Comparing Two Haptic Interfaces for Multimodal Graph Rendering

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Abstract

This paper describes the evaluation of two multimodal interfaces designed to provide visually impaired people with access to various types of graphs. The interfaces consist of audio and haptics which is rendered on commercially available force feedback devices. Usability of force feedback devices in real applications is seldom investigated and compared. Therefore this study is aimed at comparing the usability of two force feedback devices: the SensAble PHANToM and the Logitech WingMan force feedback mouse in representing graphical data. The type of graph used in the experiment is the bar chart under two experimental conditions: single mode and multimodal. The results show that PHANToM provides better performance in the haptic only condition. However, no significant difference has been found between two devices in the multimodal condition. This has confirmed the advantages of using multimodal approach in our research and that low-cost haptic devices can be successful. This paper introduces our evaluation approach and discusses the findings of the experiment.

1. Introduction

We are currently working on a research project called Multivis which is about developing a multimodal (using multiple sensory modalities) visualisation system for visually impaired people. The multimodal system uses virtual touch, 3D audio and synthesized speech to represent common data visualisation techniques, such as various types of graphs and tables. The objective is to provide visually impaired people with the same data visualisation methods used by their sighted counterparts. In order to provide virtual touch in the system, we use commercially available force feedback devices.

Currently available force feedback devices have given opportunities to researchers who are working on assistive technology to provide virtual touch to visually impaired people. Several research projects have been conducted to present 3D objects, scientific data and mathematical functions to visually impaired people by using force feedback devices [1-3]. The most commonly used device is the PHANToM force feedback device from SensAble Technologies Inc. (Figure 1). It is regarded as one of the best on the market. Its hardware functionality and software support enable developers to build many different types of applications. It is a six degrees of freedom input device and provides three degrees of freedom force feedback. When a specially designed stylus is attached, it can provide extra three degrees of freedom force feedback. Due to the hardware design, only one point of contact at a time is supported. Therefore, users can only feel the virtual object through a single contact point. This is very different from the way that we usually interact with surroundings and thus the amount of information that can be transmitted through this haptic channel at a given time is very limited. However, research has shown that this form of exploration, which maybe time consuming, can allow users to recognise simple 3D objects [4].

The major obstacle that prevents it from being used by visually impaired people is its price. The price for the desktop version of PHANToM, which is the cheapest one in the range, is over $10,000 US. Therefore, only research institutes and laboratories can afford to own one. This is highly contradictive to the purpose of assistive technology; we simply cannot develop accessible technologies on inaccessible devices for visually impaired people. Therefore, many researchers have been searching for another force feedback device which can be a cheaper alternative to the PHANToM.

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Figure 1. PHANToM from SensAble Technologies Inc.

The advent of Logitech WingMan Force Feedback (FF) mouse has given researchers an alternative. It looks like an ordinary computer mouse with attachments to a base which acts as a wrist rest and a mat (Figure 2). Forces can be felt from the device but they are not very strong and can be overcome by the user quite easily. Only two dimensional objects can be rendered on this device and the workspace is relatively small size. However, it only costs about $60 US which is affordable by most people. Moreover, developer toolkits are provided by Immersion Corp. for building applications. Therefore, the WingMan FF mouse has drawn a lot of attention in the research field and several research projects have been conducted to apply this device for visually impaired people [5-7].

Figure 2. Logitech WingMan Force Feedback mouse.

Although the WingMan FF mouse has shown some potential in rendering haptic objects for visually impaired people [5, 7], there have been very few studies conducted to compare its performance against the PHANToM. All the information we know about the devices is from their technical data sheets. The actual usability of these two devices may vary between different applications and their effectiveness in graph rendering is unknown. Therefore, we have designed a series of experiments to investigate their suitability and actual performance in bar chart exploration.

2. Multimodal Bar Chart Development

Bar charts are one of the most commonly used visualisation techniques and are often encountered daily, e.g. on newspapers, journals and magazines. They usually show discrete and independent variables. Our multimodal interface provided audio and haptic representations. Due to their physical configuration differences, the PHANToM and WingMan FF mouse used different haptic rendering techniques. The audio representation remained the same for both force feedback devices.

2.1. Haptic modelling on PHANToM

The haptic modelling technique used on the PHANToM is based on the polygons supported in the GHOST SDK. A virtual V-shaped groove is constructed to represent a bar. The haptic property of the bar is defined as touchable on the inside but not on the outside. Therefore, the PHANToM pointer can enter the groove from the outside wall but become trapped inside the groove. This technique has been evaluated in our previous study on haptic line graphs and its effectiveness has been confirmed by the findings [8]. Before rendering the haptic graph, data are scaled to fit into the frame and a small gap is created between the bars. A sample bar chart is given in Figure 3.

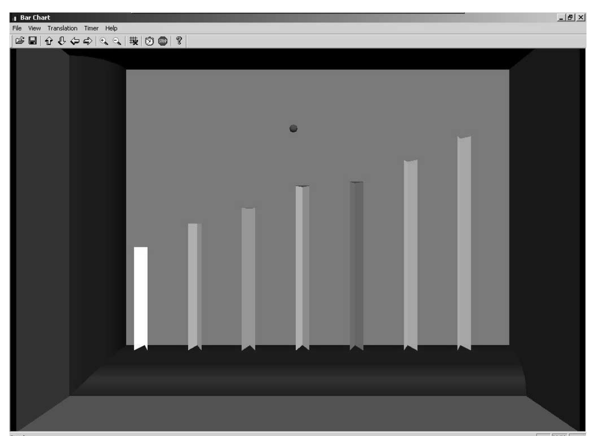

Figure 3. A sample PHANToM bar chart.

2.2. Haptic modelling on WingMan FF mouse

The haptic bars on the WingMan FF mouse are modelled by using the enclosure effects which are supported by the Immersion TouchSense SDK. A bar is simulated by an enclosed rectangular area. Once the mouse cursor enters the bar, it will be forced to remain inside. Users will thus have the same type of force feedback on the bars as in the PHANToM case. In order

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to exit from one bar to move to another, users just need to apply a bigger force to overcome the constraint force on the bar edges. A sample graph of the WingMan bar chart is shown in Figure 4.

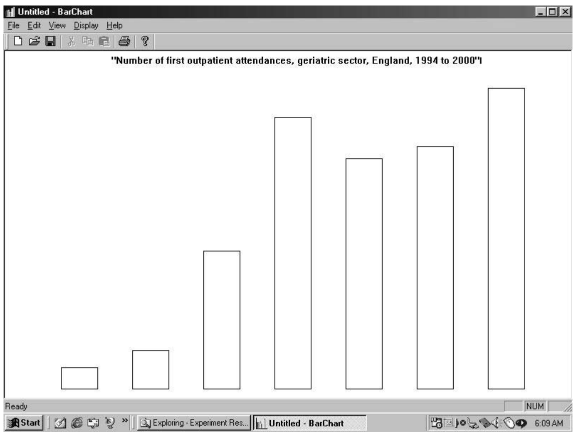

Figure 4. A sample WingMan bar chart.

2.3. Audio Implementation

The audio implementation includes speech and non-speech sound. The speech is generated by the text-to-speech engine provided by Microsoft's Speech SDK 5.0. Its purpose is to provide users with detailed information about the bar value. By pressing the right button of the mouse or the switch on the PHANToM stylus, the program will speak out the data value of the bar on which the cursor or pointer is located. The speech information includes the bar number and the bar value.

The non-speech sound is constructed by MIDI notes. 'Church organ' was used as the musical instrument. This is due to its continuous nature and wide pitch. Longer audio feedback on the bars will give a better indication of the data value to the user. Moreover, a large number of MIDI notes available can improve the audio resolution. In order to present the data, the bar's height on the graph is mapped to the pitch of the MIDI note. A tall bar produces a high pitch sound whilst a short bar produces a low pitch sound. The sound effect is triggered by detecting whether or not the cursor or pointer is on a bar. Whenever the pointer enters a bar, the assigned MIDI note will be played continuously unless the cursor or pointer moves away or the speech button is pressed.

3. Evaluation

A series of experiments was set up to evaluate the interface developed on the two different force feedback devices. Four experimental conditions were designed to investigate the effect of using different modalities in presenting bar charts. These conditions are listed below:

- WingMan audio.
- WingMan multimodal.
- PHANToM haptic.
- PHANToM multimodal.

Multimodal means combining audio and haptic representations. The reason for using WingMan audio instead of using WingMan haptic is because the results obtained in a pilot study have already shown a significant difference between the haptic and multimodal conditions. Users' performance in the WingMan haptic condition is much worse than in the WingMan multimodal condition. Therefore, we decided to investigate the effect of audio feedback in user's exploration, to see whether it is the main contributing factor in user's performance. The detailed information about the pilot study can be found in the Discussion section.

Two groups of bar charts were developed based on data obtained from the U. K. Department of Health's website [9]. The data describe the statistics of the hospitals in England from 1993/94 to 99/2000. They include the number of beds, ward attendance and out-patient rates. Twenty graphs were made and equally divided into two groups. There were seven bars on each graph.

Two groups of graphs were assigned to the experimental conditions in a random order. The order of conditions taken by each experimental participant was randomised. Therefore, learning effects and any possible unequal difficulties between graphs can be minimised. The experiment was conducted on two groups of sixteen people. They were recruited from the students at the University of Glasgow. One group of participants did the experiment on the WingMan FF mouse whilst the other group did the PHANToM experiment. No blind people took part in the experiment because of the results in our previous study did not show significant difference between blind and sighted people's performance in this task [8]. They performed equally well on the haptic interface developed for the line graph representation. Therefore, we decided to use blindfolded sighted people for this experiment and use blind people for the experiment in the next stage. Some information about our next experiment will be given in the Future Work section.

A set of four questions was designed for each graph. They were related to the contents on the graphs and the general purpose of using graphs such as trend detection and data comparison. The questions are listed below:

Q 1. Describe the overall trend of the data.
Q 2. Locate the highest bar on the graph.
Q 3. Locate the lowest bar on the graph.
Q 4. Find two bars which have closest values.

On the last question, those two bars can be either adjacent or separated by some other bars. Answers given by each participant and the time taken to answer all four questions were recorded. At the end of the experiment, participants filled in a questionnaire regarding the workload of each experimental condition. We used the NASA Task Load Index (TLX) [10] to determine the workload placed on participants in the experiment. A cursor log was also taken to record the cursor movements in the experiment.

We firstly conducted the experiment on the WingMan FF mouse and then on the PHANToM. The experimental procedures were identical in these two experiments. Participant were given four practice graphs before the experiment to familiarise themselves with the experimental procedures.

3.1. WingMan FF mouse results

The number of correct answers given by the participants is listed in Figure 5. Average number of correct answers to each question and the total number are shown. The trend of participants' performance in both audio and multimodal conditions is similar. They managed to obtain accurate answers for the first three questions but had difficulties to get the right answer for the last question. Finding similar heights between bars seems to be the hardest part in both conditions. The overall number of correct answers in the audio and multimodal condition is 82.81% and 88.59% respectively. There is a significant difference in the performance between the experimental conditions (T_{15}=3.278, p=0.005).

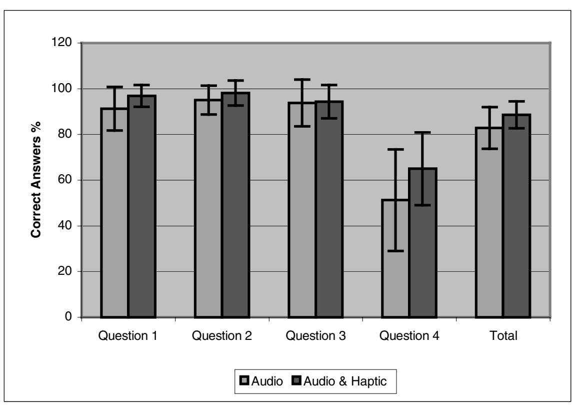

Figure 5. Correct answers in the WingMan experiment (standard error bars are shown).

The significant difference indicates that participants could obtain more correct answers in the multimodal condition than in the audio only condition. Question 4 has contributed to this difference. Audio seems to be effective to detect the data trend, and maximum and minimum bars. The major difference between audio and multimodal appears in comparing and finding similarities between bars. A multimodal approach is better than the audio only approach as haptics can be used to compare different bar heights on the graph. A user's spatial perception and proprioception can be used to locate the correct answers. Therefore, using audio alone cannot solve all the problems in graph exploration. Combining haptics and audio has shown its benefits in this experiment.

The average task completion time for each graph in the audio and multimodal condition is 122 and 127 seconds respectively. Statistical tests do not indicate any significant difference. Using a multimodal approach had no major effect on the task completion time as one more medium was introduced to the experiment. One explanation is that time spent on the haptic exploration counterbalanced the time saved from working out ambiguity of the audio feedback.

The data collected from the questionnaire filled in by the participants after the experiments in two conditions is averaged and plotted in Figure 6. The workload index is made up of six factors which are mental, physical and temporal demands, effort, performance and frustration level. Mental demand and effort received highest ratings. The scale of performance is inverted so that the higher the bar the lower the performance is. In general, participants rated less workload in the multimodal condition except on the Physical demand. This can be explained by the haptic interaction in the multimodal condition. Participants needed to apply more forces to compete against the feedback force.

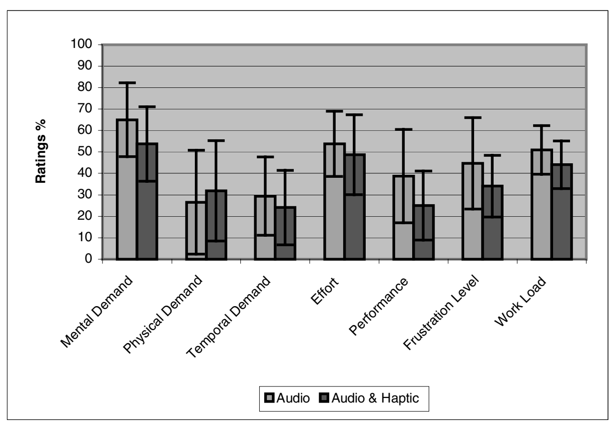

Figure 6. Task load index in the WingMan experiment.

The overall workload index again shows that the multimodal condition rating is significantly lower than the audio condition (T_{15}=2.542, p=0.023). The actual figure for the overall workload index is 50.92% in the audio condition and 44.08% in the multimodal condition. The lower workload index in the multimodal condition is crucial as it indicates that participants did not need to work so hard when both audio and haptics were present. Participants' feedback confirmed the improvement of the number of correct answers in the multimodal condition.

3.2. PHANToM results

The average number of correct answers in the PHANToM experiment is shown in Figure 7. A similar trend to the WingMan study can be seen. The first three questions again received higher scores whilst the last question has a lower figure. Overall, the total number of correct answers in each condition is quite close. They are 85.78% and 89.22% in the haptic and multimodal condition respectively. A t-test shows $T_{15}=2.112$ and $p=0.052$, which just missed the significance level.

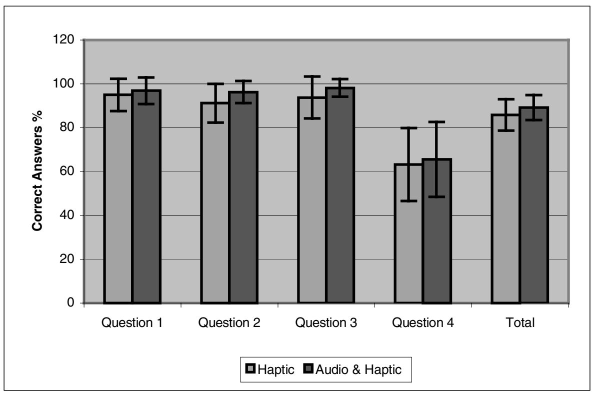

Figure 7. Correct answers in the PHANToM experiment.

From the results, the PHANToM showed its high performance in haptic representations. The force feedback alone is good enough to present information to participants. Moreover, its capability of providing 3 degrees of freedom force feedback is an advantage in users' interaction with virtual objects. They could get correct answers without visual feedback quite easily. Therefore, the number of correct answers in the haptic condition is significantly different than in the multimodal condition.

The average task completion time for a graph in the haptic and multimodal condition is 139 and 115 seconds. It shows that participants can finish the task much quicker in the multimodal condition ($T_{15}=3.034$, $p=0.008$). The task completion time gives a convincing performance improvement in the multimodal condition. Participants could use audio to speed up the process of locating answers for the questions without affecting the accuracy of their responses.

Participants' ratings on the workload index are plotted in Figure 8. The mental demand and effort again received higher ratings than the rest. The graph shows consistent reduction over all factors in the multimodal condition. The overall workload index of the haptic and multimodal conditions is 59.13% and 43.63%. A significant reduction in workload is confirmed ($T_{15}=7.538$, $p<0.001$). The multimodal approach is again proved to be more effective and requires less effort from participants, leaving more cognitive resources for dealing with the graphs.

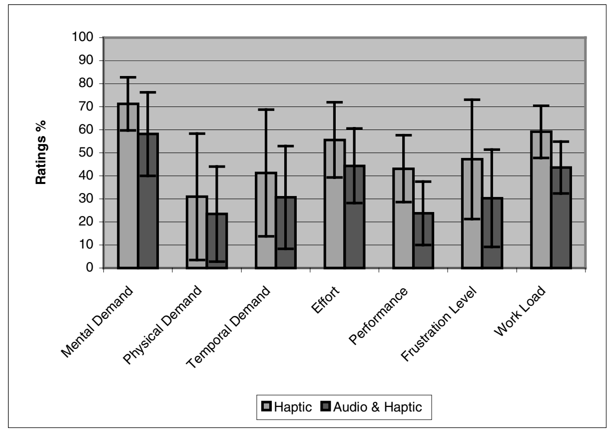

Figure 8. Task load index in the PHANToM experiment.

4. Discussion

Results obtained in the WingMan FF mouse experiment showed that the mouse is not so effective to convey information without audio feedback. The amount of force feedback is not enough to inform users about the graph content. This can be seen from the pilot study in which four participants performed the same task in the haptic only and multimodal conditions. The results listed in Figure 9 show that participants managed to extract very little information in the haptic condition when compared with the multimodal condition, especially on Question 4. The substantial improvement in the multimodal condition raised a question about the amount of audio contribution. It was interesting to know whether or not audio played a dominant role in the graph exploration and contributed to all the improvements in the multimodal condition. Therefore, we conducted the experiment on the WingMan in the audio and multimodal conditions. This would give us some indications of the audio influences.

Results from the WingMan experiment revealed that audio was not the only contributing factor in the participants' performance. Haptics also had a role to play in graph exploration. Significant differences between participants' performance in the audio and multimodal condition have proved this point.

The PHANToM experiment was conducted in the haptic and multimodal conditions. We did not investigate the audio condition because without force feedback, both devices become simple position input devices. The only difference is that the mouse works in a horizontal plane whereas the PHANToM works in the chosen vertical plane as in many other applications. The audio implementation on both devices is the same therefore we only investigated the haptic and multimodal conditions.

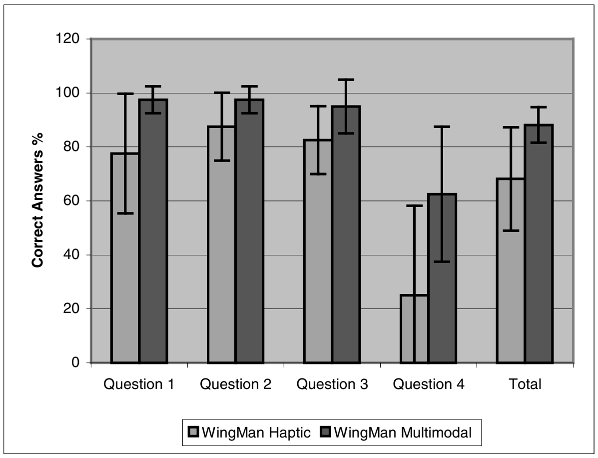

Figure 9. Correct answers in WingMan haptic only and multimodal conditions.

The experiment results have revealed that both devices can be used by participants to extract data from bar charts. The multimodal approach is better than either single modal approach. This can be seen from the objective measurements of correct answers and task completion time as well as the subjective measurement of participants' workload index. The WingMan FF mouse, which is not a very strong force feedback device, can give a better performance when audio feedback is introduced. This has similar effect on the PHANToM, which is already a good force feedback device, participants' performance can be enhanced by adding audio.

The most interesting thing is the similarity between participants' performance on the multimodal condition of the WingMan FF mouse and the PHANToM. Their performance is very close and the summarised results show very little difference between these two conditions (Figure 10). The average correct answers of the WingMan FF mouse and PHANToM is 88.59% and 89.22% respectively. The overall workload of these two conditions is also very similar, 44.08% and 43.63%. The only larger difference is on the task completion time which is 127 (52.71%) and 115 (48.11%) seconds and in the WingMan FF mouse and PHANToM respectively. However, this difference is not significant. Therefore, participants achieved almost the same performance level in these two conditions. Despite the capability differences between these two devices, using multimodal approach can actually minimise this difference and provide the same level of achievement in this situation.

The experiment results indicate that a cheaper device like the WingMan FF mouse can provide similar performance to the more expensive device PHANToM in this particular application. As graphs are usually in 2D, a WingMan FF mouse will be capable of this kind of rendering. Moreover, when audio feedback is used in the representation, the haptic role is changed from extracting information to assisting the detection and location of the interesting data. Therefore, even when the haptic cues from the mouse are not so strong, users can still make use of the device and understand the graph.

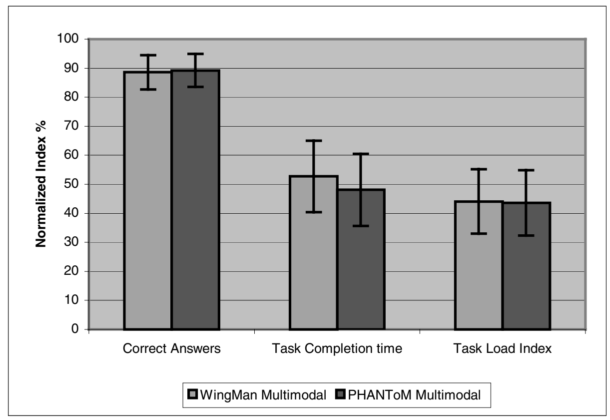

Figure 10. Summarised results of WingMan and PHANToM experiments. (All data are presented in percentage of obtained value against maximum possible value.)

As the amount of data on the bar charts used is not so large, audio can be used to represent the data very quickly. Users can obtain the answers for the trend information and maximum and minimum values based on the audio feedback. This can be seen from the results in the WingMan audio condition. The place for haptics to be used to extract information is in comparing data to locate similar values. It is not so easy to get the answer based on the musical notes. Even when synthesized speech was available, participants could not use it successfully because of the very large values of the bars. These values could be thousands to millions. Again the small number of correct answers in the WingMan audio condition illustrated this problem. Haptics become useful in this case, participants can compare the height of each bar by using the haptic cues. Therefore, significant improvement can be found in the multimodal conditions.

In this set of experiments, haptics took a major role in navigation whereas audio was used to perceive information about the graphs. This situation will remain in the type of graph on which haptic feedback does not directly represent the data value to the user. In the bar chart case, haptics is used to feel the boundary of the bars. The data value is determined by users' proprioception of the amount of movement on the bars. It is an indirect process of perceiving information compared with the instant indication of the MIDI notes. In other situations where the representing graphs are lines, curves or 3D surfaces, haptics represents the data value directly by different heights on the graph or attitudes in a 3D volume. The roles of audio and haptics may change and haptics will no longer simply be a navigation tool. However, the cross-modal effect on these types of graphs needs to be investigated further.

5. Conclusion

A series of experiments has been conducted to investigate the differences between two force feedback devices in single and multimodal conditions. The results have shown a great similarity in participants' performance on two very different force feedback devices in the multimodal condition. This indicates that in order to represent 2D plots like bar charts in our case, an economical device like the WingMan FF mouse can be used to great effect. A system developed on this device will really give visually impaired people access to the common data visualisation techniques like bar charts and line graphs. On the other hand, PHANToM works much better in other situations, for example, simulating 3D objects.

Multimodality is the key to the successful use of the WingMan FF mouse. Experimental results indicate that participants' performance is improved in the multimodal condition versus the single modal condition. Combining audio and haptic feedback enables users to locate and extract information effectively. In this particular case, haptics played a major role in navigation while audio assisted participants to understand the data more quickly. To present data trends, maximum and minimum points, audio feedback maybe enough. However, to compare data differences and find closest data values, haptics becomes useful and can reduce the ambiguity in the audio representation. To establish complementary audio and haptic inputs is the major issue in designing multimodal interfaces.

6. Future work

We have compared two force feedback devices in our experiments and found that the mouse and the PHANToM can give similar performance. The next step forward is to compare the virtual graph representation with the conventional tactile diagrams commonly used by blind people. Visually impaired people will take part into our experiments and their performance on the multimodal system and the tactile graphs will be investigated to see if we can improve access to information.

7. Acknowledgements

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