction with virtual graphical images.

The game was structured with four levels of difficulty in two phases: training (inspection phase) and testing (confirmation phase). Testing phase was to optimize the learning process and to investigate how and when it is suitable to apply one or another movement in dependence on the features discovered.

The study showed that three behavioural strategies applied resulted in different performance. The composite strategy was seen to be the fastest and the most flexible in the graph grasping. Still, basic behavioural patterns have to be improved in accordance to the features of stylus gesturing in non-visual conditions.

Finally, a fixed value of capture radius constrains accuracy and the cognitive performance in grasping continuity of the invisible track. That means that the capture radius ought to be adaptive regarding to both the player behaviour and the explored graph features.

In the future, we plan to add an adaptive capture radius which would change as a function of the stylus speed. The timbre of DPS could inform the user about the stylus position concerning both ends of the graph.

The experience acquired within simulated gameplay conditions might be applied for training of the blind children in multimodal interaction with mobile game-like applications.

4.9 General Accessible Games Discussion

Section 4 has described a series of prototype games that use haptic and audio information to aid users in navigating through and controlling a computer interface. The games described are important from a social inclusion context, however the techniques described to allow users to work with the interface can be generalised to different types of application. Many of the problems addressed in these games such as object location, context awareness, environment browsing, shape determination, spatial awareness, and memory issues are common factors that need to be considered when developing accessible interfaces in all contexts. Evaluations of these navigation and control techniques have been described with both blind and sighted users to make recommendations on the best methods of providing guidance to the user through different modalities. Single modality interfaces and multimodal interfaces have both been considered and successful techniques have been identified that can now be incorporated into different interfaces.

5. MAPS

One area of focus for the work package was on navigation and control in maps for visually impaired people. Maps are vital technologies that are hard to access. Multimodal solutions have a lot of promise and there are key navigation and control issues to be investigated. Visual maps are often very complex with spatial layouts. The spatial layout is problematic as both audio and haptic display technologies are not as good as vision in presenting spatial information.

UPPSALA have done a detailed literature review into the nature of maps, how vision and taction differ with respect to maps and the affect this has on map perception. They have also studied some of the basic issues with presenting maps. SU have looked at how sonification might be able to improve map usage. They have built a prototype that uses a tablet to allow users to navigate around a map-type display. They have also looked at the use of Scaleable Vector Graphics, and how these can be made accessible when used to present information such as maps or data sets.

5.1 UPPSALA - Tactile maps

UPPSALA have done a thorough study of tactile maps.

Roughly, there are two main groups of maps: maps for getting geographical knowledge (geographical maps) and maps for guiding locomotion (mobility maps). The needs for visually impaired readers of geographical maps are probably the same as for readers with sight, but the information has to be presented in a partly different way. Often some information is deleted or the information is distributed over several maps to increase the readability without vision.

For mobility maps the needs are probably more different for readers with and without vision. Maps are used mainly before travelling, and to some extent during travelling by visually impaired travellers (Bringhammar, Jansson & DoUGLAS, 1997). They need more map information than sighted readers as they are to a large extent deprived of immediate information from the environment (Brambring, 1985; Passini & Proulx, 1988; Edwards, Unger & Blades, 1998).

Tactile maps for the visually impaired have a long history (Eriksson, 1998), and many ways of production have been invented. Among the most common methods today are thermoforming (making an embossed plastic copy of a model made in other materials) and the use of swellpaper (applying the two-dimensional picture/map on a special kind of paper that provides an embossed version of the picture when heated). Thermoforming provides more control over the embossment, especially in height, and has a higher spatial resolution also in the two-dimensional plane, but it is relatively cumbersome to use because of the need to make a master. Swellpaper does not provide the same quality as thermoforming, but it is a much simpler method: produce the picture on it and heat it. Much practical knowledge of how to make tactile pictures with these methods is summarized in Edman (1992) and Gardiner & Perkins (2002).

Tactile pictures have been a partial success and are used by several visually impaired people, but there are also many who find it very difficult to use them. For visually impaired readers, it usually takes longer time to read a tactile picture than it takes for sighted readers to read a visual picture. It is also more common that tactile pictures are misunderstood than visual pictures. However, special training is reading tactile pictures improves the performance, as does verbal instructions in how to read.

Why are there such problems with tactile maps? Some of them will be discussed here. A more detailed discussion can be found in Jansson (2003).

5.1.1 Differences between vision and touch

A general problem is that the making of tactile maps usually starts with visual maps in order to make an analogue copy. Even if there are similarities between vision and touch, such as their ability to pick up information about edges, textures, sizes and locations, there are several differences between vision and touch that must be taken into account in the translation. One general difference concerns the *discriminatory ability* of the two senses. There are cases when touch makes better discriminations than vision, such as when judging the quality of cloth and detecting unevenness of a surface, but mostly touch cannot detect as small details and differences between details as vision. Touch has in some contexts been compared with blurred vision (Apkarian-Stielau & Loomis, 1975). It is therefore in many cases not possible just to make a tactile map in a form analogue to the visual map. It has to be edited in order to take care of the differences between the senses. Many studies have been made about maximally discriminable choice of tactile symbols (overviews in Edman, 1992, pp. 209-233 and Jansson, 2003, pp. 54-57). Efforts to standardise tactile symbols have not been successful because the available number of discriminable symbols has been found too small and because of the fact that discriminability of symbols varies with production method.

Another major difference between vision and touch is the ability to provide an *overview*. Vision usually gives an immediate overview of the map, while getting an overview via touch is a laborious task based on exploratory movements. It may take quite a long time, and it is not uncommon that observers give up understanding of a tactile map. One method to try to overcome the overview problem for maps, as well as for other pictures, is to provide a verbal description in Braille or spoken text (Levi & Amick, 1982; Eriksson, 1997). Another method is to facilitate the perception of figure and ground (Brambring & Laufenberg, 1979), for instance, by arranging symbols of different kinds at suitably different heights. A third method is to use maximally efficient ways of exploration (Berlà, 1982; Jansson & Monaci, 2003), and a fourth method to introduce reference points or lines, for example, an external memory (Wall & Brewster, 2004).

The perception of *three-dimensional information* is a third main problem with tactile two-dimensional displays. It is sometimes said that this kind of information should be avoided in tactile pictures of objects and scenes, but there are also research indicating that perspective can be perceived when presented as surface outlines (Kennedy, 1993) and as texture gradients (Holmes, Hughes & Jansson, 1998; Jansson & Holmes, 2003). However, these results have been obtained in relatively simple pictures and more research is needed to find out to what extent they can be generalized to more complex pictures. Perception of three-dimensional information is not very common for tactile maps, but successive changes may appear also on them and have to be taken into account.

5.1.2 Origin of map content

The content of tactile maps has traditionally been manually adapted from visual maps, often complemented with sight visits when it concerns mobility maps. This is of course a very time-consuming method that restricts the production of tactile maps for the visually impaired.

An important source for visual maps is Geographic Information Systems (GISs). In principle, these are available also for the visually impaired, but an important problem is that they are not adapted to their special needs. Therefore, special editing is usually necessary. One way is to use some GIS format, add layers with special information for the visually impaired and then select layers for a tactile map (Clark & Clark, 1994). Maps in some GIS format can also be a starting point for manual editing of tactile maps, as is made at Metria, Kiruna, Sweden (Hans Dahlberg, personal communication). Another way is to use a partly automatic process, maybe similar to making schematic maps such as underground maps (Elroi, 1988; Hamel, Michel & Strothotte, 1995). In an ideal world, a visually impaired person should be able to choose the information wanted from a GIS map, either automatically or by a personal choice. Michel (1999) investigated how well this can be done with different GIS formats and found some formats better than others for this purpose. It would be valuable if these studies could be followed up with the intention to provide software to be used by people with vision problems. Michel also developed software to “distort” a map by interaction between user and computer with the intention to enlarge difficult parts of the map and reduce the size of simpler parts.

5.1.3 Enhancement with auditory information

Pioneering work of coordinating auditory and tactile presentation of map information was done by Parkes (1988) with the NOMAD device, consisting of a touch pad with spoken information provided at specific points. Related efforts are the TACTISON (Burger, Mazurier, Cesarano & Sagot, 1993) and AUDIO-TOUCH (Lötzsch, 1995). The advantage of combining hearing and touch in map information has been demonstrated in several studies (e.g., Holmes, Michel & Raab, 1995; Holmes & Jansson, 1997; Holmes, Jansson & Jansson, 1996; Holmes, Jansson & Olsson, 1996; Jansson, 1999b).

5.1.4 Matrices of tactile point stimuli

Braille is usually a 2x3 matrix of point stimuli within which a number of symbols are presented, and the usefulness of this kind of stimuli for reading has been well demonstrated. Many efforts have been made to increase the size of the matrix for use in other tasks. An early effort was the development of the Electrophthalm and the Tactile Vision Substitution System intended as mobility aids, among other things. Many prototypes have been built and evaluated (Kaczmarek & Bach-y-Rita, 1995), but a basic problem with them is the problem of representing a complex pattern within such a matrix. The largest matrix has 7200 pins with a 3 mm inter-pin distance (Dot Matrix Display, built by Metec, Stuttgart, Germany) and the matrix with the highest spatial resolution has a .4 mm inter-pin distance within a total area of 8x8 mm (Pawluk, van Buskirk, Killebrew, Hsiao & Johnson, 1998). Matrices with this large size and high spatial resolution, respectively, are quite expensive and have not been available for general use; the former is built in a few copies, the latter in just one.

There are differences between these displays to what extent the whole display is available to a user. The matrices of the Electrophthalm and the Tactile Vision Substitution System are in total simultaneously available to the user's forehead and back or belly, respectively. The 8x8 mm display is in total available to a finger tip. The Dot Matrix Display is in total available for exploration, but the users have to find what point stimuli are activated and there is of course a risk that activated stimuli are not explored.

The cost of large displays has lead to the solution of having a small display that is movable in order to cover a larger area. The most generally spread device of this type is the Optacon. It has a matrix with 5x20 pins (Optacon II) and a television camera movable over the surface to be explored or a computer determining the input related to the exploratory movements and an output as a pattern within the display matrix. The device was originally intended for reading text, providing a tactile pattern corresponding to the letter forms, but it can also be used for reading maps. It looked for several years that the Optacon was a successful commercial product, but the producer stopped manufacturing it because of high cost versus low demand, probably depending on the advent of text readers with synthetic speech output that was understandable with less training. It is still used in scientific studies (e.g., Jansson, 1998).

Matrices of point stimuli have also been used on tactile mice, such as the Virtouch Mouse built by Virtouch Ltd (Gouzman, Karasin & Braunstein, 1999), a later version called the VTPlayer. The latter device has two matrices on the mouse each for one finger. The potential usefulness of the mouse for reading virtual maps has recently been studied by Elverum (2004), Jansson & Pedersen (2004) and Jansson (2004). This mouse is also being evaluated for other purposes (Steven A. Wall, Glasgow University, UK, personal communication, October 2004).

5.1.5 Maps and haptic displays

Two main topics will be discussed: Basic perceptual requirements for the use of haptic displays without vision and the use of haptic displays as aids for the visually handicapped

Basic Perceptual Requirements for Haptic Displays without Vision. The hand is very efficient in providing information about the object explored (Katz, 1925/1989). Several studies have investigated to what extent performance with haptic displays is similar. Most of those mentioned here used a PHANTOM (http://www.sensable.com) in the experiments. This is a haptic display with one point of contact with the virtual objects via a stylus or a thimble. Jansson et al. (1999; see also Jansson, 2000) studied, among other things, the possibilities of judging shape and texture via a Phantom without vision and found that textures (roughness of sandpapers) could be judged as well via the display as via the hand, but that the possibilities of identifying the shape of objects was much below those of the plain fingers. Even simple forms took a long time to identify and there were many errors. The performance deteriorates with the complexity of the shape (Jansson, 2002; Jansson & Larsson, 2002). However, the efficiency increases rapidly with short-time practice (Jansson & Ivås, 2001), probably because the way of exploring with a PHANTOM is quite different from natural exploration which hinders efficient exploration, especially in the beginning. Judging the form of virtual objects may be effected by with what surface properties they are equipped. An experiment by Jansson & Pieraccioli (2004) suggested that texture may have a deteriorating effect, but not friction or softness. The latter is especially interesting, as that indicates that the observers can adapt their exploratory behaviour to the softness of the object. Christou & Wing (2001) found that friction has an effect on curvature judgements. When vision is available, too, co-location of the visual and the haptic virtual object is advantageous (Jansson & Öström, 2004).

Even if it has been found that it is possible to get useful information from haptic displays to some extent, the constraints in the information means that they are far from utilizing the capacities of the natural hand. This is shown when restrictions similar to those of the haptic displays are applied to the hand. Lederman & Klatzky (2004) found identification of common objects to be much effected when information was constrained. Similarly, Jansson & Monaci (2004a) found a large effect when the number of fingers involved in the exploration was varied. Especially, the use of only one finger was much poorer than when the use of two or more fingers was allowed. In this experiment, the area in contact with not restricted to one point, but consisted of a portion of the pad. In a subsequent experiment both number of contact areas (fingers) and amount of information at each contact was varied. Minimum of information was obtained by a sheath covering the contact area, which reduced the information to be practically the same over the whole area. Maximum of information meant that the uncovered finger was allowed to pick up all haptic information available simultaneously as well as successively, including both shape and texture properties. The result was a drastic deterioration in performance when it was restricted, both in kind of errors in identification and exploration time (Jansson & Monaci, 2004b). The conclusions are that the most efficient improvement of haptic displays would be obtained by increasing the information at the contact areas, and that also increasing the number of contact areas would be useful, even if it is not to the same extent.

The use of haptic displays as aids for visually disabled people. Haptic displays can be expected to improve the perception of three-dimensional aspect of a depicted scene in comparison with tactile maps, as the third dimension can be perceived directly, not via perspective information (Jansson, 1999a, 2001). Investigations reported above demonstrate that haptic displays have potentials in this way also without visual support. Within the context of the EU project PURE-FORM (IST-2000-29580) the use of a new exoskeleton haptic display for exploration of virtual copies of statues at museums was studied, mainly as a complement for sighted museum visitors, but also for visually impaired people (Jansson, Bergamasco & Frisoli, 2003). Answers to questionnaires during exhibitions at museums demonstrated a great interest among sighted visitor for the added haptic information (Frisoli, Jansson, Bergamasco & Loscos, 2004). A relatively small number of visually impaired visitors also answered the questionnaire. The result is preliminary because of the few participants, but it suggests an interest that is somewhat disturbed by the well-known problem of getting an overview. This problem is with us also in the context of haptic displays used by visually impaired people, and it should to be attacked especially by trying to find auditory information, probable oral descriptions and instructions, to enhance the haptic information.

Haptic displays can be expected to be increasingly useful for visually impaired people, especially if the technical development improves information at the contact areas, as well as the number of contact areas. Work with combinations of visual and auditory information is probably also a most important endeavour.

5.2 SU - Sonically-enhanced maps

SU have been working on the augmentation of tactile maps using sound.

With the increasing usage of multimedia systems, there is a real need to develop tools able to offer aids for visually impaired or blind people in accessing graphical information. This technological development would open new prospects in the realization of man-machine interfaces for blind users: Many efforts have been devoted to the development of sensory substitution systems that may help visually impaired and blind users in accessing visual information such as text, graphics, or images. Some of them are based on the transformation of visual information to audio signals. These approaches assume a sufficient knowledge of both visual and auditory systems. At the present time, we can consider that the various solutions suggested for text access are acceptable. However, the information presented in the form of graphics or images presents a major obstacle in the daily life of blind users.

One approach to solving the problem is based on the sound screen concept [1]. Its principle rests primarily on the auditory localization of virtual sound sources (VSS). The sense of hearing presents many analogies with the parameters of vision. The human being exploits this resource very much, in particular with speech which transports important semantic components, just like text with vision. If speech uses hearing in one way, music exploits all the related resources for artistic ends. However, an important advantage with visual space is that one can represent a particular semantic in a graphical form. Whereas, there is no equivalent representation of semantics in the sound space. Here, as an alternative solution, we propose an audio display system based on sound localization which allows us to represent some graphic information in the sound space. The basic idea is to project graphics on a virtual sound screen.

Another approach is a coding scheme is based on a pixel-frequency association [2]. The sensory substitution model can now be summarized as follows. According to our model of vision, the acquired image matrix is first convolved by an edge detector filter and, second, converted into a multiresolution image. Then, coupling between the model of vision and the inverse model of audition is achieved by assigning a specific sinusoidal tone to each pixel of this multiresolution image; the amplitude of each sinewave is modulated by the gray level of the corresponding pixel. Finally, according to the inverse model of audition, the left and right complex sounds consist of weighted summations of these sinusoidal tones.

Whatever the coding scheme may be, translation of images into sounds has to meet certain specifications:

1. Visual perception of a given object remains steady whatever its location within a visual scene (we called that “position invariance”); hence, displacements of an object in a visual scene should lead to neighbour auditory signals.
2. Different levels of resolution in the model of vision should correspond to specific sets of tones, in order to facilitate evaluation of object dimension and localization. Signals produced by the inverse model of audition have to meet the human auditory system features. Accordingly, their specifications are as follows.
3. Frequencies must belong to the audible bandwidth of the human hearing system. Its range is 20 Hz to 20 kHz in young human adult subjects. Usually, frequencies are limited to the useful bandwidth of the hearing system, i.e., from 50 Hz to 15 kHz. Outside this bandwidth, the sensitivity drops rapidly, especially for older people at high frequencies.
4. Selection of neighbour frequencies must respect the frequency discrimination threshold for the ear. Above 500 Hz, the frequency discrimination limit—or just noticeable difference (JND)—for frequency is approximately 0.7% of the frequency value; below 500 Hz, the JND is no more related to frequency and has a constant value of about 3.5 Hz.

In agreement with cochlear tonotopy, sinewave frequencies associated to pixels should be equally distributed along an exponential scale to be perceived as approximately equidistant.

There were some EU FP projects to develop systems for blind people. One of them is the system developed in the TeDUB project ("Technical Drawings Understanding for the Blind")[3], which aims at providing blind computer users with an accessible representation of technical diagrams. The TeDUB system consists of two separate parts: one for the (semi-) automatic analysis of images containing diagrams from a number of formally defined domains and one for the representation of previously analysed material to blind people. The joystick was used for navigation.

Web-related technologies are emerging that make map-based information accessible online for those who need it most. The flexibility of the SVG format and the interactive features of the maps created with it, significantly enhance the user experience. For the blind user, tactile, audio, and haptic effects convey the information that a sighted person would primarily receive visually.

Mapping represents a perfect application of SVG, because maps are, by nature, vector layered representations of the earth. The SVG grammar allows the same layering concepts that are so crucial to Geographic Information Systems (GIS). Since maps are graphics that depict our environment, there is a great need for maps to be informative and interactive. SVG provides this interaction with very high quality output capability, directly on the web. Because of the complexity of geographic data (projection, coordinate systems, complex objects, etc.), the current SVG Specification [5] does not contain all the particularities of a GIS particularities. However, the current specification is sufficient to help the mapping community produce open source interactive maps in SVG format.

Until recently, the use of tactile maps has been very limited, as most of the maps have been produced by hand, for example using string and glue, a very slow process. Recent developments facilitated the production of cost effective maps. Examples are:

- New types of papers (Swell paper permitted the user to download, print, and produce tactile maps using a thermal image enhancer.)
- New types of ink (These allowed production of high quality tactile maps with long durability on ordinary paper.)

The purpose of interactive audio-tactile maps was to provide a multimodal environment thereby making all the rich geospatial information available and accessible to people with visual impairment. Placement of a tactile map on a touch tablet allowed the user to interact with the SVG map. Sound effects were added using pre-recorded sounds. Voice annotation was implemented using text-to-speech software or screen reader software.

The user found a map on the Mapping for Persons with Visual Impairments (MVI) web site and downloaded and printed the corresponding PDF file. The printout was run through a thermal enhancer. This device raised the ink so that lines became recognizable to the touch. The printed map was then placed on a touch tablet.

Once the map was placed on the tablet and carefully registered with the same image on the monitor, the user could trigger events. The finger of the user interacted with the SVG maps as a mouse. When the user slid his finger over an element, a sound effect was heard. When the user wanted more information on a feature, a simple tap of the fingertip caused the name of that feature to be spoken by the user's screen reader. Using this method, we were able to label any element on the map.

To enhance the interactivity, the maps contained haptic effects. For low vision users, who did not rely on the touch tablet, different types of vibrations were associated with map features. The user required a tactile mouse, to take advantage of the effects.

Several methods were experimentally evaluated to generate interactive SVG maps. The most attractive method is to use maps created with Adobe Illustrator and to add haptic effects through JavaScript. The maps are then exported as SVG. The SVG code is edited directly to add the sound effects. Another method that was tried was to open maps from existing databases in a GIS, export them into SVG format, and add the interactive features in a text editor.

The methodology was compatible with the following file formats: CorelDraw, Adobe Illustrator, Macromedia Freehand, SVGMapMaker SVG files.

Some recommendations on how prepare maps using SVG have been proposed [4]:

- **Apply Common Visual Standard.** There are cartographic conventions that apply to maps for people with visual impairment. The main concern is to ensure the maps had a consistent look.
- **Organize Objects in Layers for Interactivity.** The second step in the methodology was to group all the elements in appropriate layers and label both elements and layers. All elements affected by the interactivity had to be grouped. This was done in Illustrator using the layers palette. This created a group tag in the SVG document. Each element that was later identified by the screen reader had to be given a label. This label was what the screen reader spoke out loud. We grouped the symbols for train station, bus station, and airport together. Primary, secondary and tertiary roads formed another group. Mountains and bodies of water formed two more groups.
- **Assign Haptic Effects.** The third step was to assign JavaScript functions to layers. Each haptic effect was paired with a sound effect. We hoped this would make map features stand out more to people with visual impairment. Each category of map element was assigned a separate haptic effect via JavaScript; one for roads, one for built-up areas, one for water and occasionally one for borders. Using the interactivity palette in Illustrator, the JavaScript functions to drive the events were added. This tool added the code and the event in the SVG document. The code could have been added with a text editor.
- **Assign Sound Effect.** The final step was to link in pre-recorded sound effects. By using the Adobe SVG Viewer implementation for audio, we were able to play a recorded sound when mouseover or mouseout occurred on a map feature.

Below are examples, how achieve effects in HTML pages [4].

5.2.1 Voice Annotation

The label of the feature that was clicked on was sent to the HTML page to be read by the text-to-speech software.

```
<g id="Haptic_Layers" onclick="OnClickEvent(evt)" . . .>
      <g id="Water" . . . >
            <path id="Strait_of_Georgia" . . ./>
```

5.2.2 *Haptic Effects*

Event functions were added to layers to provide the haptic effects.

```
<g id="Haptic_Layers"  onclick="OnClickEvent(evt)" . . . >
      <g id="Water" onmouseover="OnMouseover(evt, 'Spring')"
                        onmouseout="OnMouseout(evt, 'Spring')" . . . >
```

5.2.3 *Audio Effects*

Recorded sounds are played using the audio implementation of the Adobe SVG viewer.

```
<a:audio xlink:href="\water.wav" begin="Waters.mouseover"/>
<a:audio xlink:href="\water.wav" begin="Waters.mouseout"/>
```

5.2.4 *Users' Feedback*

The publication of and access to tactile maps on the Internet was a very recent development. The first version of the MVI [6] web site was officially launched in October 2002. For the hardcopy production of the Tactile Atlas of Canada, which is available in a downloadable format on the web site, extensive user testing was conducted. Students, teachers and mobility training instructors tested both the raised ink maps and capsule paper tactile maps. The maps published on the MVI web site follow the international guidelines recommended by the International Cartographic Association Commission on Maps and Graphics for Blind and Visually Impaired People.

Feedback was also solicited from cartographic professionals working in the field of tactile maps and graphics [4]. The maps for the Thematic Tactile Atlas of Canada were also tested at W. Ross Macdonald, the largest residential school for blind and visually impaired students in Canada. This user centric approach resulted in development of high quality maps, which will serve blind and visually impaired users well. The Tactile Atlas of Canada received high praise from users and the professional cartographic community and was selected for national and international exhibitions by the Canadian National Cartographic Committee.

5.2.5 *Prototypes specification*

Technical equipment: PC computer with sound card, speakers and digitizer Wacom Intuos2 A4 oversize.

Figure 5.2.1: User and hardware

Currently we use open source project AutoTrace [7] to convert from bitmap formats to SVG format. The output from AutoTrace is input to our system. Further, a hierarchical structure for map information storage was developed (Figure 5.2.2). The text and sonification information are appended to vector graphics information. The format is compatible with Adobe SVG Viewer format.

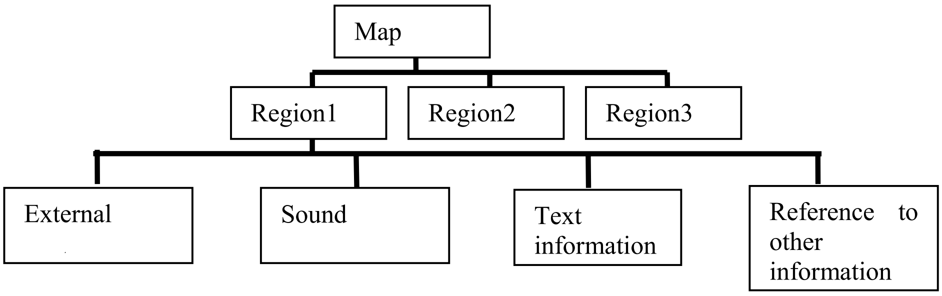


Figure 5.2.2: Hierarchical structure for information storage

The software for map exploration by visually impaired person was developed. The coloured regions on maps are accompanied by different sounds when the user enters them. The text information could be listened to, after mouse button click. An innovative feature was developed that gave an audio warning signal when the user's stylus was near a boundary, allowing them to know when they were approaching an edge before they had reached it.

Basic forms of SVG format is shown in Figure 5.2.3. Most is used **path** element. It approximates contour by cubic spline.

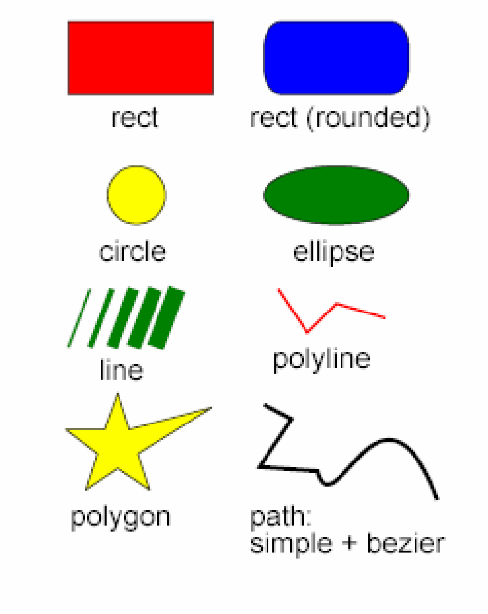


Figure 5.2.3: Basic shapes of SVG.

Visual C#.NET from Microsoft Visual Studio.NET is used for software prototyping. Software could recognize only part of Adobe SVG Viewer tags.

5.2.6 Conclusions

Reference analysis revealed that SVG format is widely used for presentation of interactive maps and free plugins exist for web browsers (the Adobe SVG Viewer). This makes the SVG format a good one to investigate the integration of audio-enhancements into maps. SU have developed an application that allows tactile raised paper maps to be accompanied by audio enhancements to increase their usability.

5.2.7 References

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5.3 Discussion

Results of our work on maps have shown that there are many problems accessing maps, but maps are a very valuable source of information, so further investigation is needed to really solve the problems. Multimodal solutions are the most promising as neither touch nor hearing can replace the power of vision.

6. DEMONSTRATORS

Demonstrations of several of our work package prototypes are available on the MICOLE project website (http:// micole.cs.uta.fi).

7. OTHER ACTIVITIES

A workshop was also held at the ACM CHI 2005 Conference in Portland, USA on 4/5th April, 2005. This was organised by Steven Wall, Andrew Crossan and Stephen Brewster of UGLAS. This was attended by other MICOLE partners plus research groups from across Europe and the US. It also included European and US companies. The first day of the workshop was presentations from the different groups to share knowledge. The second day tried out a range of haptic prototyping techniques with real world objects and materials. The aim was to find better ways to develop haptic prototypes than just writing computer code.

UGLAS demonstrated their work package prototypes at the Science Museum in London in July to over 300 members of the public.

Jansson at UPPSALA is part of the ISO Working Group 9 on "Tactile and haptic interactions" (ISO/IC159/SC4/WG9). Jansson took part in the 1st meeting of WG9 and the preceding conference. He will feed results from the MICOLE project into the ISO standard. The following paper was a contribution to the conference:

Jansson, G. (2005). Two recommendations for tactile/haptic displays: One for all kinds of presentations and one for the development of haptic displays. Paper for GOTHI'05, October 24-26, 2005, Saskatoon, SC, Canada. In Conference Proceedings.

ULUND demonstrated their prototypes to the public at an open house day at the University of Lund on 5th October, 2005.

METZ presented their work at the Festival of Science at Metz University for 3 days in October 2005. They also presented the work at a special meeting on sport for visually disabled people in Vittel, France in February, 2005. They also used this meeting to test some of their prototypes on visually impaired children.

8. GUIDELINES

One of the aims of our work was to distil some guidelines from the research we have done to allow others to make use of our results. Here is a summary of our preliminary guidelines from the work package, we intend to add more as the work progresses.

8.1 Guidelines from Section 3.3

- While learning shapes through force playback is possible for both sighted and blind participants, be aware that there is a far greater variability in the level of performance for visually impaired users.
- The perceived shape of a trajectory can be altered when the user is released from the playback constraint once the trajectory is complete. The user's hand has a tendency to sink slightly before compensating for gravity giving the perception of vertical downwards tail to the end of the trajectory.
- Segmentation of multiple shapes felt purely through force playback can be confusing. Multimodal feedback could significantly reduce confusion to the user through, for example, using auditory cues to mark the start and the end of the playback.
- During force playback users will not feel the exact path that is played to them. Perturbations from the users force on the device and gravitational effects can alter the trajectory. The effect will be less for smooth transitions than sharp transitions.

8.2 Guidelines from Section 3.4

- Predictable behaviour that mimics nature like gravity makes it easier to control objects.
- Fixed reference points like walls, floor, ceiling and fixed objects like shelves are important in an environment in order to support orientation.
- Verbal communication between the participants is important to support awareness of the status of the shared environment.
- It is better to have restricting surfaces in all directions otherwise haptic hardware volume limits sometimes are mistaken for being an object in the environment.
- It is important that perspectives and angles are natural haptically and relevant for the task that is performed as it is very confusing for a blind person to use an unusual haptic perspective with not so common/natural angles.
- Referring to objects is relatively easy because users experienced that they had a good mental representation of the content and layout of the environments.
- It was hard to talk about directions in the environments when both participants were in the same room facing each other. Referencing thus depends on the physical location of the participants during the interaction in the virtual environment.
- Joint manipulation of objects was possible and haptic feedback was used in order to coordinate joint handling of objects.

8.3 Guidelines from Section 3.7

- Users can recognize easily 6 directions guided bumps and 4 directions half-guided bumps
- Using several amplitudes for the bumps doesn't disturb the direction discrimination
- Two amplitudes are discriminable, but if we add a third one there is an ambiguity

8.4 Guidelines from Section 3.8

- The patterns of different icons must de different enough to make the users differentiate them
- The maximum tactile surface must be used in order to increase recognition
- When using 8 directions, we must change a parameter (shape, animation length, size, etc.) between radial (horizontal and vertical) icons and diagonal icons
- We must do a pause after wave-like icons to be able to recognize the sense of the wave's movement
- Users rather prefer static icons than dynamic icons
- Using too much pins makes too small pattern difference and thus bad recognition.
- Users have difficulties to recognize the position of a shape on the matrix, because of the lack of reference point

8.5 Guidelines from Section 4.2

- To build user-friendly interfaces for visually impaired users there is a need to carefully balance performance of interaction and perceptive and cognitive abilities of the person.
- Mapping (with any cues) should rely on:
    - a restricted memory capacity, that is, an external memory aid should be inherent property of the signals (primary feedbacks) and pointing behaviour patterns (motor/kinaesthetic memory)

  - cross-modal interaction (coordination and integration) should be considered as a basis in designing the basic structures, components and their relationships to be efficiently managed by the user
  - memory (brain) plasticity, that is, being simplified to a basic structure (3 by 3) and amodal directions might be flexible and adaptive as well, in use. ("dynamical grid", dynamical cues…)
- It is reasonable to assume that advanced interface design for visually impaired users might rely on a higher level of cognitive processing and natural way of perceptual cooperation and integration of the notions, concepts and models.

8.6 Guidelines from Section 4.3

- Once there is a need for design tools to allow visually impaired people to navigate the information which is presented to them, then the use of an auditory display is suggested. However, one should consider how complicated and expensive the setup is (large number of loudspeakers, advanced audio card, etc.). Alternatively, an HRTF-based auditory display can be used instead (it simulates the presence of a sound-emitting object in any position within the listener's environment), which requires only a pair of headphones but the main drawback of that approach is that the 3D auditory environment around the listener, which is reproduced on the headphones, appears to be moving when the listener's head moves.

- Once there is a need for presenting information to visually impaired children, then the use of a haptic device is suggested. The main advantage is that a vibration feedback controller does not cost much. On the other hand, it is possible some children to not be familiarized with this device and have several difficulties at the beginning.

8.7 Guidelines from Section 4.4

- Direct translation of a visual to a tactile representation will not necessarily result in usable tactile feedback.
- Visually impaired users can successfully integrate force feedback cues and tactile cues presented to different hands.
- Static tactile cues provide better performance than dynamic tactile cues when working in a two-handed navigation task.

8.8 Guidelines from Section 4.5

- This small test shows that vertical orientation may at times be preferred, but one has to keep the effects of long time use in mind. The general recommendation has to be that the suitable orientation for each environment needs to be determined by testing.
- Labyrinth games seem appreciated, although one needs to consider the "idea of the game".
- Another obvious recommendation is that a labyrinth like this should not have exits. This is essentially the same consideration as the recommendation to use a limiting box – the user should not be able to "fall out" of the environment. The limiting box of course has another motivation: it allows the user to separate objects from environment limitations (if now limiting box is used the PHANToM physical limitations may be felt as objects).
- There is also an indication that this type of restricted environment is a good starting point when people are introduced to haptics – particularly if you have problems feeling the haptic illusion.

8.9 Guidelines from Section 4.6

- A weak constant attractive force has been showed to be useful in locating objects non-visually in a 3D space.
- This force should be weak enough to allow the user to resist it, while at the same time being strong enough to attract the user to the target once the grip is released.
- The results from this test highlight the importance of being able to "check back" – to be able to easily go back to objects in the environment to check their properties and positions.
- 3D sound feedback with the ears of the listener attached to the PHANToM position ("ears in hand") is a type of feedback which may help users to get an understanding of a spatial environment and which possibly also increases the sense of immersion within the environment (this, however was not tested).
- This type of audio is also a tool for navigation, but in this kind of environment (with few, small objects) it is less effective. User comments (as well as results from the pilot tests) show that if possible it is useful if the sound feedback allows object identification from a distance.
- The borders between different object spaces provide important information, and it is useful if the sound feedback gives this type of information.
- In the case of sound identification from a distance this is provided automatically, since the sound will change as the object changes, but in the case of a general navigation sound this is something that needs to be considered.
- Depending on the type of environment and the type of task the use of fixtures is another possibility to guide the user towards a target – this type of interaction may also illustrate a path. To do this with an attractive force a sequence of targets has to be used, but path following has not been tested within this series of tests.

8.10 Guidelines from Section 4.7

- Both positive and negative relief is possible to feel and to work with.
- Drawing lines with a haptic drawing tool is not too easy, but not too difficult either.
- Both vertical and horizontal virtual paper will work in the short run – but what about ergonomics?
- Simple shapes can be recognized when they are kept in a specific context.
- The sound feedback was used to get information about the program mode.
- Using keyboard to control application tools may give users too much memory workload.

9. OVERALL DISCUSSION AND CONCLUSIONS

The work for this deliverable has concentrated on investigating how we can design basic multimodal navigation tools for visually impaired children. After initial discussions amongst the partners we decided to focus on games and maps as application areas, with a strong emphasis on how to design the basic navigation and control techniques needed, and clear evaluations with end-users to understand if the designs were effective or not. One strand of our work was to investigate novel basic navigation and interaction techniques using the different senses, needed to provide access to a range of new applications. We focused on sonic techniques (UTA, KTH), gestures and force-feedback (METZ, UGLAS, KTH) and tactile interactions (METZ). This gave us much knowledge about how to use the different senses and ways that we could apply them in our application domains.

Games proved to be an excellent testing ground for our ideas. They were highly motivating for our users making the experiments successful. Their real-time nature and need for dynamic interaction challenged us to create novel tools to support the game play. They allowed us to test out ideas for the different modalities individually and in combination for multimodal solutions. We looked at audio only games (the work from UTA and KTH), haptic (using both force-feedback and tactile displays from UGLAS and ULUND) and multimodal games using sound and haptics (FORTH and ULUND).

Maps also proved to be an interesting area of investigation. UPPSALA looked at tactile and force-feedback interactions in maps and SU with audio displays (with some additional tactile feedback). We have made an excellent start in this area with good ideas on how to proceed further.

Future research in this part of the work package will develop these ideas and application areas further and create more sophisticated tools and expand our knowledge. For example, we will be looking at improved navigation aids based on beacons. The user would be able to mark a point on a map or table and leave a note (this might be done by tapping with the PHANToM device or touch screen displaying the data). Non-speech audio beacons would be presented using 3D audio to indicate the location of these notes. Users will be able to hear them wherever they are in the data and the direction of the sound will indicate the location of the marked point, making them easy to find. At the beacon users will be able to type or record a voice message describing the point of interest. This will allow them to easily return to items (e.g. be moved to a beacon automatically by the PHANToM) to facilitate comparisons with other data points, etc. giving some of the flexibility available to sighted users (this is only an initial proposal and may be changed as the project progresses). No other research to date has looked at such external memory aids.

We will investigate the design of the beacons, how they should be presented to avoid conflict with the other audio information being displayed and how users would leave notes so that the process does not disrupt the browsing experience. Prototypes will be built and full experimental evaluations will be undertaken with our users to ensure that the tools we produce are usable and solve the intended navigation problems. A report will be written describing external memory, the tools developed to add it into our systems and their evaluation. Results will be fed into WP4 to inform the development of the software systems for the project and into WP5 and its design recommendations.

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