Comparison Between Augmented Reality and Mobile Virtual Reality in Anatomy Education

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***Abstract*—Virtual Reality (VR) and Augmented Reality (AR) are perfect training tools. The success in testing professionals such as Doctors and Veterinarians using anatomy simulators has proved this clearly, as the result of the pilot test is positive. One problem in the current VR headset is the low capacity of movement, which causes the choice of working and study environments quite narrow. It limits the efficiency of communications between the lecturers and students, which affects the teaching quality directly. Instead of using VR as a teaching tool, using AR would be another choice. This project will focus on comparing the difference between the mobile platform AR and mobile immersive headset VR in different aspects of Veterinary Education.**

***Index Terms*—Augmented Reality, Mobile Virtual Reality, Veterinary Anatomy Education**

I. Introduction

Recent researches prove Virtual Reality (VR) and Augmented Reality (AR) as good training and teaching assistant tool in medical anatomy education industry. The virtual volume of the anatomical specimens not only provides a stereoscopic environment for the spatial information but also solves lacking anatomy materials challenge in medical education. With the help of VR and AR training simulator, medical students can gain better surgeons technical skills and attention-motivation during the process of simulation.

In anatomy education, it is essential to make sure the knowledge of anatomical structure is detailed and accurate. The best way to obtain knowledge is from the actual cadaver. As Leblanc et al [1] claimed in their experiment about comparing AR simulator with cadaver model, the actual laparoscopic sigmoid colectomy training on cadaver was more difficult but better appreciated. However, they still indicated the benefits of maintaining the AR simulator and applying it before the cadaver training. Codd et al [2] also designed an experiment to verify whether VR anatomy is comparable with using cadavers to teach human forearm musculoskeletal anatomy. They got positive feedback from all participants and indicated that VR anatomy learning could be used to complement the traditional way of teaching effectively.

In previous work of Xu et al [3], they developed a veterinary anatomy application for anatomy education. The pilot test result showed a positive result and proved that VR could be anatomy teaching support effectively. How the application will perform in the AR platform rather than the VR platform would be entertaining to figure out. As is known to all, the AR platform has higher mobility and gives the instructor the ability to supervise the learner well. There are generally three types of techniques used on the mobile AR end, which are the physics object components, image anchor and artificial intelligence. The object tracking components are commonly used in both AR and VR platforms, especially in the vocational education and training as they can simulate the actual scene accurately. Which is different from the tracking component, the image anchor-based AR is more lightweight and suitable for the regular and primary education and contributes a lot in stereo cognition. While artificial intelligence combined with AR may have massive potential in the future, helping with image recognition and teaching assistant. With the advantages of the mobile and CAVE-like AR, the teaching way of medical anatomy might be changed to get a better result.

This paper aims to convert the previous VR anatomy application into mobile VR version and AR version. The conversion process needs to consider the usability of the final application, making adjustments depending on the features of the devices. For instance, the mobile version VR headset only has one controller with three degree of freedom, which means some of the function achieved in the desktop version cannot achieve due to the device limitation. Similarly, the mainstream of AR devices is a mobile phone with high capability in computing and rendering. As the mobile phone will not equip with a controller, all operation gesture will base on screen touch. From the aspect of human-computer interactions, we need to think about how to increase the usability, including suitability, learn-ability and error tolerance, of the application on each type of device. At the end of the project, a pilot test experiment will be raised to get the evaluation of both versions of applications. As the size of the participants will not be great, the test will run with-in group, and it will consider about counterbalancing to estimate the effect from the previous test.

The paper is structured as follows. A Background Research section will discuss the developments in the medicine area by both VR and AR, and compare them in anatomy area. A methodology section will outline the work-flow to converting desktop version into mobile versions in this research. An implementation section will outline the set-up of the mobile VR applications and AR application environment and corresponding adjustments. With the implementation outlined, a pilot study section will evaluate both mobile VR and AR versions by comparing the same functionality and work scene. Finally, conclusions from this work and possible future work will be discussed.

II. Background Research

A. VR in Anatomy Training

VR is a perfect training tool in many areas, including medical and anatomy. Just like what Satava et al [4] claimed in 1995, The next generation in medical education can learn anatomy from a new perspective by flying inside and around the organs, using sophisticated computer systems and 3-D visualization. nowadays, with VR and Internet, a physician can get the majority of knowledge he needs from electronic means. Izard et al [5] implemented a VR software as an anatomy education tool, which allows students to observe the inside of the organs, and illustrated the teaching potential of applying VR in the field of anatomy. Throughout the researches of all the researchers, the fact that the resources of anatomy materials and live tissues do not satisfy the requirement in medicine and veterinary education may be eased by VR. Xu et al [3] developed a veterinary anatomy software and designed a pilot test based on the software. The result of the experiment is positive to prove that comparing to the traditional teaching method, the VR teaching and testing system may improve anatomy education.

Except for the benefits of solving troublesome problems in medical education, VR can also provide a more interactive experience in learning, which the traditional way of studying cannot be competitive. The training from the interactive 3D model benefits anatomy training in many different ways. Nicholson et al [6] designed an experiment to see whether VR can help with anatomy training. They reconstructed a fully interactive model of the middle and inner ear from an MR imaging scan of a human cadaver ear and used it for the experiment. The compassion between each group is learning ear anatomy from a website with the interactive 3D model generated by computer and learning based on tutorials. The result decisively proves that the manipulation of the 3D model can help with training compared to the pure 2D images. Similarly, Jang et al [7] compared the difference between direct manipulation learning and passive viewing learning in VR anatomy training of the inner ear. The results indicate that the manipulation group performance better to point out the observed structure at the post-test than the viewing group. Also, the manipulation process helps a lot with participants who have the lower spatial ability. All the experiments show that VR is capable of helping with clarifying the anatomical structure and maintain a clear frame of reference during the training process.

Although VR can improve learner's stereoscopic cognition of the structure of anatomy object, virtual simulation is not as same as the real case. So whether there are any influences of the simulation process matters in the final goal. Piromchai et al [8] developed an experiment by simulating surgery of the ear, nose or throat with VR with 210 medical students. There is no substantial evidence to prove whether the training in VR influences patient outcomes or non-technical skills, however, the results show that the VR training does improve the performance of surgeons technical skills, which means, VR can be added as a training support material in surgical training programs but need time to prove whether it can replace the traditional teaching method.

When it comes to the actual teaching scenario, VR can make a contribution to classical education on campus. Fairen et al [9] presented an experiment that allowed students to interact with 3D models by using a VR system and measured the understanding and the satisfaction of the students. As the teaching system had to be capable of sharing the experience, the VR system they used is projection-based Powerwall and four wall CAVE rather than HMDs (Head-Mounted Displays). The result of the experiment shows that the VR session is helpful to understand the anatomical structures and learn. Campbell et al [10] outlined a mixed reality space on campus to apply Massive Open Online Courses (MOOC). With the help of the VR technique, current education method would improve, and the teaching gap would be able to be bridged. No matter how far between the instructors and students, students can always get the best educational resources and academic assistance.

To sum up, VR is a perfect tool for the next generation of medical education, not only because of solving the problems like lacking the cadaver materials for survey training, but also changing the methods of teaching and testing. On the one hand, VR seems to be the best alternative for anatomy education, but on the other hand, VR also has its shortages, such as the uncomfortable feeling after long time usage and the limitation of the HMDs gears. So, whether AR can perform as good as VR in anatomy survey education is what we are trying to figure out.

B. AR in Anatomy Training

AR is all known as an excellent training support tool in many areas like architecture and mechanical science. The best feature of AR in education is that it augments all the virtual information pieces to a real physics base. Users would then know the inside structure of a meticulous device or the working principle behind it without too much effort. There are generally three types of techniques used on the mobile AR end the physics object components, image anchor and artificial intelligence. With distinct technologies, the application of AR anatomy training simulator can have many forms. In this chapter, how well each technique performances will be discussed.

1) Depth Camera and Object Tracking Component: One of the most common ways to implement AR for training propose is using a depth camera. Blum et al [11] presented an AR software called Magic Mirror System, which used a depth camera to track the pose of a user for teaching anatomy. The volume of organs generated from CT data set will be shown based on the user's position, creating an illusion of seeing through the user's body. They also implemented gestures to change different slices of data to be shown. After this, Ma et al [12] improved Magic Mirror System based on the previous work, making the system customized for each of the users (tracking the users and modifying the biological features, e.g. height). To make the augmented volume suitable to the body, they also improved the Kinect skeleton with the CT data. Moreover, user can use gesture to choose the organ they want to learn, and the information of that organ will show on the screen, and the result of this experiment is approval for the educational value. With the help of a depth camera and RGB-D sensor, the AR device can achieve real-time tracking, which makes the performance much better.

Except by using the depth camera, using a tracking component with proper tracking system could be another way to achieve AR implementation, which also allows the in-situ visualization show on a solid base. Bichlmeier et al [13] presented a hybrid in-situ visualization method to improve depth perception used in medical AR. When the augmented virtual volume shows up directly on a solid base, the object is inside or in front of the solid base is hard to tell. By using multiple sensors, they successfully transfer the video images to the solid base and adjust the image according to the position of the device, the shape of the sensors and the location of the instrument. Then they developed a series of experiments and results showed the possibility of applying this method in the design stage of medical AR training and education applications.

Based on this method, many problems in medical education have chances to be solved. For instance, it is always hard to learn ultrasound medical imaging modality as the image quality is low and requires some specific knowledge about the ultrasound physics and anatomy. Blum et al [14] proposed an AR ultrasound simulator by visualizing the ultrasound with CT volume. The CT slice image was generated according to the position of the probe to the phantom, and then ultrasound slice was simulated based this CT slice. They also added two additional virtual monitors to show the ultrasound slice and CT slice simultaneously, which makes it easier for the learners to learn the ultrasound image. This kind of interactive anatomy-augmented virtual simulation training is proved to be suitable education support as Aebersold et al. [15] proved in their experiment. They used an anatomy AR virtual simulation training module that showed the anatomy tube replacement on the iPad. Comparing to the control group, the AR module group had better performance in general, which proved AR as training and understanding promoting tool.

2) Image Anchor: Another traditional way to display virtual components is using image anchor that can also be treated as a plain marker of the virtual model. Comparing to the Pedagogical Virtual Machine, the image anchor are not usually related to the target project. The main feature they need to keep it easy to be recognized by the computer under different situations, for instance, different light conditions and the blocked area of the marker image. As it only involves image recognition, the compute pressure of computer is much lower than the volume recognition, which makes it a lighter method to achieve AR.

Due to those features of the image anchor, image anchor-based AR is widely used as a teaching-supporting material. Ferrer et al [16] used two years to create a software called ARBOOK, focusing on the anatomy of the lower limb based on TC and MRN (Magnetic resonance neurography) images to show whether can this kind of tech be a good teaching-supporting material. They designed an experiment on lower limb anatomy to evaluate the ARBOOK system, using the AR image as additional teaching material. The result of the ARBOOK group is significantly better than the control group in many ways such as autonomous work, attention-motivation, three-dimensional comprehension task and even written test, which strongly suggest that AR may be suitable for anatomical students. However, deal to the equipment limitation at that time, the AR camera is a webcam fixed to a monitor and the augmented image still shows on the monitor, which makes it less different than a traditional anatomy software on PC platform, in other words, the only thing they changed might be only the interaction way (from mouse or keyboard to a piece of paper).

Kuccuk et al [17] then applied this technology on a mobile device to overcome the shortage of the ARBOOK and called it mAR (mobile Augmented Reality) technology. They developed an application called MagicBook that can use AR to show additional teaching material on a mobile device for the experiment. Unlike the usual experiment, the experiment gave a 5-hour course for MagicBook group and control group while the essential knowledge is precisely the same. The result of the experiment is also quite positive as the medical students in the MagicBook group have higher academic achievements and lower cognitive loads. Jamali et al [18] presented a similar experiment based on a so-called prototype HuMAR (Human Anatomy in Mobile Augmented Reality) and got positive comments of it in terms of its usability and features. When the camera of a tablet detects the image marker, the model of bones of the lower appendicular skeleton will show on the screen, which provides benefits in the learning and training process.

3) Artificial Intelligence: Before doing this literature review, the original hypothesis is that artificial intelligence must be used widely with AR because it might be a good assistant in many aspects. For example, it may achieve markerless and tracking component less object tracking, which may make the AR device much more portable; or it may be a teaching assistant during the training progress and be an artificial agent, or it may identify the surface of the target solid base, analysis it and automatically achieve in-situ visualization. However, it is hard to find such kind of papers in anatomy or the medical. Karambakhsh et al. [19] provided a new way to apply artificial intelligence in anatomy AR. They applied the convolutional neural network (CNN) for gesture recognition and then applied the gestures as an input source to increase the accuracy of recognition. In the end, they combined CNN and AR to get an immersive experience and a better user-friendly operation and claimed the future potential of applying neural network into AR.

The chapter shows that AR could be a sufficient teaching assistant material in anatomy education and depending on the different implementation method, the feature of the AR application would be suitable for different situations. As both VR and AR have great potential in anatomical education, which one is more suitable for teaching and training process will be discussed in the next.

C. VR and AR Comparison in Anatomy

The main difference between VR and AR in anatomy the way of presenting medical images. VR allows an immersive visualization and can view multiple images at the same time. While AR can supply anatomy learning by superimposing a radiological image on to a body, generating a view of spatial anatomy scenes for learners.

Although VR and AR can both solve the problem and help with training and education in anatomy, the performance forms of two different technologies are different. So, which device is more suitable to utilise within a curriculum is worth to discuss. Desktop-based VR has better performance no matter in the graphics quality or the immersive experience, while the setup cost is much higher than a mobile AR device, and the flexibility of the device is much lower. Mobile-based VR gets better portability and maintains the immersive feelings, primarily when the Oculus Quest is published, and there is no such big gap between desktop-based VR and mobile-based VR. According to Moro et al. [20]'s comparison research about two kinds of VR, mobile-based VR is more suitable and effective in medical and health science education.

Meanwhile, mobile AR, such as HMDs and smartphones, have higher mobility. As the background of the world is the real world, the environment could be more suitable for discussion and cooperation in training or teaching. The instructor would be able to see the teaching material at the same time, which makes sure the accuracy and efficiency of the education process. However, the immersion of the AR device is worse than the VR devices as the field of view for the AR HMD is too low comparing to the VR device. Moro et al [21] again discussed the effectiveness of VR and AR in health sciences and medical anatomy. The result of their experiment showed that there was no significant difference between mean assessment scores in VR, AR and tablet-based application. VR participants had physical effects like headaches and dizziness but increased learner immersion and engagement at the same time. The experiment did not decide which platform is the best for the anatomy simulation. However, it indicated the effective use of VR and AR in anatomical education.

According to Khor et al [22], AR has a more significant benefit in real surgery compared with VR because the AR device is see-through-able. Because of this, the traditional "head's up" visualisation method through a monitor can be changed into the "see-through" display, which may support the real surgery accurately and safely. They claimed that AR would have an essential role in the image-based augmentation of the surgical environment as the AR device can be a natural extension of the surgeon's senses. It would be light, mobile, comfortable and functional for a potentially long period.

A better way to overcome the shortage and keep the best features of each platform might be blending them. An AR and VR display blending system for human anatomy called HoloBody Galleries was proposed by Santoso et al [23]. It blended real-world anatomy specimens into VR scenes and used AR to move between different modalities. Because this system contained the AR and VR device, the learner would not lose the immersive feeling and engagement while the instructor would be able to supervise through the AR device at the same time. It provided a multi-user, distributed exploration environment for medical anatomy education.

As AR and VR devices have their advantages and unique features, each one can achieve some function that the other one cannot achieve perfection. VR generates a more immersive, completely artificial image and the environment with real-time interactions, which makes it a perfect tool for training the learner before they practice with an actual cadaver. For decades, VR has been an endoscopic training tool and testing assessment tool. At the same time, AR can supply anatomy learning by superimposing a radiological image on to a body, generating a view of spatial anatomy scenes for learners. Because of this, AR is also the best tool for the surgery support, creating an environment for "look through" display rather than "head's up" display and improving the accuracy and security for the operation process. With both VR and AR applied in anatomy education and training, a perfect training system that may meet all the requirements and overcome all the problems may arise in the future.

III. Methodology

As this project contains two different platforms for testing and experimenting, the chosen SDKs are targeting mobile VR and AR platforms. The SDK chosen for mobile VR is VIVE Input Utility, while the one chosen for AR platform is AR Core from Google.

A. VIVE Input Utility SDK

The original pick for mobile VR development was the SDK called WaveVR, which is developed by HTC VIVE and shown as the original development kit. However, the API of this SDK is too hard to use and cannot achieve some basic functions easily, such as action listening functions. Moreover, the simulator of the WaveVR is too difficult to configure, and the reason why this happened might be the strict condition of the IDE version. Because of the above reasons, the SDK chosen for this project is the VIVE Input Utility. It is a free and open sources package on Unity asset store and GitHub, and it supports all kinds of Vive device development including mobile VR headset VIVE Focus. The development environment setup for this package is also easier than WaveVR SDK. After installing the Unity with Android Support and importing the WaveVR and VIVE Input Utility SDKs, the environment is ready for development.

According to the sample scene of the VIVE Input Utility APK, the basic VR gestures, such as laser pointer that can interact with user interface and objects, are all packed into the scene. To point out, the VIVE Focus headset we are using this time only supports 3 degree of freedom (DOF), which means the headset can only track the rotation of the controller and makes it hard for the user to grab object by using the controller only. Instead of using the controller itself to interact with objects, a laser pointer is applied to grab and move objects in the scene. However, the controller grab function stays, as we noticed that by moving the headset, the position of the controller in the scene could be moved as well, which makes it possible to fake an experience of the 6-DOF device.

B. ARCore SDK

Because of the device limitation, the SDK chosen for AR is ARCore by Google rather than ARKit by Apple. This SDK provides all the essential AR features such as motion tracking, environmental understanding and light estimation for the developer to build AR apps. By using ARCore SDK, it is possible to calculate the plane positions in real life based on the could points and create a virtual plane for the user to place virtual objects. The generated objects will stay at where they are by motion tracking. The light estimation system will understand the real light environment and change the virtual light to fit the real circumstances.

Due to the result of the pilot test experiment, the performance of the AR device is not satisfying in the aspect of user experience. Firstly, it takes a long time to detect the plane of the real world, generally from 3 seconds to 10 seconds. When the light circumstances become complicated, especially on a reflective surface or in a dark area, the response time of surface detection can extend to one minute or more. Moreover, the generated virtual plane is not stable. When the device moves from one place to another place, the plane will sometimes shift randomly, which decreases the immersive experience of the virtual object to some extent. The reason why those happen might be the low capability of the mobile device.

C. Workflow

The data used in the project is from Xu's [3] previous work. As the DICOM data has already transformed into 3D models that can be imported into the game engine, the only work left to do is decimate the model faces to fit the mobile device capability. Instead of using MeshLab this time, the software used to reduce the number of model faces is Blender. Based on ensuring the performance of the mobile application, the faces number decreases to 20 per cent of the original. After testing different figures, the 20 per cent can guarantee the performance of the application and keep most of the details of the models.

The game engine chosen to build up two different applications is the Unity engine. Both VIVE Input Utility and ARCore provide SDK for Unity platform, which makes the development process convenient and unified. The Unity engine also builds the original version of the canine research lab application. Because of this, the conversions from the desktop VR version to mobile VR and AR version are all based on C# language. The experiment needs to make sure that the two versions have the same or similar functionalities for the further experiment comparison. As a result of this, the conversion process should meet the features of different devices based on keeping the original functions.

The mobile VR device used this time is the second generation of HTC VIVE Focus. Comparing to the first generation, the capability of the device improves, which makes the user experience better. However, the fact that the device only has one controller and only supports 3 DOF limits the functionality of the application, which means it cannot reach the same experience of the desktop version, and it needs adjustments to achieve the origin functions.

The AR device used this time is Samsung Galaxy S7, the very first Samsung device that announced to support ARCore. Due to the outstanding capability of the phone back in 2016, the Galaxy S7 can handle the complex environment calculation of AR support. Unlike the HTC VIVE Focus, AR device does not have a controller to let the user interact with the virtual object, and all the operations rely on touching screen to active. Because of this, the conversion needs several adjustments to be done to keep the original features and functionalities. The ARCore SDK also supports cloud anchor, which allows multiple users to share the same anchor at the same time. The cloud anchor function should be implemented in this project to determine the potential of AR in communication, cooperation, and teaching areas. Due to the limitation of the number of devices, the cloud anchor cannot achieve and test this time, which, to some extents, reduces the score of AR devices as it cannot provide the same level of immersive and controllable feelings.

IV. Implementation

A. Model Modification

The model complexity has to be reduced to maximize the performance of the application on mobile devices. At the meantime, the details of the model should remain as much as possible. The modelling software used to decimate the model is Blender that provides plenty of model modification functions. After testing different figures, only keeping 20 per cent of the original faces number can guarantee the performance of the application and reserve most of the details of the models.

The anchor point of the model also affects a lot in the later implementation process. For instance, the rotation of the model relies on the anchor point. If the anchor point of the model is not the centre point, the rotation can be weird and out of control. Although the anchor point can shift in the Unity editor by adding the model into an empty father object, it is always better to change the anchor in the modelling software.

B. Mobile VR Version

1) Set Up Environment: Because the SDK applied to set up the VR environment is not VRTK package, the basic operation methods are all needed to change to the target SDK, which is VIVE Input Utility SDK. After setting the Android SDK and Java JDK correctly in Unity editor and switching target Unity platform to Android, the development environment is good to go with WaveVR, and VIVE Input Utility SDK imported.

As we mentioned before, the controller of the mobile VR headset used in the project only supports 3 DOF, which means the headset can only track the rotation of the controller. Instead of using controller collider to interact with the game object, a laser pointer is used to achieve most of the interaction. By setting up the pointer prefab and draggable script, the model can be moved and rotated by the controller. Although the degree of freedom of the controller is only three, the headset has 6 DOF itself. We noticed that, if users move their headset, the position of the controller can change at the same time. Then the user can reach the controller out and grab the game object back. To some extents, it fakes the experience of 6 DOF devices.

One adjustment needs to do in the mobile version is the mobile device only have one controller. Because of this, the user is not able to enlarge the model by using two hands or move the model and control the user interface simultaneously. Other than this, the majority of functionalities remain in the mobile VR version, including slice function and two MCQ tests.

2) Research Lab & UI based Test System: Unlike in the desktop version VR devices, the user has less controllability in the mobile one. It requires the user to have a larger space than before to achieve some basic movements, such as reaching out a hand and grab virtual objects.

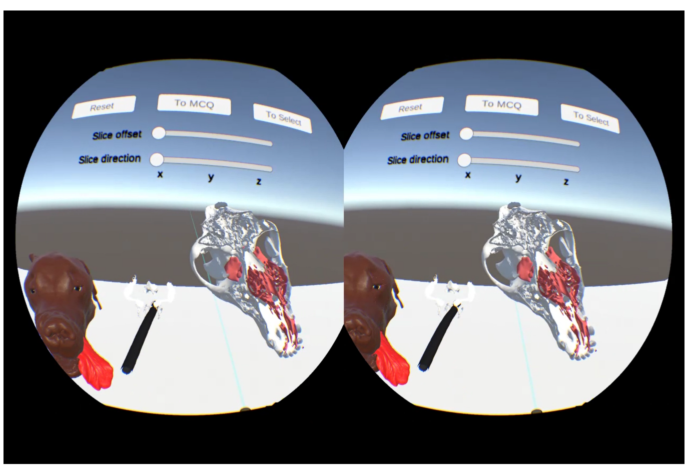

Fig. 1. Mobile VR Research Lab

At the beginning of this project, the mobile VR version did not contain too many VR features. There is a list that contains all the canine components in the users field of view. Users use a laser pointer to choose which part they want to interact with and then the chosen part will fly towards the users, making it easy for them to reach. However, due to the compaction problem of the SDK code and Unity editor, once the model has added an animation, the scripts attached to it will be disabled. So it makes it impossible for the user to do further interactions. Because of this, the animation plan was dropped. Instead, we used the draggable function brought with the SDK, which is much closer to the original version. After setting the playground manager-script on a target game object, the laser pointer can drag it with its mesh collider and a draggable script attached. Again, once the object is in dragging status, the distance between the game object and controller cannot be changed. If users want to move the object close to them, their head needs to get close to the object first and then bring the object back. Surprisingly, the slice function can fully convert into mobile VR devices without too much effort, and the result is positive (Fig. 1).

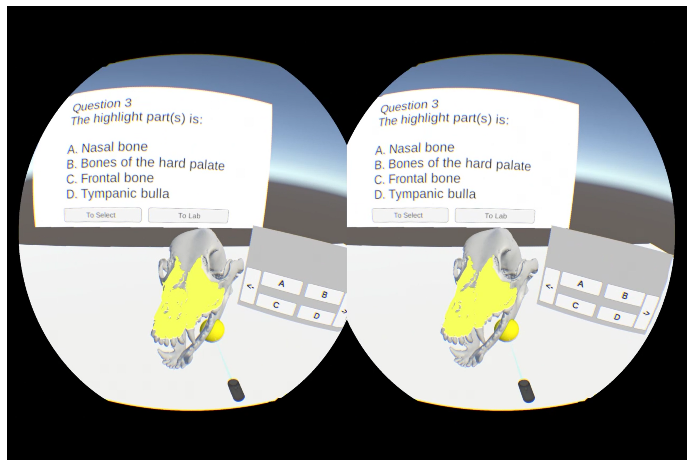

Fig. 2. UI based MCQ

The conversion of the UI based MCQ system is straightforward to implement as the laser pointer can interact with UI. Two problems are raising during the process of conversion:

- The shader of the highlighted material cannot be used in mobile devices. The shader brought with VRTK requires proper GPU to do the calculation of the transparency layer relations. The highlight shader changed to the one does not require GPU to solve this problem, although, the effect of the new shader is not as good as the previous one. The highlighted part will always show at the very front of the screen, and the user might confuse the position of it.
- Another issue is the low-resolution shadow of the light in the mobile device. Consider the limitation of the capability of the mobile device, the fineness of the shadow is decreased to the lowest point, causing the flicking effect on the object. To minimize the flicking effect, the shadow generated by the direct light in the game is turned off.

Other than those two problems, the mobile version VR can get the same level functionalities as the desktop version (Fig. 2).

3) Volume Based Selective Test System: The selective test system (Fig. 3) is more complicated than the UI based MCQ because of mobile VR controller. In the original version, two controllers have different functions; one is to grab and rotate the object, while the other one is to highlight the corresponding question parts. However, in this case, the only controller we have needs to equip with both functions.

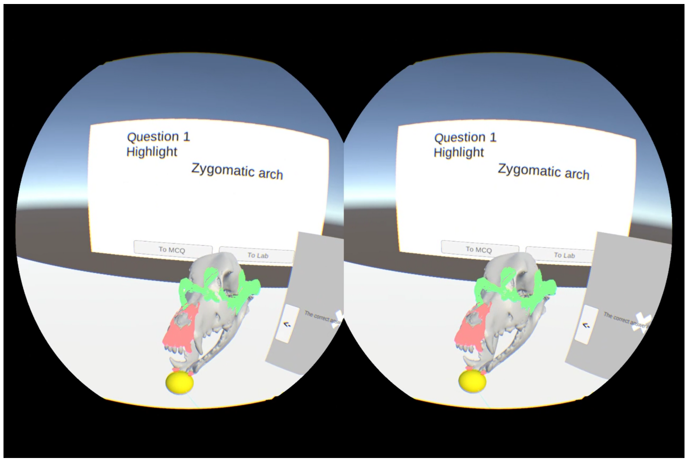

Fig. 3. Volume Based Selective MCQ

The SDK does not provide event listening script to check whether the object collides or not. Thankfully, it supplies the statement of the buttons on the controller. So, when the controller enters the components collider, the system will check whether the button is pressed and then highlight the corresponding part. Furthermore, the collider sphere of the controller itself is too big to select within a small area, plus the movement limitation of this mobile device, the error tolerance is affecting the normal usage. So, the collider of the controller is downsized to get more accurate control feeling and also avoid multiple chooses at one-click time.

C. AR Version

1) Set Up Environment: The Android SDK and ARCore SDK are all imported into the Unity engine to set up the AR environment. A prefab called ARCore device will apply for the access of the camera of the mobile phone and track the pose of the device, which is the core configures of the AR application. The Point cloud prefab is used to visualise the point cloud generated by the system. The AR device will try to figure out the point with most significant features, mark the point as an anchor point and add it into the point cloud. This information is combined with the devices inertial measurements to estimate the pose (position and orientation) of the camera and then generate the plane by aligning the pose. The Environmental light would estimate the light circumstances of the real world and adjust the virtual object to the same conditions as the environment to increase the sense of realism.

After configuring all the prefabs into the scene, the AR environment is built up for the development. In the sample scene of the SDK, a script called AR Controller is applied to interact with the detected virtual plane. The script would get the coordinate corresponding to the screen and projects a ray along the camera's direction to see whether it interact with a virtual plane or feature points. By replacing the prefab of the script, the canine skull can move into the AR world.

Before activating the AR function, the system would ask users to move their phone gently to get enough feature points. It also requires a plane with texture and enough light intensity to get a quicker and stable scan. When the virtual plane appears, the users can select or otherwise interact with the virtual objects.

2) Research Lab: The conversion from VR to AR is much more different than the previous conversion. Because the mobile phone does not have a controller for the user to interact with the virtual object, all the operation would achieve by finger gesture, touch mainly.

Fig. 4. AR Version of Research Lab

A virtual canine model will initialise when the user touches the plane detected by the AR system. The number of models is limited to one, as too many models can cause a waste of cellular phone resources, decreasing the user experience. After the virtual canine model sitting on a plane, users can rotate the model and change its height by using the user interface. As on mobile phone, users cannot grab the object and rotate it, the only ways to do this are moving the phone or using the UI joystick. However, once a rotation UI is added, the user would intend to use the rotate function to move the virtual object, instead of standing up and walking to see in different angles. The UI buttons are the easiest way to achieve this, which makes the AR application have no different from the non-AR application.

Unlike the VR version, AR version needs a dropdown box to change the component shown on the screen. An alternative solution might be touching the models and drag to separate them, which can have a closer experience to the VR one. The slice function successfully transferred to the AR platform, and the slice direction can also change by a dropdown menu (Fig. 4). Users are also able to rotate the model by touching and sliding on the model and can zoom the model by using two fingers. In addition to the adjustment of dragging and rotating functions due to the characteristic of the mobile phone, the

AR version contains all the main features on the VR version, which makes the comparison experiment possible.

3) UI Based and Volume Based Test Systems: When converting the test system into AR platform, the very first problem occurred is the model can be removed any time during the test, which means the information of the volume that is destroyed must be stored correspondingly to the current question number. In order to solve this problem, when a new object merges into the scene, the children objects of it would be stored into a dictionary and active the question part at the same time. So, when the question moves on, the system can fetch the next question part according to the new dictionary of the children objects. The system will stop responding to any input if the model is not generated in the scene, making sure the test system goes well. The second problem is the same as the mobile VR version, which is the highlight shader acting wrong on mobile devices. The problem solved by the same method, replacing the shader.

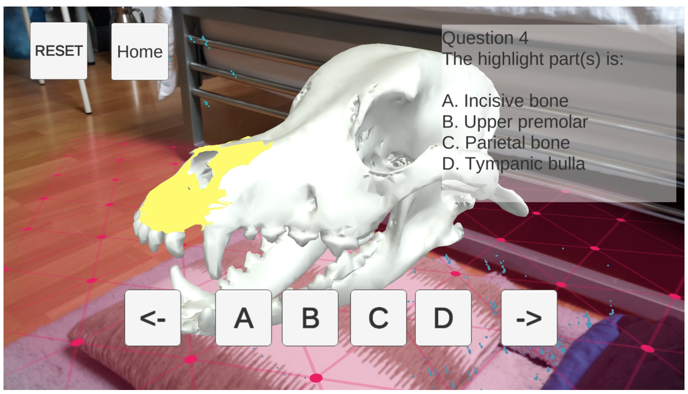

Fig. 5. AR version of UI Based MCQ System

The UI based MCQ test system is similar to the VR version (Fig. 5). Users place the model on a plane, then observe the highlighted part of the question and press the correct answer button.

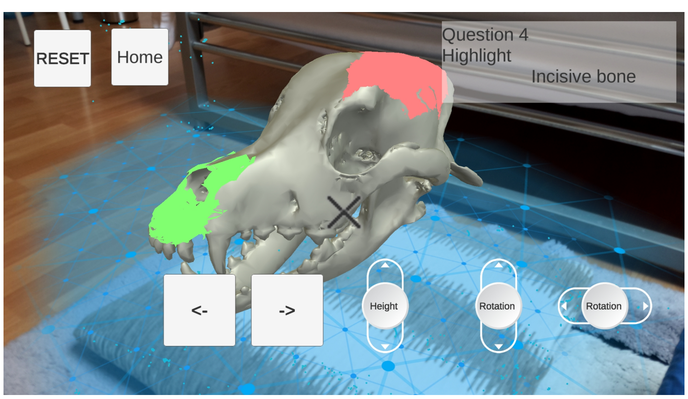

Fig. 6. AR version of Volume Based Selective MCQ System

The volume-based selective test system (Fig. 6) is implemented by using the ray cast function in Unity engine. The model components are all marked in one layer and the ray only responses to this layer. The ray cast function will return a hit game object, which is the first game object in the layer that hit by the ray. If it is not selected, the corresponding selected part will be active, and the answer will set to this question.

V. Pilot Study

A. Pilot Hypothesis

As the applications are designed for veterinary students and lecturers, they become the test subjects to see which device is suitable for vet education. Student and staff from UCD school of veterinary medicine were invited to evaluate the applications on both devices. The ethical approval was sought and obtained from the last time. Independent from the initial veterinary staff and students that reviewed the project, six lecturers and a student had attended the pilot test.

The pilot aimed to compare mobile VR and AR devices with same VR summative assessment content in a different aspect, including user experience, portability, education and communication. The participants will try both devices. Because the number of participants is quite limited, the experiment is a within-group test and counterbalancing is also considered.

The hypothesis of the experiment is as follows: Mobile VR version has a more immersive experience and more portability comparing to the desktop version; AR version has better mobile experience and is more suitable for cooperation and communication.

B. Participants

When the lecturers came, the purpose of the project was explained to them. Firstly, the AR device was shown to all participants. They were able to pass the device around and experience the research lab of the application. Then, the mobile VR device was shown with a monitor casting. While a participant was experiencing the research lab mode, the rest were allowed to watch the test going on. During this process, they could express whatever they thought about the system and discuss it amongst themselves.

After experiencing the research lab, participants were aware of the basic operations in mobile VR and AR and knew how to use the user interface, which was helpful for the next tests. Half of the participants were randomly chosen for a test system, and the test system is also random, either UI based MCQ or volume-based selective MCQ. Each test system had ten questions, and the result of the test would come out immediately, participants were able to see the result and see the details of each question if they wanted.

After finishing the whole experiment, all participants were asked to fill up three questionnaires. For each device, they were told to rate their feelings in different aspects from 1 point to 9 points by considering the closest real-life feeling they had. The last questionnaire contained some basic information, like gender and age and general feelings of both devices such as portability, teaching and communication aspects.

C. Result

Most participants have the experience of using VR before while none of them has AR experience before. According to the result of the experiment (Fig. 7) (Blue background is the answer preferring VR, while the red is AR), the AR device did not have impressive performance compared to VR. Four out of seven people think VR has better feelings and two people think both devices are good but in different aspects. The main reasons why people prefer VR can be concluded as a better feeling of control and the details kept in the models.

Num	Gender	Age	Did you feel the test was better in VR or AR?	Why	Which device do you think is better in terms of the teaching aspect	Why	Which device do you think is better in terms of the portability aspect	Why	Which device do you think is better in terms of the communication aspect	Why
1	Female	36-45	VR	Because there's a feeling of control and proximity which is good for looking at detail	VR	I want to see higher resolution for desktop version	AR	Student could work independently	AR	For group work, the # of devices in the room lends to better group discussion
2	Female	36-45	VR	Easier to see the image and its details	VR	Immsersion experience	VR	For the better quality image I would use the VR, it isn't that bulky	AR	Possibly AR for group work
3	Male	36-45	VR	More	AR	All students use the same structure	AR	Easy to use, and no headset required	VR	Easier to see structures and enlarge them
4	Female	26-35	Both	VR = more detail, better interaction, easier to see detail; AR = more useful, i.e. can use at home	VR	Better ability to visualise, and see details = more useful to learn	AR	On your dvice at anytime	AR	More availability/flexibility for location of use = more useful to revise and for group work
5	Female	46-55	VR	More detail, more control	Both	Both are good but with different benefits... AR for groups. VR for individual study.	AR	As students generally all have phones	AR	VR would be better for individual experience compared to AR where you chould use in a group of people
6	Male	36-45	Both		AR		AR		AR	
7	Female	26-35			AR		AR		AR	
			Feeling better		teaching		portability		communication	
			VR:4 Both:2		VR:3 AR:3 Both:1		VR:1 AR:6		VR:1 AR:6	

Fig. 7. Comparison between VR and AR

As for the teaching experience aspect, half people think VR is better because of the higher resolution of the model and the immersive experience, while the other think AR is better for group teaching. There is one participant who thinks both devices suit the teaching environment. She said Both are good but with different benefits. AR for groups. VR for individual study, which shows that two devices have their suitable circumstances.

Num	Gender	Age	Have you used Virtual Reality before	If yes , what Equipment have you used and roughly how many times	Have you used Augmented Reality before	If yes , what Equipment have you used and roughly how many times	Do you think VR and AR are better ways of testing Anatomy than a paper based MCQ	Any other comments on the experience
1	Female	36-45	Yes	Once, Isaac's dog head in Science	No		not yet, student are not used to it which would cause stress	It has so much exciting potential for teaching . I'd like to see soft tissue(May be from MRI data) and if vascular + nervous tissues can be reproduced. I'd like to see desktop higher resolution as otherwise it's a compliment to other resources, requiring previous or background knowledge to get the most of it.
2	Female	36-45	Yes	Once before, virtual doj in Canada	No		Unsure	
3	Male	36-45	Yes	Once / Twice	No		Yes	
4	Female	26-35	Yes	Once, used this same program last semester	No		I think they would complement current forms of testing. The opportunity to test on 3D structures without using multiple cadavers or unclear pictures is what is quite innuiging.	The AR is etremely cool - a portable way to revise 3D structures at home, in the library etc. Without having to carry around a skull. The AR would make, group work easier for projects, all members can look at the structure at once.
5	Female	46-55	No		No		I think it would be a more interesting way of teaching. If internet it was very user friendly it would work. I don't know id it would be a better way necessarily	Really interesting experience
6	Male	36-45	No		No		Yes	
7	Female	26-35	No		No		Yes	Very good & would be excellent for students pre-director Clane before encounteuring a cadaver

Fig. 8. Use experience and comments

According to the result (Fig. 8), six out of seven people think AR device has better performance in portability and communication aspects, which is a quite surprising result as the VR device compared with AR is also a mobile device. Except one participant said the mobile VR device is not that bulky to carry around and has high-quality images, the others all thought that AR was easy to use and can be used at any time, any place. As for the aspect of communication, the majority think AR is more flexible for the location of use and the multiple devices are better for group discussion.

When it comes to whether VR and AR are better ways to do the anatomy test, four out of the seven participants give a definite answer. A participant concluded that I think they would complement current forms of testing. The opportunity to test on 3D structures without using multiple cadavers or unclear pictures is what is quite needing. Two of them are not sure about this method, while one participant thinks it is not the perfect time to use it as an examination tool as the devices are too new to hand on.

VR							
Numebr	Gender	Age	(Positive/Negative)	(Inside/Outside)	(Excited/Calm)	(Lack of/In control)	(Far away/ Beside)
1	Female	36-45	1	1	3	2	1
2	Female	36-45	3	2	3	6	4
3	Male	36-45	1	1	5	4	8
4	Female	26-35	1	1	1	4	1
5	Female	46-55	1	2	8	3	3
6	Male	35-45	1	1	1	4	1
7	Female	26-35	1	2	2	7	8
AR							
Numebr	Gender	Age	(Positive/Negative)	(Inside/Outside)	(Excited/Calm)	(Lack of/In control)	(Far away/ Beside)
1	Female	36-45	5	8	6	7	7
2	Female	36-45	5	7	4	6	8
3	Male	36-45	2	4	3	3	7
4	Female	26-35	1	3	1	3	2
5	Female	46-55	3	7	8	2	6
6	Male	35-45	1	5	1	3	2
7	Female	26-35	1	2	2	7	5
	Lower better	T-test p value	**0.063335539**	**0.005127704**	**0.631374258**	**0.868832341**	**0.22140339**

Fig. 9. Student's T-test figures

The p-value of the t-test is shown in the chart (Fig. 9) As the values in most of the aspects are more than 0.05, it is hard to prove that the figure difference between two different devices has significant meanings. However, in the inside/outside category, the p-value is 0.005, which is even less than 0.01. It shows that the figure difference between two devices in this area has significant meanings and proves the hypothesis. The inside/outside aspect is related to the immersive feeling of a VR device and the realism feeling of an AR device. Based on this, the mobile VR version has more immersive experience than the AR one. The reason why the experience of AR is worse than VR might be:

- The screen of the device is too small to see the details of the model. If the model is enlarged to show the details, the realism experience could vanish as the user cannot see the whole virtual object or either the real world.
- The motion tracking of the device is not stable. The model shifts phenomenon happened a lot during the experiment. Moreover, it took a too long time to recognize the surface of the real world, even though the light condition and the texture of the surface are good enough.

In general, the mobile VR version has better performance in the experiment, and the result of the Students T-Test proved that the VR is more immersive than the AR one. However, AR has much potential in group work, and its portability can also help student with their study.

VI. Conclusion and Future Work

To explore a better way that can overcome the portability limitation of teaching and learning anatomy, the works presented in this paper focus on transferring all the functionalities and user experience onto mobile devices. The problem this work seeks to address is the difficulty in teaching communication and space limitation of the desktop teaching device. As most of the VR headset is connected to a PC, carrying all the equipment around for teaching and studying is not handy.

Mobile VR headset inherits almost every single function from the desktop version and keeps the high-quality immersive experience. Although the three degrees of freedom controller decreases users control feeling, it still works fine with the study user, just like an experiment participant said, Because there is a feeling of control and proximity which is good for looking at detail. However, the low capacity of the mobile device reduces the resolution of the model details and hinder the performance of some graphic effect. If further improvements need to be planned, the essential condition is the capacity of the head-mounted display. The controllers that support six degrees of freedom would boost the user experience of the application. Moreover, by casting the image to a mobile phone, people around would also see the image simultaneously, which makes VR device only for the individual student, motivating students and lecturers to communicate.

Due to the characteristic difference between the mobile phone and VR headset, it is hard to convert all the features from the desktop version into the mobile phone. On the one hand, the AR version of anatomy application is not as good as the desktop version in many aspects, such as realism feelings and sense of control. Current AR device is not capable of providing the user with a real experience of AR. The screen of a mobile phone can only fit in a small object, which makes it impossible to see the details and the whole object at the same time. Besides, as long as the user can rotate the object by getting interact with the user interface, they have no reason to stand up and try to find the perfect angle to see the particular area, not to mention that the motion tracking of the device is not stable.

On the other hand, AR devices still have considerable potential in anatomy education, especially in the portability aspect. Like the participants mentioned in the experiment, AR is easy to use, and the user can take them out at any time any place. The screen that is open to others also makes it a better tool to cooperate and communicate within a group. The current plan is to use cloud anchor between multiple devices to make the system better. By using cloud anchor, all the devices would share the same scene but from a different angle. Instead of looking to one small screen, everyone present can take out their phone and do the operation at the same time, from their angle.

The contribution of this paper is to demonstrate how a functional VR application converts into a mobile platform, which overcomes the shortage of current device, proposing a way to benefit the efficiency of veterinary education.

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