# Design, Development, and Evaluation of Haptic- and Olfactory-based Application for Visually Impaired Learners

**Chit Su Mon[1], Kian Meng Yap[1] and Azlina Ahmad[2]**
**[1]Sunway University, Malaysia**
**[2]Universiti Kebangsaan Malaysia, Malaysia**
07013782@imail.sunway.edu.my
kmyap@sunway.edu.my
azlinaivi@ukm.edu.my

**Abstract**: Educational entertainment or edutainment is a popular approach to allow learners experience a fun learning environment while acquiring knowledge. Currently, this approach is widely used and has promising benefits, whereby not only it provides a fun learning environment but also cause learners to hardly notice the learning process. However, as there are a minimum of 2.2 billion people worldwide with vision impairment or blindness, this approach can be a challenging experience for them. It is thus important to provide equal opportunities for these members of the community in the teaching and learning environment. Owing to the limited applications available for the visually impaired in virtual edutainment tailored for them, this research aims to design and develop an edutainment application for visually impaired users using a user-centered design. The application allows users to touch 3D objects using Touch by 3DSystems. In addition, sounds and smells will be released from the speaker and olfactory devices, respectively. The usability and satisfaction of users toward this application was tested on the visually impaired as well as blindfolded users using a 7-point Likert scale questionnaire. This questionnaire was constructed in accordance with USE (Usefulness, Satisfaction, and Ease of use) by Lund. A total of 10 participants – including visually impaired teachers and blindfolded students – participated in this study. Participants in this study agreed that the proposed application is useful, easy to use, easy to learn, and were satisfied with the application. The average rating of the results out of 7 was 5.92 for usefulness, 5.6 for ease of use, 6.22 for ease of learning, and 6.25 for satisfaction.

**Keywords**: Haptic, Audio, Olfactory, Edutainment learning, Visually Impaired

## 1. Introduction

Education is life's essential factor, and thus, it is important to ensure that every child receives equal learning opportunities. Education must be accessible not only to ordinary children but also to those with special needs. Technology-based learning is widely available, including educational applications for children (Mon and Subaramaniam, 2020). They range from accessing school syllabus to learning extracurricular knowledge such as moral values (Jian, Mon and Subaramaniam, 2020). Thus, educational entertainment or edutainment has become one of the popular approaches used in the teaching and learning environment. Edutainment applications usually involve rich media content and are only suitable for learners with sight. They are not suitable for visually impaired leaners. There are about 2.2 billion visually impaired or blind people globally (World Health Organisation (WHO), 2021), and vision impairment is one of the most serious issues with direct and indirect economic impacts. With the rapid growth of virtual learning tools, the accessibility to these tool-assisted environments remains lacking for the visually impaired.

The sense of touch applies forces, vibrations, or motions on the user. It has been widely used in investigations on both the sighted and visually impaired (Sreelakshmi and Subash, 2017). Haptic is typically used together with visual (sight) and audio (sound) media in edutainment applications for the visually impaired. An application that includes multiple senses such as visual, auditory, touch, and haptic is developed to provide multivariate data representation in multimodal virtual environment (Yasmin, 2019). The integration of visual presentation and audio feedback helps further exploration of the data and the haptic glyph, which enables users to feel the different shapes, sizes, and other physical properties such as friction.

Another interesting and useful media to enhance user experience is the olfactory media. It facilitates knowledge acquisition and content understanding for the user (Covaci, et al., 2018). However, there is no concrete research conducted to improve the users' experience using olfactory media for the visually impaired in the teaching and learning environment. Learners with visual impairment typically opt for non-technology assistive tools to learn shapes in an inclusive classroom, and thus, will not be engaging if visually impaired users were asked about existing edutainment application in their learning process. To the best of our knowledge, there is no research


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that explores or designs applications that use haptic, olfactory, and audio together for the visually impaired in a virtual learning environment. It is important to understand how and what to learn, as learning is essentially the dynamic modification of memory (Savage, 2018). What a user reads or sees alters their memory, which subsequently does the interpretation to input the data as knowledge. Olfaction is the sense of smell and involves specialized sensory cells in the nasal cavity and molecules in the sensory system to transmit signals to the olfactory bulb ( Vokshoor and Meyers, 2013). There are two olfactory systems in humans; the primary one detects volatile chemicals, whereas the secondary one detects fluid chemicals. Smell memory in humans is strong in recalling previous situations or conditions when a particular smell was encountered.

As mentioned earlier, because of a significant proportion of population with visual impairment, it is important to provide equal opportunity in teaching and learning for the visually impaired. Virtual education or e-learning can assist learners in many ways and provide a number of advantages. However, there are many limitations for visually impaired learners to use e-learning or virtual learning applications. In the context of learning different shapes of fruits, visually impaired learners are unable to see the way sighted learners see the shapes by looking at the visual media via e-learning application. According to a study conducted by Mon, Yap and Ahmad (2019a), visually impaired users relied on olfactory sense in order to identify different shapes. However, there is no research on how the olfactory system can benefit the visually impaired.

Therefore, this research aims to design and develop a 3D-based olfactory, haptic–audio (3DOHA)-enabled virtual learning application for the visually impaired. When designing the application, user-centered design (UCD) was used as this approach primarily focuses on the requirements of the user, thereby producing highly usable and accessible products. UCD is used in a wide array of applications ranging from standalone mobile-based learning applications to applications for children with special needs. The current research was targeted toward an application as smart phones are widely used in education and has become an important tool to provide suitable contents that fosters collaboration between children and parents (Wardhana, et al., 2017).

Current available assistive applications for the visually impaired in learning and learning limitation of visually impaired learners in virtual edutainment environment are elaborated in the background section. Methodology section discusses designing the prototype, choices of haptic and odor devices, development of the prototype as well as questionnaire and participants. Results and discussion will then be discussed, followed by conclusion and future recommendation of the research. The block diagram of the structure of this paper is shown in Figure 1.

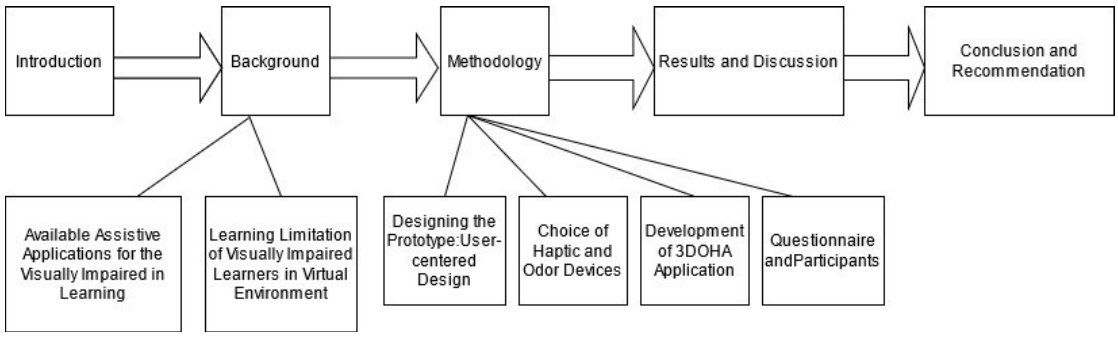


**Figure 1**: Block diagram of the structure of this paper

## 2. Background

### 2.1 Available Assistive Applications for the Visually Impaired in Learning

In accordance with the background study, assistive tools for visually impaired can be categorized into visual, tactile, and audio. Braille is one of the most popular tools and is widely used by the visually impaired. It is often used in conjunction with an audio feedback system. Visual assistive tools such as video magnifiers and screen magnifiers are also useful for individuals with insufficient vision. Acrobat short arm free standing video magnifier is one of the examples. This system is stable, easy to transport, and has connectivity to a portable monitor such as a computer monitor or television display (Nanopac, 2018). Tactile tools such as Braille books, keyboard, watches, and printers are also useful for visually impaired learners (American Council of the Blind, 2014). Furthermore, there are several computer and mobile applications with a screen reader to assist the visually impaired in their learning environment. Screen readers automatically read text aloud and assist users in navigating the applications. JAWS is one of the examples of widely used popular screen readers (Jaws, 2020).

Non-technology assistive tools such as plastic, wooden blocks, paper, or cardboards are used for teaching shapes to visually impaired learners . These materials create 2D representations of shapes easily and effectively but can be time consuming. Materials such as sponge paper, embossing paper, thermoforming a shape into a plastic sheet, and gluing yarn onto a paper can be used to draw shapes with a felt tip pen. Teaching the shapes of different fruits, for example, can be done using tactile tools. However, the shapes of some fruits are similar, and thus, visually impaired users face difficulties while differentiating them.

Geoboards enables visually impaired learners to explore different types of geometric shapes in mathematical lessons (Gwyn, 2020). Geoboards are physical boards that use a number of nails or pins and rubber bands to outline shapes. They are interactive for both visually impaired learners and sighted classmates, encouraging learning together (Didax, 2020). Different visually impaired users use different kinds of tools depending on their level of sight. Some learners also opt for magnifying tools or software which can be used together with computer display screen. Some of the devices such as touch screens with voice over or Braille devices can also be used together with computer display.

Simple magnifying glass or powerful and flexing magnifier is popular among visually impaired users for reading books, magazines, and newspapers. Smaller devices are portable and suitable for reading small amount of text and larger devices are usually hands-free and are suitable for reading large amount of text or reading for long period of time. Video magnifier and scaled-up paper copies are also used by teachers in teaching visually impaired learners.

Assistive tools such as plastic, wooden shapes, papers, or cardboard cut and materials found in their environment are also widely used to teach the visually impaired. 3D printers are widely used to develop assistive tools for the visually impaired and they are great source for printing 3D shapes. Another way is to cut 2D and 3D shapes from paper box or cardboard as it is cheaper and easier to produce, albeit more time consuming to prepare.

## 2.2 Learning Limitation of Visually Impaired Learners in Virtual Environments

As stated in Article 24 of the United Nation’s convention on the Rights of Persons with disabilities, it is vital to ensure inclusive education and lifelong learning for visually impaired learners (Braier, et al., 2014). Visual information is widely used in classrooms as it is accessible to most learners, but visually impaired learners require assistive tools to access the same information. In this environment, they are either supported by personal assistants or classmates in a traditional inclusive classroom setting. As a result, teachers or assistants need to spend more time explaining contents to allow their visually impaired peers or students to follow lessons.

Additionally, visually impaired or blind individuals are often sidelined by society in many ways. Learners with low vision or special needs require social and emotional support in order to ensure both academic and social success (Sacks, et al., 2011). According to them, visually impaired learners are more prone to being isolated and have less self-esteem and self-determination. In research conducted by Ishtiaq, et at. (2016), in an upper secondary school for the blind in Bahawalpur, 22 of 40 students were found to be depressed and 60% (22 out of 40) visually impaired experienced difficulties in their daily lives.

Nevertheless, visually impaired individuals are also frequently curious and eager to learn about the world around them, similar to any other sighted person. In this digital era, virtual learning or e-learning has been introduced and is dramatically advancing. E-learning approaches have benefited not only normal learners but also learners with different types of disabilities. However, there are a number of limitations for the visually impaired as these learning techniques only cater for sighted learners. Hence, it is important to redesign traditional approaches to cater for learners who are visually impaired by integrating information and communication technologies (Arrigo, 2005).

As the visually impaired can currently access the Internet, which was previously inaccessible, there is no doubt that e-learning can benefit visually impaired learners, but suitable methods and appropriate technologies should be chosen while designing e-learning platforms for them. Thus, an edutainment tool, such as YouTube, is not new and is one of the ways to encourage learning. However, because of the rich media involvement but no engagement between the application and the user, the usage of virtual edutainment application among visually impaired users is very low (Mon, Yap and Ahmad, 2019b).

## 3. Methodology

### 3.1 Designing the Prototype: User-centered Design

UCD is chosen as the design methodology for this research to promote an understanding of the human subjects involved in the study and subsequently focus on their requirements as users (Norman and Draper, 1984). As an outcome of UCD, highly usable and accessible products can be produced for users. It imperative in this research to provide a user interface that closely relates to the users performing the task and ensure convenience in interaction, and thus, UCD is a good choice. The designing, prototyping, and evaluation phases were required to be repeated and results from each stage were used as the input or area for improvement for next stage as shown in Figure 2. The processes are incremental and thus better than the waterfall model (Sommerville, 2015).

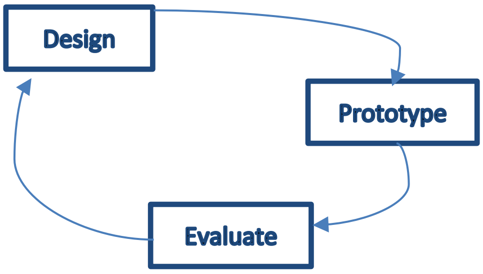


**Figure 2:** Iterative design process

The design of 3DOHA is considered carefully as the users of the system are visually impaired. Hence, the user interface of the application is not necessary to be attractive, but it should be easy to navigate for the users. The prototype that has been developed provides computer-based haptic-enabled 3D fruit objects with audio explanation and smell corresponding to the objects. These 3D objects can be touched using a haptic device. Haptic or tactile feedback technology creates a sense of touch by applying forces, vibrations, or motions to the users. The simulation is usually used in creating virtual objects in computer-based environment.

### 3.2 Choice of Haptic and Odor Devices

Haptic devices act as a medium between human and computer by generating force feedback in which motion is felt by users and perceived as haptic information (Liu, Li and Dai, 2017). Haptic devices are widely used in various fields such as, but not limited to, medicine, education, research, and training (Wong, et al., 2018). One of the well-known uses of haptic in the medical field is as a training tool for taking pulse and palpation (Kandee, Boonbrahm and Tantayotai, 2018). 3D systems, previously known as SensAble technologies, has developed a wide range of haptic devices, thereby becoming an option for researchers who do not want to develop their own haptic device (3DSystems, 2020a).

One of the popular haptic devices developed by 3DSystems is Touch, previously known as PHANToM OMNI (3DSystems, 2020b). This device generates force feedback that allows users to receive 3D information in a virtual environment. It is widely used in various research across many disciplines. A research that studied the association between color and tactile sensation used a haptic device from 3DSystems to provide virtual simulation to users (Slobodenyuk, et al., 2015). The study aimed to provide virtual haptic simulation through substances related to roughness and smoothness, hardness and softness, and other aspects. The Touch device by 3DSystems is shown in Figure 3.


**Figure 3**: Touch by 3DSystems (3DSystems, 2020a)

With Touch, users can feel the force feedback and 3D virtual objects by using a motor system provided by the Touch device. In addition, this device allows researchers to design and develop more advanced haptic programs together with the OpenHaptic toolkit in various fields. Touch X is another haptic device and an extension of Touch, developed by 3DSystems. This device is mostly used in advanced scientific or medical simulations as it provides more precise force feedback. A sample usage of Touch X in the medical field for surgical training is presented in Figure 4.

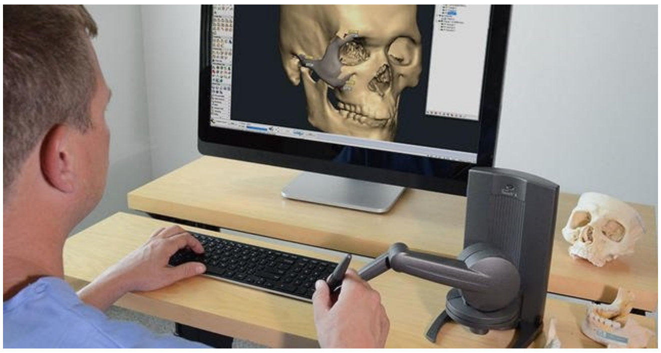

**Figure 4**: The use of Touch X in surgical training (3DSystems, 2020a)

Another premium haptic device, Sensable Phantom Premium provides the highest sense and force including motion and stiffness. These functionalities are suitable for high-end research as well as commercial applications. There are three ranges according to their motion and stiffness specifications: (i) Premium 1.0, (ii) Premium 1.5 and 1.5HF, and (ii) Premium 3.0 (3DSystems, 2020a). Figure 5 shows the design of the Premium haptic device used in rehabilitation, to design and develop a haptic Peg-Board exercise for the users (Xydas and Louca, 2007).

**Figure 5:** Phantom Premium Haptic Device (3DSystems, 2020a)

Another developer, Novint Technologies, designed and built various haptic and touch devices like 3DSystems and their main objective was for commercialization. The device shown in Figure 6 is the Novint Falcon which was the first 3D touch device developed by Novint Technologies for ordinary users (Amazon, 2007) .

**Figure 6:** Novint Falcon game controller (white) (Amazon, 2007)

Novinct Falcon provides the sense of touch in a virtual environment and is primarily used for video games as well as by professionals. The device enhances the quality of user experience for video game players. Furthermore, it is also used in professional applications or scientific research. An example of a scientific research application using Novint falcon is the eTouch Sciences Apps **"**A New Way to Interact with Math and Science Content" (Darrah, 2013).

**Figure 7:** The use of Novint Falcon in scientific application to study science, technology, engineering, and math ( Darrah, 2013)

Another kind of haptic device is the glove type, which is typically used in virtual reality (VR) applications and research. This type of device is not widely and commercially used because of the high cost associated with it. Therefore, research institutes and universities are working to develop their own haptic glove devices (Nordrum, 2017a). The haptic glove device shown in  Figure 8 was produced by HaptX Inc, formerly known as AxonVR, for VR applications ( Nordrum, 2017b).

**Figure 8**: Haptic glove by HaptX Inc (Nordrum, 2017a)

The primary use of this device is for training in healthcare, defense sectors, design and manufacturing industries, and location-based entertainment such as VR theme parks. Its main target users are the corporate sectors and not individuals because of its high cost.

An odor-based device was also used in this research to develop an engaging virtual edutainment prototype for visually impaired learners. Odor generators are not widely used like air fresheners, which emit fragrance or scent. Odor generators are used in VR studies and generate a whole different level of odor experience with computer programming.

Krumins (2017) introduced a virtual nose, Vaqso, or a scent generator. This device is of the size of a large candy bar and can be inserted with up to three scent cartridges. It comes with an embedded small fan to enhance the smell and can be attached directly to the VR headset as shown in Figure 9.


**Figure 9:** Vaqso scent generator (Krumins, 2017)

Another odor device developed by Feelreal is shown in the figure 10. It allows users to create smells while wearing VR helmets (Malkovich, 2015). In this device, blowers, temperature generator, vibration motor, and microphone are inbuilt, and its essential power is supplied by a battery. The Bluetooth technology is used to connect the device to the helmet and is useful with any other applications that require scent generation.

**Figure 10:** FeelReal odor generator fitted with VR helmet (Malkovich, 2015)

A desktop version of a scent generator was developed by ScentSciences and packed into a system that is about the size of a loaf of bread. The aroma generator is programmable to be used together with movies for an enhanced and enjoyable experience. It can hold up to 20 distinct smells and the cartridges can last up to 200 hours of use (McCollum, 2011). This device can also be used to generate smells; however, data have shown that wearing the device causes controversial feelings as it covers the entire face and air is supplied only through the vents. These effects engender fear and can cause asthma attacks. Nevertheless, novelty in the invention has attracted many fans. Figure 11 shows a model of this invention, Scentscape.

**Figure 11:** Scentscape odor generator (McCollum, 2011)

Another type of odor generator that can be used together with a mobile device is Cyrano developed by Vapor Communications. It is a battery-operated portable device and allows users to design their own personal scent for relaxation, empowerment, and personal wellness (Vapor Communications, 2016). The device is user-friendly and can be used together with different mobile applications. Figure 12 shows the invention alongside its accompanying application.

**Figure 12:** Cyrano and oNotes application (Vapor Communications, 2016)

Similar to Cyrano, a Scentee Machina was produced to be used together with a smartphone. This device can be switched on and off from any location and used with a timer. The type of smell and smell density are selectable, and an artificial intelligence algorithm has been incorporated to track usage history and favorite scents of its users. (Chalmers, 2014). Figure 13 shows a Scentee.

**Figure 13:** Scentee balloon attached to the earphone jack of a smartphone (Chalmers, 2014)

#### *3.2.1 Development of 3DOHA Application*

Touch by 3D system, a stylus-based haptic device, was used in this research. This device comes with an adapter, firewire cable, and is compatible with Windows or Mac operating systems. The device also provides true 3D navigation and force feedback that can integrate the sense of touch to users. Users will be able to interact and feel the shapes of 3D data and touch is simulated when the cursor interacts with the 3D objects in a virtual environment.

3D objects were created using the Blender software in this project. Blender is a free and open-source software used to create 3D computer graphics. The 3D objects created in Blender are then imported into H3DAPI and modified using Python in order to be haptically enabled. The following describes the segment of code used to transfer 3D objects into haptically enabled 3D objects.

To transform 3D objects into haptically enabled 3D objects, there are a few steps to be followed, and they are enumerated below.

Step 1: Create 3D object with extension of stl, obj, 3ds, dae, abc, fbx, bvh, ply, svg, x3d file type. Next, use blender to import the file.
Step 2: Do rotation, enlargement, and other adjustments in Blender. Next, export the object with .x3d file type.
Step 3: Remove Transform tag code and camplight code from the x3d file.
Step 4: Add the code for Spring effect, box position, background color, etc.

The 3D objects will be paired with an audio when audio files are also integrated into the Python code. Add the code to link the 3D objects with the Python code.

The application allows visually impaired users to learn shapes in a virtual environment. Users will feel the virtual information from the haptically enabled 3D shapes by using the haptic device and receive the corresponding scent for 3D shapes via the olfactory device. An odor or olfactory generator is developed using a basic framework of the Vortex Activ smell-dispensing system but re-assembled using the Arduino Nano board. The odor generator consists of four fans that can be programmed to emit an aroma at specified times. The aroma is supplied from a small removable and replaceable circular cartridge. The appearance of Vortex Activ can be seen in Figure 14.

**Figure 14:** Vortex Activ device with refills aroma

The Arduino Nano board is programmed using Python and there are four 5v DC fans on the Vortex Activ. There are four control pins, one assigned to each fan. Upon request, the control pin will activate one of the four fans. The communication between the vortex device, 3D shapes, and haptic device were programmed using Python, and the application can be operated using Python 2.7.15. Users will be able to choose a character between "1" to "4" and the individual fan will be controlled by the chosen character.

The same steps will be used to activate Fan 2, Fan 3, and Fan 4, respectively. Arduino version 1.8.3 is installed in the workstation and Arduino executable files together with necessary library files will be bundled in the same folder. This application also generates the names of 3D shapes via audio speaker when users touch the corresponding 3D shapes. The control instructions are written in Python and will call an audio file when users touch the 3D object using the stylus haptic device. It also passes the character "1" to "4" to the pin to activate the respective fans in the olfactory device.

In this research, H3D API, an open-source, cross-platform, scene-graph API for graphic rendering was used together with OpenHaptic for haptic rendering (SenseGraphics, 2019). H3D API is written in C++ and can be used in multiple platforms such as Windows XP, Linux, and Mac OS X. By combining X3D, C++ and the scripting language Python, H3D provides a rapid development process. H3D API uses Python, X3D for high-level interface and C++ for raw access to the API. The advantage of using C++ is to create highly efficient code when writing haptic rendering algorithms or by using OpenGL.

However, it has a relatively slow development time, and finding bugs can often be a time-consuming process. While designing using H3D API, it is important to take note of two components, fields and notes. SenseGraphic recommends utilizing encapsulation by using fields and scene-graph nodes for reusability and a good application design. Field is an event-handling mechanism and is arranged into a directed graph (called the field network), where events are passed from one field to another. It is a data container where data properties are stored and manipulated. Nodes are containers and managers of fields and filed networks. Figure 15 depicts overall process follow of the proposed prototype.

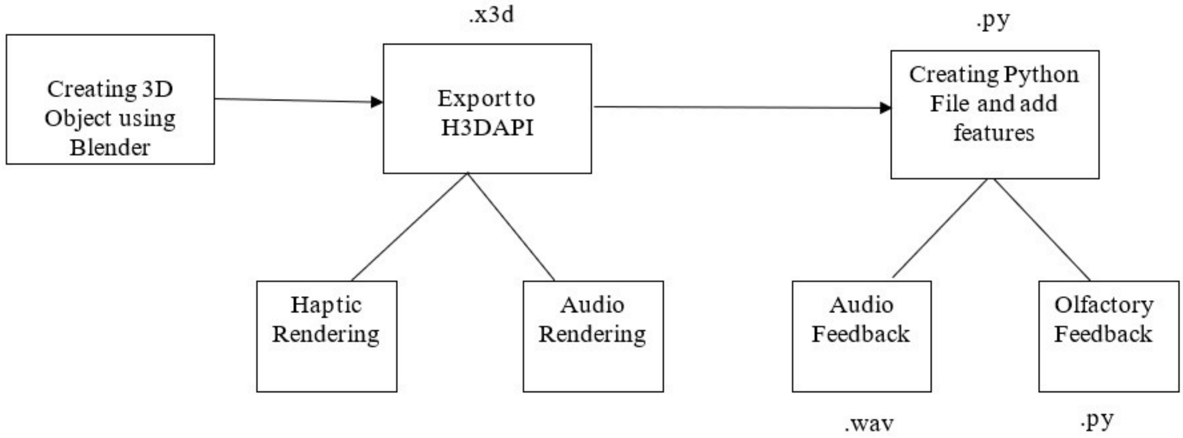


**Figure 15**: Overall Process Flow of Proposed Prototype.

Screenshots of the application's interface is as shown in the following Figures 16 (a), (b), (c), (d).

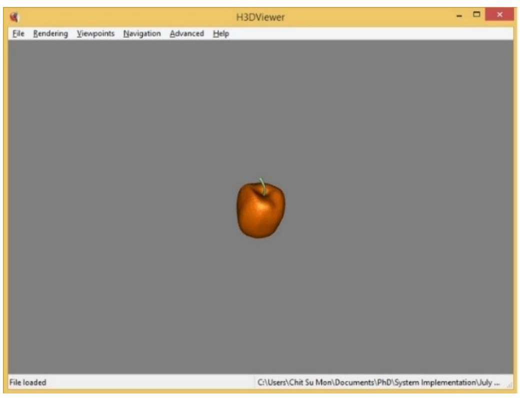


**Figure 16 a.** 3D object of an apple

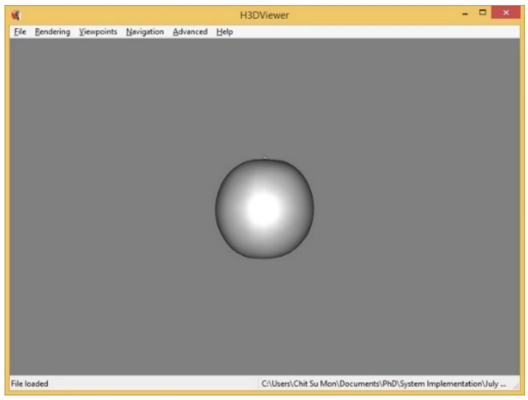


**Figure 16 b.** 3D object of an orange

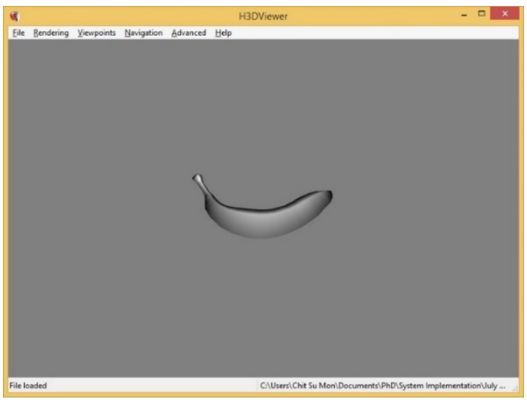


**Figure 16 c**. 3D object of a banana

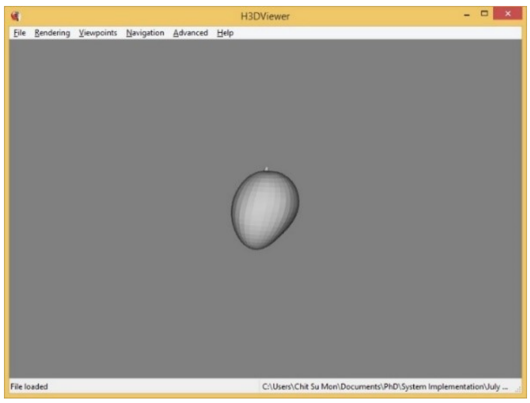


**Figure 16 d.** 3D object of a mango

Figure 17 depicts the overview of the application's framework in which haptic, audio, and olfactory can be used together in a virtual edutainment environment for visually impaired users. With this system, users can access 3D objects via a PC connected to haptic and olfactory sensors and headphones of choice. The haptic device will be used to access the 3D objects and the corresponding scent will be dispensed from the olfactory device. Corresponding sounds will also be generated from the PC whereby users can listen to the sounds either through a speaker or preferred microphone. This proposed framework is expected to enhance the visually impaired users' learning experience in the virtual learning environment by providing a fun and engaging experience, thereby boosting their interest in using the application on a frequent basis.

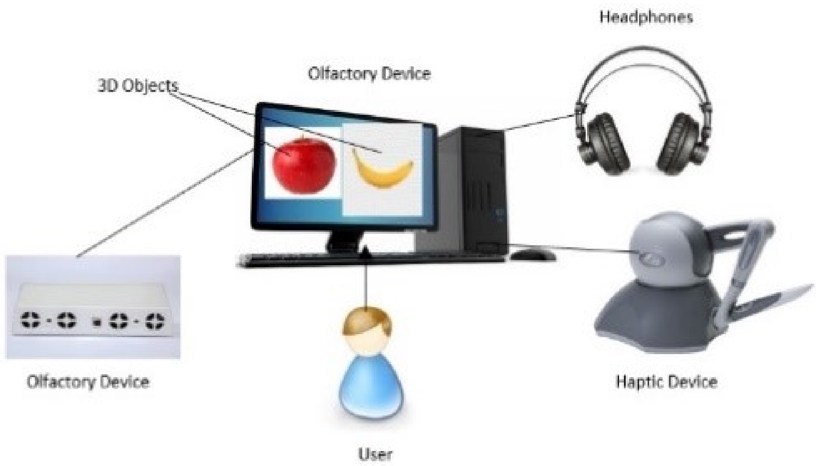


**Figure 17:** Proposed framework for virtual edutainment environment using haptic, audio, and olfactory Sensors

### 3.3 Questionnaire and Participants

The evaluation of the prototype was conducted at the Malaysian Association for the Blind (MAB) at Off Jalan Tun Sambanthan 4, Kuala Lumpur, starting with a pilot testing. In this testing, 10 participants were involved to express the usability of the 3DOHA application as well as how well visually impaired users can correctly identify 3D objects using all haptic, olfactory, and auditory senses in a virtual learning environment. The background of the research and the process were explained to the visually impaired participants prior to the actual testing. Once they were ready to begin the experiment, they were given a haptic device to touch the shapes of the different types of fruits. The corresponding smells were dispensed while the users were touching the shapes. The users were then asked questions from the questionnaire, and the tester filled up the answers according to the users' responses. The questionnaire adopted in this pilot testing is based on USE (Lund, 2001) corresponding to the objective to evaluate the prototype using usefulness, satisfaction, ease of use, and ease of learning. The questionnaire was designed with a 7-point Likert rating scale and participants were asked to rate their agreement to the statements, ranging from "1" as *strongly disagree* to "7" as *strongly agree*. This type of questionnaire was used as, according to (Lund, 2001), users primarily evaluate products according to three constructs, usefulness, satisfaction, and the ease of use, although there is evidence of other common dimensions. However, in this research, USE most effectively served the interfaces involved.

## 4. Results and discussion

Among the 10 participants, five were visually impaired teachers above 25 years old and another five were blindfolded students between the age of 19 and 25 years old. There were four female and six male participants. At this stage of prototype development, it is important to collect focused feedback on the functionality; thus adult users with academic background were approached. According to Lazar, Feng and Hochheiser (2017), it is a common approach to use blindfold sighted users as proxy users when target participants are not freely or readily available. It is not always to use proxy users for this reason; however, it is acceptable to use them when specific application or tool is being developed and is undergoing multiple iterations before a proof-of-concept is completed. As this research uses both proxy users and actual visually impaired user, it is reasonable to accept the findings obtained from this experiment.

The vision level of these participants is shown in Figure 18.

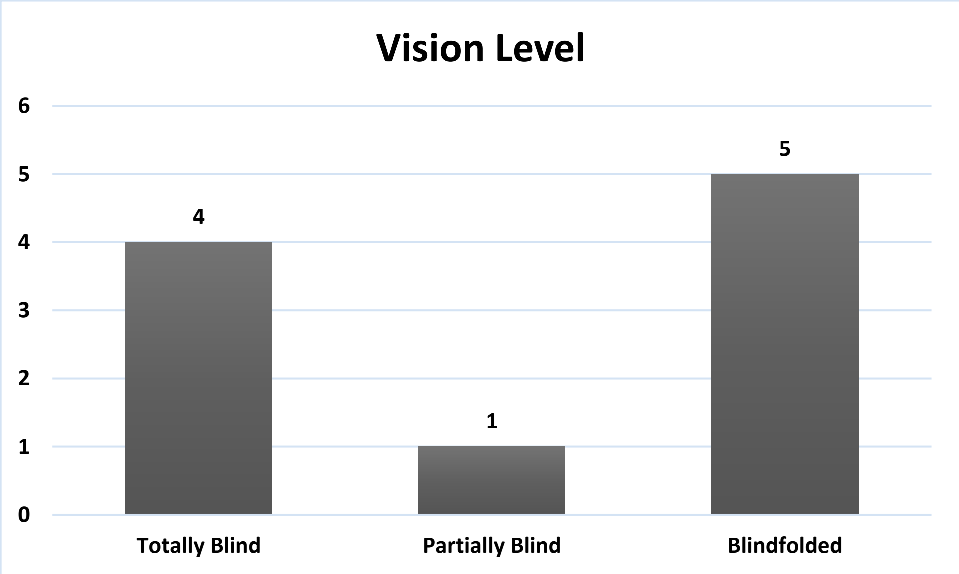


**Figure 18**: Vision level of participants

Majority of the participants use computer very frequently for various reasons such as surfing the Internet, requirement of their job, for learning new things, as well as for leisure. However, they have no prior knowledge on the haptic device and they have not used similar devices before. Figure 19 depicts the purpose of computer usage by participants. All the participants use computer for learning as well as Internet activities.

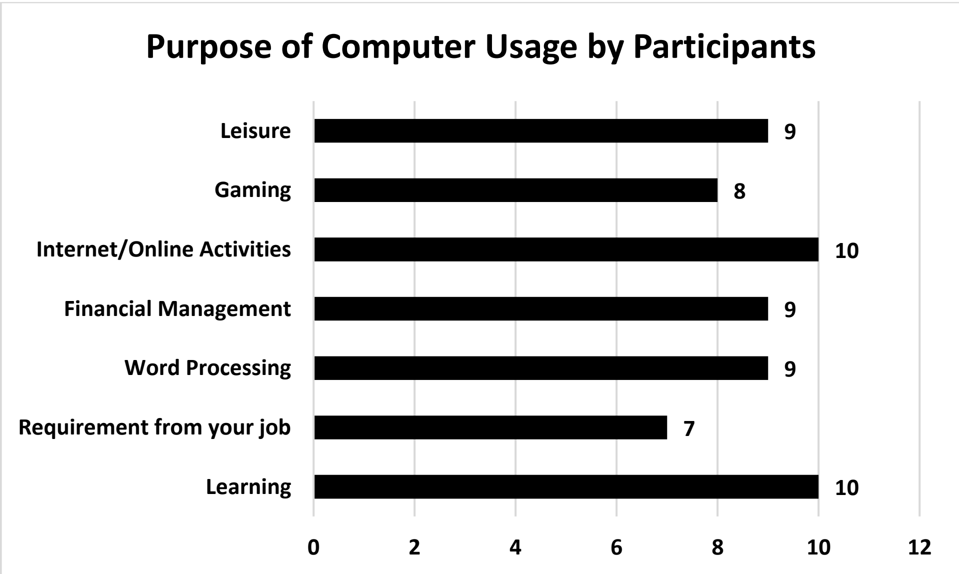


**Figure 19:** Purpose of computer usage by participants

The breakdown of results from all the participants in the 7-point Likert scale questionnaire is shown in Table 1.

**Table 1**: Breakdown of results from all participants

| | Gender | Age (in years) | Vision Level | Blindness Since | Occupation | Usage of Computer | Usefulness | Ease of Use | Ease of Learning | Satisfaction |
|---|---|---|---|---|---|---|---|---|---|---|
| **Participant 1** | Female | >25 | Totally blind | Progressive loss | Teacher | Very frequently | 6 | 5.67 | 6.17 | 6.67 |
| **Participant 2** | Female | >25 | Totally blind | Birth | Teacher | Very frequently | 6.29 | 5.44 | 6.5 | 6 |
| **Participant 3** | Male | >25 | Totally blind | Birth | Teacher | Frequently | 5.86 | 5.11 | 5.67 | 6.17 |
| **Participant 4** | Male | >25 | Totally blind | Progressive loss | Teacher | Very frequently | 5.57 | 5.33 | 4.83 | 6 |
| **Participant 5** | Male | >25 | Partially blind | Sudden loss | Teacher | Very frequently | 2.57 | 2.89 | 5.33 | 4.33 |
| **Participant 6** | Male | 19-25 | Blindfolded | Blindfolded | Student | Very frequently | 6.86 | 5.89 | 6.83 | 7 |
| **Participant 7** | Female | 19-25 | Blindfolded | Blindfolded | Student | Very frequently | 6.86 | 6.56 | 7 | 7 |
| **Participant 8** | Male | 19-25 | Blindfolded | Blindfolded | Student | Very frequently | 6.71 | 7 | 7 | 7 |
| **Participant 9** | Female | 19-25 | Blindfolded | Blindfolded | Student | Very frequently | 6.14 | 6.44 | 6.67 | 6.17 |
| **Participant 10** | Male | 19-25 | Blindfolded | Blindfolded | Student | Very frequently | 6.29 | 5.67 | 6.17 | 6.17 |

Majority of the participants rated high for usefulness and most agreed that the proposed application will be more effective in the learning experience and encouraging in a virtual environment. In addition, the participants agreed that the 3DOHA application is useful in learning and would use the application frequently in learning. They also find this application easy and simple to use as well as easy in learning to use the application. Among all the participants, 80% mentioned that the application is fun to use and 50% *very strongly agree* that they need to have the application. Furthermore, 90% of them rated *strongly agree* and *very strongly agree* to recommend the application to their fellow friends.

The average rating and standard deviation according to each of the three constructs are encapsulated in Table 2. The rating of each construct was above average, which indicates that the application is satisfactory for users to use, easy to use, easy to learn, and useful for them in their learning activities.

**Table 2:** Average, standard deviation, maximum, and minimum of the rating

| | Usefulness | Ease of Use | Ease of Learning | Satisfaction |
|---|---|---|---|---|
| **Average** | 5.92 | 5.60 | 6.22 | 6.25 |
| **Standard Deviation** | 1.25 | 1.12 | 0.74 | 0.80 |
| **Maximum** | 6.86 | 7 | 7 | 7 |
| **Minimum** | 2.57 | 2.89 | 4.83 | 4.33 |

## 5. Conclusion and future recommendation

This research designed and developed a 3D-based haptic-, audio-, and olfactory-enabled edutainment application for visually impaired learners. Haptic and audio have been used together in many assisted applications, with the proven ability to help users with visual impairments. Additionally, there are several haptic-related applications available, but not all are designed for the visually impaired. UCD approach was also used to design the current prototype. Choice of haptic device was made carefully and a stylus-based haptic device from Geomagic (3Dsystems) was used in this research. Vortex Activ smell-dispensing system was used as the basic apparatus. The odor generator has four fans that can be programmed to emit an aroma at specified times. The types of aromas come in the form of a small circular cartridge, which is removable and replaceable. 3D shapes were generated using the Blender software and the control instructions were written in Python. It can call respective audio files as well as dispense corresponding smells when users touch the 3D object. To evaluate the prototype, usability testing was conducted to obtain user's feedback, and out of the maximum possible rating of 7, the participants rated 5.92 for usefulness, 5.6 for ease of use, 6.22 for ease of learning, and 6.25 for satisfaction. Majority of the participants agreed that the application is useful in learning and encourages them to carry out learning activities in a virtual environment. Furthermore, they also agreed that the application is simple and easy to use and requires minimum steps to accomplish the tasks. However, some of them needed a technical person to assist them in using the application. This could be because of them not having been exposed to a haptic device before. Nevertheless, they learned to use the application very quickly and remembered how to use the application easily in subsequent attempts. The majority of participants agreed that the application is fun to use, and they would recommend the current application to their fellow friends. There is more evidence that e-learning can benefit visually impaired learners, but suitable methods and appropriate technologies should be chosen when designing e-learning platforms for them. Using this prototype, visually impaired learners can embark on a journey of continuous learning with the aid of e-learning.

This research is based on Malaysian context as the research was conducted at the MAB. Thus, infrastructure related support can be different from other developing and undeveloped countries. The challenge was in identifying visually impaired subjects between the age of 9 and 14 years. Owing to the pandemic situation in Malaysia, the schools were not opened, and thus, we had some difficulties in identifying the subjects that forced us to have limited samples. Once this pandemic is over, we will look for a larger sample of subjects in the said age range. Additionally, a comparative study of visually impaired adults can be carried out between the subjects in Malaysia and other countries to determine the effectiveness of the proposed system. Besides, this research can be enhanced for those who are deaf, blind, and mute learners to achieve the desired learning outcomes in virtual learning environment.

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