AN INVESTIGATION INTO VIRTUAL OBJECTS LEARNING BY USING HAPTIC INTERFACE FOR VISUALLY IMPAIRED CHILDREN

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ABSTRACT

Children play, touch, see and listen in order to build the foundation for later learning stage of solving problems and understanding themselves within the world surrounding them. However, visually impaired children have limited opportunities in learning new things compared to normal sighted children who have one of the important senses of a human being. Children gain knowledge through learning, playing, touching, seeing, listening and interacting with things that they are interested in. For visually impaired children, learning is different from normal sighted children in that they cannot go out and play with things without guidance and they are not able to see the picture or video of the things or objects like normal children are. A computer simulated virtual reality environment can provide better opportunities for visually impaired children especially in learning the shapes of new objects. An application utilizing the force feedback technology, i.e. Haptic technology, together with the aid of audio has been developed in this research project. Seven different objects are modelled to create haptic shapes for this application which allows visually impaired users to have a better learning environment and assists them in learning the shapes of different objects and also memorizing the shapes of different objects together with the name. The created application is deployed in a fully equipped computer with a stylus based haptic device and a set of speakers. The new architecture can provide an alternative learning environment for visually impaired children especially in learning the shapes of new objects. Based on the findings of this research, as 79% of the users agreed that virtual reality learning is useful in learning the shapes of new objects, the new architecture creates a significant contribution in a novel research area and assists visually impaired children in continuing their learning process.

Keywords: virtual objects, learning, visually impaired children, haptics, auditory

INTRODUCTION

Visually impaired children have limited opportunities in learning new things compared to normal sighted children. Learning at a young age is crucial for visually impaired children because they gain knowledge through learning, playing, touching, seeing, listening and interacting with things that they show an interest in. However, visually impaired children do not have the privilege of sight and because of this, learning new things can be very much different for these children compared to normal sighted children. It is extremely challenging for them to play and explore things around them without sight which is which is one of the most important human senses. According to the World Health Organization (2011), there are approximately 19 million children who are visually impaired worldwide.

Therefore, allowing visually impaired children to learn new objects by providing a virtual environment of the objects is one of the alternative solutions for them to experience learning. A virtual interface application which is connected with a haptic device and a set of speakers can assist them to improve their learning process and provide them a better learning environment without requiring the actual physical presence of the objects and without going outside to learn new things (Morelli, 2010) . Besides, the application can also help them to improve in remembering the shapes of different objects together with the names of the objects with the help of audio (Yu, Kangas & Brewster, 2003). The aim of the experiment is to find out how well the application can help visually impaired users in learning the shapes of new objects in a virtual environment and how well the users can use the virtual interface application with the help of a stylus-based haptic device.

In addition to audio and visual information, the provision of haptic feedback (the sense of touch) can profoundly improve the way children interact with virtual environments. Systems that support interfaces between a haptic device and a virtual environment are called Haptic Virtual Environments (HVEs). Recent researches (Yap, Marshall, & Yu, 2007; Yap, 2010) have shown that to have a satisfying experience in interaction with a HVE, the graphics and haptic update rates need to be maintained at around 30 Hz and 1 KHz respectively. In summary, HVE can provide an alternative opportunity for visually impaired children in learning new things without having actual physical objects.

LITERATURE REVIEW

There are many researches that have helped the learning process of visually impaired people in different ways as visually impaired people have limited opportunities in learning new things. Kaklanis et al. (2008) researched on the haptic rendering engine of web pages for blind users. The main purpose of their research was to transform the normal web pages to 3D based web pages for visually impaired users. They mentioned that most of the work was done on audio rendering of the contents of web pages for blind users and because of this, their project was to try rendering the elements of the web pages into the haptically enhanced widget (hapget). The users of the application are required to provide the URL of the webpages that they would like to browse and then the application will transform the webpages into three dimensional haptic web pages. Although the project idea was good, they faced some limitations in generating 3D based web pages from normal webpages.

A study on assessing haptic properties for data representation was done by Wall and Brewster (2003). The main objective of the study was to provide a flexible way for blind people to have access to graphical information. The idea was to replace the traditional way of graphical data representation for blind users which includes presenting the graphical data on specially prepared data. In this research, Phantom device was used to explore the haptic graphs which include height and shape. The idea of the research was a great approach in learning and utilizing the features of haptic devices. However, the research was mainly for blind people who want to learn mathematics and science-related subjects or about careers in such areas. There are no specific features for visually-impaired children, especially those who are starting their learning stage at a very young age.

Yu et al. (2003) developed a system which helps blind people to create virtual graphs on the web. The main objective of the research is to provide graphical information to blind people and to allow them to create types of graphs such as line graphs, pie charts and bar charts by using a low-cost Haptic device, the Logitech WingMan Force Feedback Mouse, and web audio. They have tested the system with both blind and sighted people by using audio only, haptic only, and audio with Haptic. Based on the results, audio with Haptic condition has the highest accuracy. Haptic with audio applications for blind people is useful. This application is helping blind people to create simple pie, bar and line charts, but could not help them in learning the shapes of different objects.

Another study has been done by Oliveira, Cowan, Fang, and Quek (2010) on how gaming can be used to help the embodied skills of visually impaired individuals with the assistance of haptic device or technology. In their research, the technology of haptic glove was used to allow visually impaired students to access the pointing behaviour of instructor in mathematics and science instruction when the instructor is performing together with the help of audio. The aim of the project was to solve problems for blind students as they do have the capabilities of reference when the lecturer is using instructional material during the class and to improve the embodied skills of communication between the tutor and student in the class. In their study, it mentioned that the gaming approach in the class helped to improve in gaining interaction from students in the class. The system helps the student in fingertips reading together with speech.

An approach to haptic emulation of games was conducted by Gutschmidt, Schiewe, Zinke, and Jurgensen (2010) on Haptic Sudoku for the blind. The research project was done using a new haptic display for blind users and using Sudoku as a game paradigm. Sudoku squares are represented on the haptic display and the users will be able to enter numbers and notes in the Sudoku square boxes. The blind user will be able to access the information through the sense of touch and interacting by movements of fingers. The blind user will be able to know the outcomes of actions with the help of audio. The research provides opportunities for those blind users in playing the particular board or card game, for example Sudoku. However, it would not help the visually impaired children in learning the shapes of different objects as the system did not provide any distinguished features on learning shapes of different objects.

Moreover, Magnusson et al. (2009) has made geographical information to be more effective and useful with the aid of haptic techonology. The idea of the project was to provide the geographical information with the sense of touch or hearing when the user has impaired eyesight (e.g. when the user is exploring the environment to access the information). Based on the growing number of mobile devices being used, the researchers are planning to make use of mobile devices in order to provide location-based services to mobile device and to make geographical information more effective and usable by users especially when they are in a situation of visual difficulties. However, their previous study shows that there are some barriers such as lack of knowledge and tools to practise, cost and time in order to develop the project, and because of this, they are still in the process of planning to develop this project in the near future.

Tzovaras, Moustakas, Nikolakis, and Strintzis (2007) proposed a highly interactive and extensible haptic Mixed Reality training system that allows visually impaired persons to navigate into real size Virtual Reality Environments by using CyberGraspTM haptic device. Superquadrics-based collision detection algorithm is integrated into the system to allow real-time collision detection in complex environments. They used various evaluation tests to identify the importance of haptic, auditory and multimodal feedback. In their test, the user is asked to cross the traffic light using virtual cane. The test was being tested in the test room while the user is wearing the CyberGraspTM and waistcoat of FCU for the CyberGraspTM. Their evaluation results were promising. However they experienced some technical limitations in the case of cane simulation applicability as the system cannot prevent the user from penetrating objects in a virtual environment but leaves room for improvement and further research. This approach would improve the life of the blind but this can only help visually impaired adults and does not provide any privileges to visually impaired children in learning the shapes of new objects.

Amemiya, Maeda and Ando (2008) have proposed and developed an interactive force-sensation-based navigation system as conventional human navigation systems are available through visual and auditory modality and lacks the use of Haptic modality. They indicated that Haptic modality provides non-verbal interaction so that it is less distracting than audio and visual modalities and can be used by both adults and children. The potential of application is accessed by questionnaires based on haptic sensation information and directional information of Haptic sensations for interactive systems. Based on their results, users are well perceived of force sensation and aware of directional information and provided directional information is intuitive. Besides, most of the users recognized the importance of force sensation in interactive systems. In their research, they pointed out the main use of Haptic sensing modality rather than audio and visual modalities.

Bradley and Dunlop (2005) have done an experimental investigation into Wayfinding Directions for visually impaired people. The main objective of their study is to investigate different mental and physical demands among sighted and visually impaired users by giving them two different sets of verbal instruction to direct them to four landmarks. Both sighted and visually impaired individuals are involved in their study and involved two different sets of route direction descriptions from sighted participants and visually impaired participants. Based on their results, workloads between sighted and visually impaired individuals are different. Visually impaired individuals were less frustrated and required less mental and overall effort compared to normal sighted individuals when condition two route direction descriptions from visually impaired participants is given to normal sighted participants. The whole research intention is to investigate different mental and physical demands between sighted persons and visually impaired persons but does not involve any contribution to research in teaching different shapes of objects to visually impaired children.

A study group, Kahol, French, Bratton, and Panchanathan (2006), has done a study on learning and perceiving colours haptically. The main objective of the study was to allow the blind individuals to have colour perception and basic information in assessing different colours. In their study, the researchers mentioned that learning to differentiate colours for visually impaired individuals is more difficult than learning the shapes and textures of the objects as the features of colours are purely visual whereas the features of shapes and textures can be learned through touch. They mentioned that learning features of different colours is not achievable through touch sensors or with the help of audio as the presentation of colour information to blind people is complicated. Because of this, they used the temperature based colour representation, for example red is hot, green is cool. Even the idea of the study did not provide any interest in learning shapes of different objects; it was a great approach in helping visually impaired individuals in learning different features of colours.

Crossan and Brewster (2008) mentioned that providing non textual information to visually impaired computer users is one of the challenging problems, when describing the teaching shape information. PHANTOM OMNI device, which is developed by SensAble Technologies (2011), were used by both sighted and visually impaired users in this study. The study involved asking the users to feel the 2D trajectory by using a haptic device and the user will then be asked to redraw the shapes of 2D trajectory. Their test results proved that visually impaired computer users can perform better if they are provided a multimodal haptic device together with audio playback of the shapes rather than haptic device only.

Sanchez and Tadres (2010) have done the research on using audio and haptic based virtual environments for blind people. The main objective of the study was to test the hypothesis of using audio and haptic together compared to using them separately. They developed a virtual-environment video game which uses both audio and haptic interfaces that allow the stimulation of orientation and mobility skills of blind people. They mentioned that it is a complex task for blind people to navigate through unfamiliar spaces. The project was developed to train the orientation and mobility of blind people in virtual environments by using specially designed interfaces to receive sounds and haptic feedback from the environment. Based on their results, it has shown that it is more effective if both audio and haptic are used together and it is less effective for blind users in identifying complex shapes via haptic alone.

Patomaki, Raissamo, Salo, Pasto, and Hippula (2004) have conducted the survey on the experience of haptic interface environments used by a group of visually impaired children. Based on their research, they conclude that the computing environments will be usable by visually impaired children if the tasks of computing environments are carefully designed with the aid of haptic and auditory features. A range of multimodal applications were designed for use in their research. The candidates for the research are aged between 3.5 years to7.5 years. The research was a great approach in studying the nature of the learning process of visually impaired children. However, the applications they used were not targeted at teaching shapes of new objects to visually impaired children.

METHODOLOGY

The system was evaluated with a sample of 13 visually impaired users of between the ages of 8 and 12 years from SMK (Klang) and a sample of 11 blindfolded sighted users, students from School of Computer Technology, Sunway University and their friends. Visually impaired users from Target research subjects are only visually impaired and do not have any other additional disabilities. All participants in both groups have no prior exposure to the chosen stylus based haptic device, PHANTOM Omni. Sighted users are blindfolded during the study.

Virtual reality haptic application is implemented by using OpenHaptics API and C++ programming language with the help of audio API called irrKlang Version 1.3.0. The application provides seven different common objects and visually impaired users to be able to feel the shapes of the objects with the help of a haptic device and hear the names of the objects with the help of an audio device. PHANToM Omni, a stylus-based haptic device which is developed by senseable technologies, is chosen for trajectory playback in this research. It is a pen-based haptic device which provides high resolution force feedback and allows users to touch and manipulate virtual objects. The following figure shows the high level architecture of the system.

Figure 1: High-Level Architecture of System.

The task in this study is to allow users to feel virtual objects in virtual haptic interface and hear the name of the objects that they touch with the help of audio device. The application is deployed on a fully equipped desktop or laptop PC which can support Microsoft Visual Studio 2005 Version 8.0 and Open Haptics Academic Edition Version 2.0. In this study, a fully equipped desktop with specification of Intel ® core ™ 2 Duo CPU E7200 ,2.53GHz with 2.00 GB of RAM is used. Desktop PC should be able to support firewire port, or additional firewire cardbus can be used to connect the desktop PC with the chosen stylus-based haptic device, PHANTOM Omni. The desktop or laptop PC will then be connected to the stylus-based haptic device and a set of speakers. The application is ready to be executed only after the chosen haptic device is connected to the desktop PC and can be executed using Microsoft Visual Studio. Finally, visually impaired users will be able to use the application with the help of stylus-based haptic device called PHANTOM Omni.

The model used in the research is shown in Figure 2. It uses a combination of both incremental and evolutionary developments, consisting of analysis, design, development, test bed and experiment, and validation stages. All the stages are used to produce a prototype and the processes are repeated until all the requirements are fulfilled. In the analysis stage, gathering information and defining the requirements took place. According to the requirements gathered in the analysis stage, the design metaphor for virtual environment and scenes are defined. In the development stage, implementation of software using feature driven development is established. A test bed is set up to perform the experiment and the results are obtained from the users. In the validation stage, usability evaluation is conducted to obtain data about the user's acceptance of the software and device.

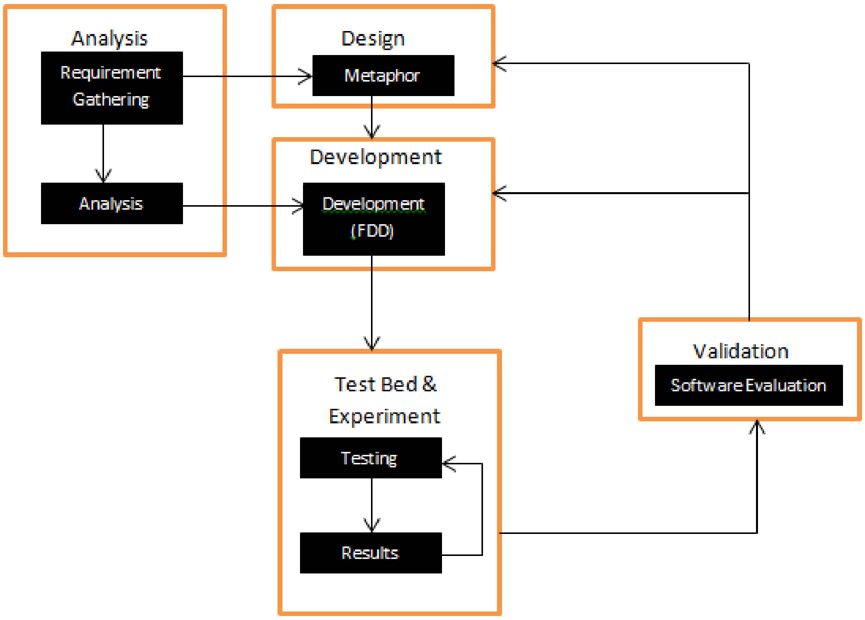
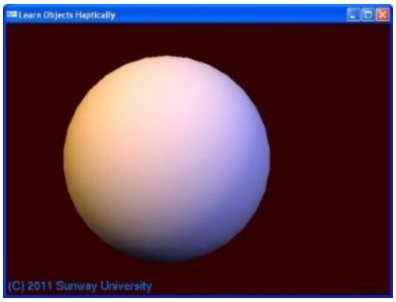


Figure 2: High Level Architecture of Methodogy

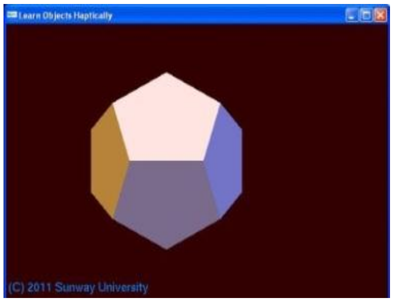
In order to perform the test, a total of seven objects are selected to be created as virtual objects, namely;

1. A sphere with a radius of 2.0cm, 30 slices (number of subdivisions around the Z axis (similar to lines of longitude)) and 30 stacks (number of subdivisions along the Z axis (similar to lines of latitude)).
2. A cone with a radius of 1.4cm , height of 1.6 cm and (number of subdivisions around the Z axis (similar to lines of longitude)) and 30 stacks (number of subdivisions along the Z axis (similar to lines of latitude)).
3. A cube with width, height and depth/length of 2.5 cm.
4. A dodecahedron (12-sided polyhedron centered at the origin) with 2.5 vertices
5. A tetrahedron (4- sided polyhedron centered at the origin) with 2.0 vertices
6. A cylinder with parameters of quadric (Specifies the quadrics object created with gluNewQuadric), radius of the base and the top of cylinder of 1.0 cm, height of cylinder of 2.0 cm, 52 slices of divisions horizontally and 100 stacks of divisions vertically.
7. A torus with innerRadius (Radius of tube) of 0.5, outerRadius (Radius of path) of 0.8, sides (Facets around tube) of 30 and Rings (Joints along path) of 30.

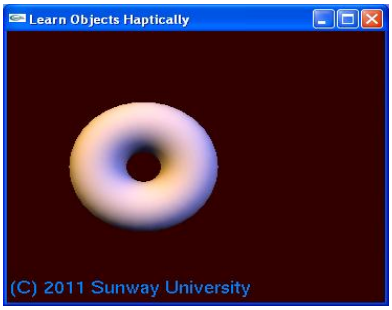
A questionnaire is used as one of the research instruments to gather information from targeted respondents, the visually impaired users, for the research. The questionnaire is prepared before carrying out the usability testing with the targeted visually impaired users. The face-to-face questionnaire administration mode, whereby an interviewer presents the items orally, is used, as targeted respondents are visually impaired and they need assistance in reading the content from the questionnaire. By using questionnaire, users' interests in learning the shapes of new objects haptically using virtual objects in a virtual environment can be examined. Questionnaires are used to test the user perception on learning the shapes of different objects by using a stylus-based haptic device. A training period for the users to familiarize themselves with the device is provided before the actual experiment is started.



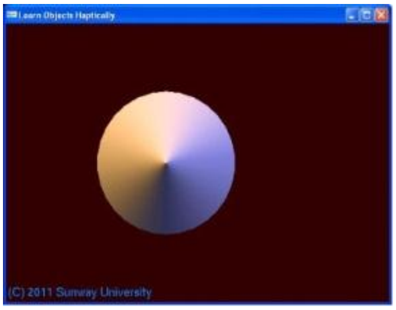
(a) Haptic Shape of Sphere



(b) Haptic Shape of Dodecahedron

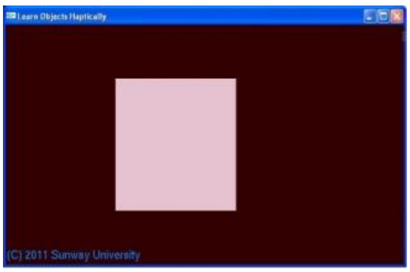


(c) Haptic Shape of Torus

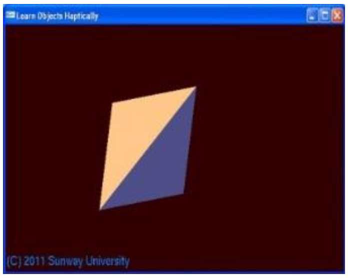


(d) Haptic shape of Cone

(e) Haptic Shape of Cylinder



(f) Haptic shape of Cube



(f) Haptic shape of Tetrahedron

Figure 3: Selected Virtual objects for Visually Impaired Children

The users are allowed to play with the stylus-based haptic device for four minutes in order to get familiar with the device. At the same time, they are also briefed on the purpose of the application and the usage of the device. Once the user has adapted to the usage of the device, the testing on the application begins. Users are asked to move the device around on the computer screen and let them experience the application which provides the sense of touching the objects. The name of the corresponding touched object will be spoken out with the help of an audio device when the user uses the stylus-based haptic device and touches the object so that users will able to know what the shapes are that they are touching together with their names. Once the users become familiar with the shapes and names, the audio will be switched off. The users will then be asked to touch the shapes again and asked the name of objects that they are touching. This testing is carried out to know whether the application can help the users in training their memory on how well they can remember the shapes of objects together with the names with the help of the stylus-based haptic device and the audio device. Questionnaires are used to test the user perception on learning shapes of different objects by using the stylus-based haptic device. It also allows testing on whether set sizes of 3D shapes, types of shapes, etc. are effective for visually impaired users.

RESULTS AND DISCUSSION

Experimental testing was done on two groups of users; thirteen visually impaired users and eleven blindfolded sighted users. Two groups of users are used in this study in order to compare the users' acceptance and mental model of representation in a virtual environment and also to extend the research details in future by comparing results from two different categories. The sphere, cube, cone, tetrahedron, dodecahedron, torus and cylinder are chosen for use in this testing as those are the most common shapes for children. Visually impaired users are tested with shapes of sphere, cube, cone, tetrahedron and dodecahedron and blindfolded sighted users are tested with shapes of sphere, cube, cone, tetrahedron, dodecahedron, torus and cylinder. Upon the suggestion of the trainer from a school for the blind, two more shapes are added to the testing with the blindfolded sighted users. Only seven objects in all are chosen, as the targeted outcome is only for prototyping. Users are also tested on how accurately they can guess the correct shapes of the objects together with the names. The results of the visually impaired users who guess the shapes of objects and names correctly are shown in Figure 3 and the results of the blindfolded sighted users are shown in Figure 4. Based on the results by visually impaired users, 13 out of 13 users guessed correctly the shapes of the common objects such as sphere, cone and cube together with the names. However, only 3 out of 13 users guessed correctly the shape of tetrahedron and 5 out of 13 users correctly guessed the shape of dodecahedron as these types of shapes are complex for young learners. Based on the results by blindfolded users, 11 out of 11 users guessed correctly the shapes of sphere and torus together with the names. However, users have confusion between cone and cylinder and only 9 out of 11 users can correctly guessed the shape of cone and 4 out of 11 users guessed correctly the shape of cylinder. As for the complex shapes such as tetrahedron and dodecahedron, 4 out of 11 users accurately guessed the shape of tetrahedron and 6 out of 11 users guessed accurately the shape of dodecahedron. Accurate attempts for cube are fewer compared to attempts by visually impaired users, and only 8 out of 11 users could correctly guess the shape of cube.

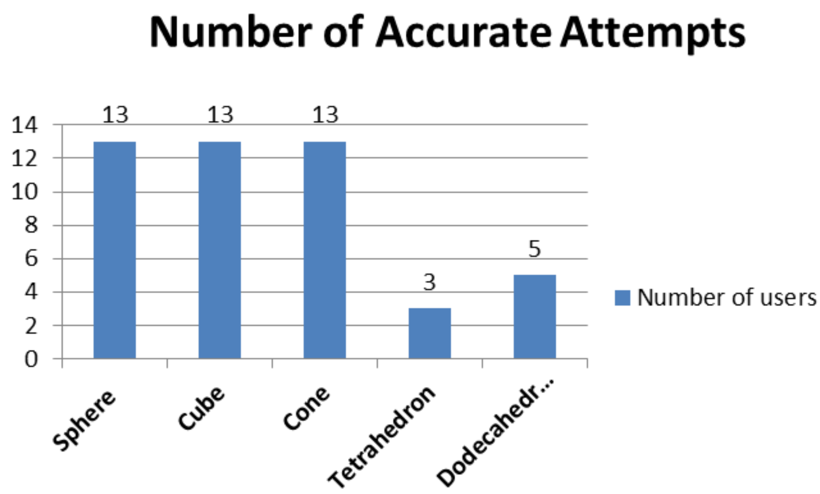


Figure 4: Numbers of Accurate Attempts on Shapes of Objects by Visually Impaired Users. (Total of 13)

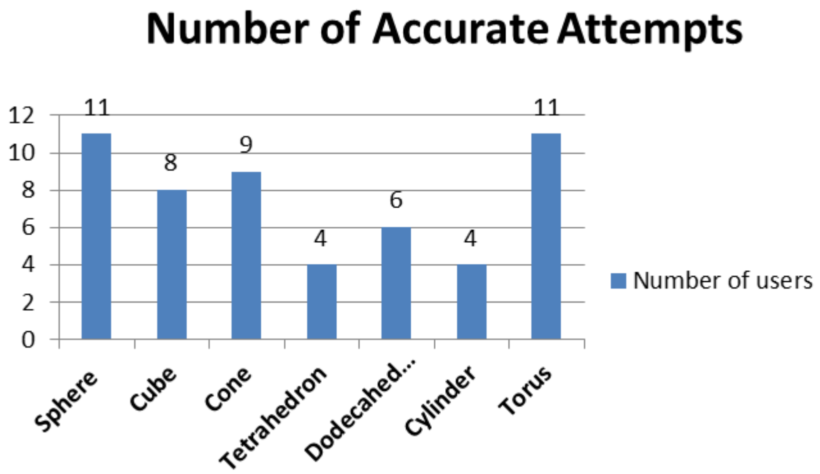


Figure 5: Numbers of Accurate Attempts on Shapes of Objects by Blindfolded Users. (Total of 11)

Users are also asked to rate their satisfaction on the application and haptic device in terms of clearance of provided audio, ease of use of the stylus-based haptic device, performance of application in helping the users to remember the shapes of the new objects and improving the imagining of the shapes of different objects. The ratings are 1 to 10 in terms of 1 for least satisfied and 10 for most satisfied. The results of the contents mentioned provided by visually impaired users are shown in figure 5 and results provided by blindfolded users are shown in figure 6.

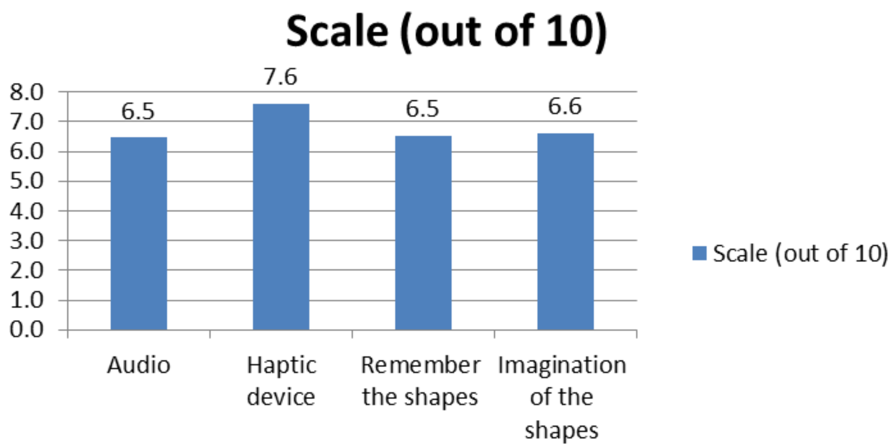


Figure 6: Summary of Users (Visually Impaired) Satisfaction on Application with Haptic Device.

Based on the results provided by the visually impaired users in Figure 5, the rating on the audio which played out the names of the objects that the users touch is 6.5 out of 10. Based on the observation on the experiment by the visually impaired users, it is learned that users are able to adapt quick familiarity with the haptic device, and its ratings for haptic device is 7.6 out of 10. The ratings on the helpfulness of the application for users to remember the shapes of new objects and the effectiveness of application in improving the imagining of the shapes of different objects are 6.5 and 6.6 out of 10 respectively.

Based on another set of results which is provided by the blindfolded users in Figure 6, the rating on the audio which played out the names of the objects that the users touch is obviously the same as the rating provided by the visually impaired users, which is 6.5 out of 10. However, due to the users experience with IT, their ratings for the haptic device are lower than visually impaired users' and they rated 6.6 out of 10. The rating on the helpfulness of the application for the users to remember the shapes of new objects and the effectiveness of application in improving the imagining of the shapes of different objects are 5.5 and 5.3 out of 10 respectively. The average time to complete the whole task for both the visually impaired users and the blindfolded users is 20 minutes. In summary, 77% of the visually impaired users and 82% of the blindfolded users agreed that virtual reality learning is useful in the learning of the shapes of new objects.

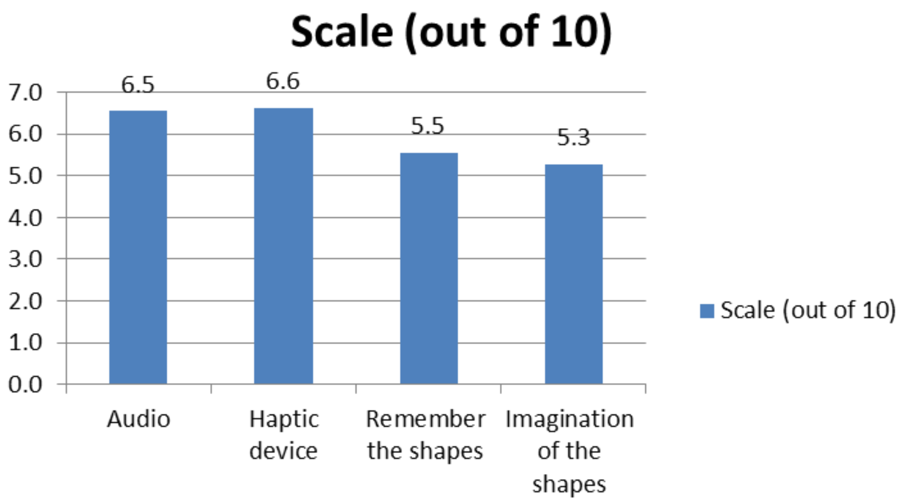


Figure 7: Summary of Users (Blindfolded) Satisfaction on Application with Haptic Device.

CONCLUSION AND FUTURE WORK

In this paper, an architecture which allows visually impaired users to learn the shapes of new objects in a virtual reality environment has been developed. The new architecture uses a stylus-based haptic device in order to allow the users to feel the shapes of virtual objects and provide the names of the objects with the help of audio. The majority of the users agreed that the system can help visually impaired users to remember the shapes of new objects and the virtual reality environment is useful in learning the shapes of new objects. Based on the results provided by both the visually impaired and the blindfolded users, 79% of the total users agreed that virtual reality learning is useful in learning the shapes of new objects. For future extension, we plan to work on more than one type of haptic devices in order to compare the users' performance and acceptance of device and application and the accuracy of the user's attempt.

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REFERENCES

Bradley, N. A., & Dunlop, M. D. (2005). An experimental investigation into wayfinding directions for visually impaired people. *Personal and Ubiquitous Computing*, *9*(6), 395-403.

Amemiya, T., Maeda, T., & Ando, H. (2009). Location-free haptic interaction for large-area social applications. *Personal and Ubiquitous Computing*, *13*(5), 379-386.

Crossan, A., & Brewster, S. (2008). Multimodal trajectory playback for teaching shape information and trajectories to visually impaired computer users. *ACM Transactions on Accessible Computing, 1*(2), 12.1-12.34.

Gutschmidt, R., Schiewe, M., Zinke, F., & Jurgensen, H. (2010). Haptic emulation of games: Haptic sudoku for the blind. In F. Makedon, I. Maglogiannis & S. Kapidakis (Eds.), *PETRA '10*: *Proceedings of the 3rd International Conference on Pervasive Technologies Related to Assistive Environments.* New York: ACM Press. doi:10.1145/1839294.1839297

Kahol, K., French, J., Bratton, L., & Panchanathan, S. (2006). Learning and perceiving colors haptically. *Assets '06*: *Proceedings of the 8th International ACM SIGACCESS Conference on Computers and Accessibility* (pp.173-180). New York: ACM Press.

Kaklanis, N., Calleros, J. G., Vanderdonckt, J., & Tzovaras, D. (2008). A haptic rendering engine of web pages for blind users. *AVI '08: Proceeding of the Working Conference on Advanced Visual Interfaces* (pp. 437- 440). New York: ACM Press.

Magnusson, C., Tollmar, K., Brewster, S., Sarjakoski, T., Sarjakoski, T., & Roselier, S. (2009). Exploring future challenges for haptic audio and visual interfaces for mobile maps and location based services. *LOCWEB '09: Proceedings of the 2nd International Workshop on Location and the Web.* New York: ACM Press.

Morelli, A. (2010). Haptic/audio based exergaming for visually impaired individuals . CAN *SIGACCESS Accessibility and Computing*, *96*, 50-53.

Oliveira, F., Cowan, H., Fang, B., & Quek, F. (2010). Fun to develop embodied skill: How games help the blind to understand pointing. In F. Makedon, I. Maglogiannis & S. Kapidakis (Eds.), *PETRA '10*: *Proceedings of the 3rd International Conference on Pervasive Technologies Related to Assistive Environments.* New York: ACM Press. doi:10.1145/1839294.1839313.

Patomaki, S., Raisamo, R., Salo, J., Pasto, V., & Hippula, A. (2004). Experiences on haptic interfaces for visually impaired young children. *ICMI '04: Proceedings of the 6th International Conference on Multimodal Interfaces* (pp. 281-288). New York: ACM Press.

Sanchez, J., & Tadres, A. (2010). Audio and haptic based virtual environments for orientation and mobility in people who are blind. *ASSETS '10: Proceedings of the 12th International ACM*

SIGACCESS Conference on Computers and Accessbility (pp. 237-238). New York: ACM Press.

Sensable Technologies. (2011). PHANTOM OMNI [Apparatus and software]. Retrieved from Sensable Technologies site: http://www.sensable.com

Tzovaras, D., Moustakas, K., Nikolakis, G., & G. Strintzis, M. (2007). Interactive mixed reality white cane simulation for the training of the blind and the visually impaired. *Personal and Ubiquitous Computing, 13*(1), 51-58.

Wall, S. A. & Brewster, S. A (2003). Assessing haptic properties for data representation. In G. Cockton & P. Korhonen (Eds,), *Proceedings of ACM CHI 2003 Conference on Human Factors in Computing Systems, 5-10 April 2003 Ft. Lauderdale, Florida,* (pp.858-859). New York: ACM Press.

World Health Organization. Media Center. (2011). Visual impairment and blindness. Retrieved from http://www.who.int/mediacentre /factsheets /fs282/en/

Yap, K. M. (2010). Supporting collaborative interaction with real time force feedback in distributed haptic virtual environments over IP networks. In J. S. Pan et al. (Eds.), *Genetic and evlutionary computing: Proceedings Fourth International Conference on Genetic and Evolutionary Computing, 13-15 December 2010, Shenzhen,China* (pp. 495-500). Los Alamitos, CA: IEEE Compuer Society.

Yap, K. M., Marshall, A., & Yu, W. (2007). Providing QoS for multimodal system traffic flows in distributed haptic virtual environments. In N. Agoulmine, R. Boutaba & A. Serhrouchni (Eds.), *2007 1st International Global Infrastructure Symposium*), *2-6 July 2007 Marrakech, Morocco*, (pp. 153-158). Piscataway, NJ: Institute of Electrical and Electronics Engineers.

Yu, W., Kangas, K., & Brewster, S. (2003). Web-based haptic applications for blind people to create virtual graphs. *Proceedings of the 11th Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems (HAPTICS 03),* (p. 318). Washington, DC: IEEE Computer Society.