Final Year Project Report

Virtual Reality Canine Autopsy

XUANHUI XU

A thesis submitted in part fulfilment of the degree of

BSc. (Hons.) in Computer Science

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Project Specification

General Information:
The project is to work with UCD School of Veterinary Medicine (David Kilroy in Anatomy) to develop a VR dog from MRI and CAT scans. You will be working within the UCD VR lab under Dr. Abraham Campbell and work with the VIVE VR system aswell as the Oculus Rift.

The aim of the project is to develop a VR dog that potentially could be used for education purposes. As such UCD computer science Associated Professor Eleni Mangina will also mentor the project and aid the student in developing a VR learning object for the VR dog, this is a form of mark-up language to allow the model be used in a multitude of different VR learning environments.

Core:

- The student will develop a VR dog model .
- This model allows for the separation of bones from the internal organs. The VR dog will be placed in a Immersive VR environment using the UCD CAVE using a VIVE .
- The student will be given techniques developed in UCD and will research new technologies to achieve the goals of this project.
- The student may use either Unity, another game engine or construct their own 3d VR engine using openGL. We assume the student will use Unity or another game engine for this project as we would not advise the student attempting to code a 3D engine from scratch. There are many open source tools available to help construct the 3D model, the project expects the student to explore which ones are the most suitable to use and it is not expected that the student would write their own volume render.
- The student will utilise Learning Objects' standards developed by Eleni Mangina for the 3D object created and will help contribute to research group on VR learning objects,

Advanced:

- The VR dog will be sufficiently modeled to allow for a mock exam to be performed.
- The volume render is of sufficient quality that a virtual plane can be placed to cut across the model and allow a virtual MRI / X-Ray to be conducted.

Abstract

There still exists multiple challenges in the education of veterinary students. One particular challenge, which is thought to be impossible to solve, is timeless issue of a lack of anatomy materials. Either due to a lack of donations or simply the financial costs of storage limit the availability of anatomy materials to any given module. Hence, most of the students learn anatomy from 2D images, and cannot get the specific information of space, only imaging the solid. Virtual Reality offers a possible solution which this project explores. In this project, virtual volumes were generated from DICOM data, using certain viewer tools. In the next stage, these volumes were imported into Unity game engine where basic and advanced operations (e.g., grabbing, slicing, etc.) can be programmed. Finally, a pilot test was implemented in order to collect the user experience and feedbacks from veterinary students, who were asked to use this VR system. Last but not least, the results of the test is positive and shows that VR can indeed be utilized for the improvement of the veterinary education.

Keywords: Virtual Reality, Veterinary, DICOM 3D Modeling

Acknowledgments

Here I would like to express my deepest appreciation to people who helped me in this project.

My supervisor professor Abey Campbell provided me with a perfect environment and devices for my final year project and gave me a lot of advice and encouragement during the whole process.

My supervisor professor Eleni Mangina guided me from the beginning, gave me a lot of advice on report and presentation to put me to the right track.

Staff from vet college: Professor David Kilroy provided help for me on biologic aspect and with the pilot test; professor Arun Kumar provided his idea and supported me during the presentation; Cliona Skelly helped with DICOM data; everyone that attended for pilot test and demonstration for their feedbacks and help.

Last but not least, the support that my friends, my family and my love gave me throughout this.

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Chapter 1: **Introduction**

Nowadays, Virtual Reality (VR) has been used in various applications (e.g., academic research, biology, architecture, gaming, etc). It can generate a virtual space where operations can be done without having to have the actual physical devices. Throughout the process of rendering organ volume from DICOM data, the usage of VR in biology helps surgeons do pre-operative planning before the actual surgery. Thus, the possibility of the unexpected risks could be reduced, and unnecessary casualties could be avoided. Furthermore, as for the educational aspect of both veterinary and medicine, the prospective surgeons can practice on a virtual object as the matter of their study in order to obtain the required skills for an actual surgery. However, without tactile feedbacks, the simulation is incomplete. So, in order to elevate this problem and enhance user immersion, customized controllers could be developed in order to produce tactile feedbacks in different situations. In this work, the results of the experiments show that immersive virtual reality has a lot of potential for improving the efficiency of the education while maximizing the similarity with actuality.

One particular challenge, which is thought to be impossible to solve, is the lack of anatomy materials. Either due to a lack of donations or simply high financial costs of storage, the availability of anatomy materials for any given module, is limited. The education in veterinary needs a huge number of bodies for the autopsy, which is a common issue in both medicine and veterinary, especially for topics such as Digital Rectal Examination (DRE) training for curing prostate malignancies. Some companies have tried to produce silicon models to solve this problem, which seems to be a good solution. However, it is too costly: in 2016, SynDaver tried to raise a 24,000,000 dollar crowd-funding for the synthetic canine research, but in the end, only received 16,000 dollars.

From another point of view, the main materials from which the students acquire their knowledge are mainly articles or books, which are only capable of showing 2D images. The knowledge acquired from imagination based on 2D structures could create a huge gap between theory and reality, which could make a novice surgeon to spend more time on correcting their knowledge when facing a real-life scenario. Considering all these issues, the efficiency of the traditional way of education seems to have much more room for improvement.

The aim of this project is to create a VR application to solve the aforementioned problems in the realm of veterinary anatomy, by creating an interactive model in to an immersive environment. This model could become highly accurate, provided that it is generated from the DICOM data. For teaching, students would have the ability to slice the model and view the specific contents of the tissues or organs, down to their fine details. When the users want to check the detailed information of a specific part of the organ/tissue, the User Interface (UI) can lead them to the page number of the textbook that contains the relevant information. For the examination, the VR system could initiate some internal tests for the students, including self-checking functions, knowledge point review mode, etc.

This report is organized as follows: Chapter.2 provides the background research, mainly about the state of virtual reality in veterinary and the motivation behind this project. Chapter.3 is about the design and methodology of the whole project. Chapter.4 is the detailed implementation of some difficult points. Chapter.5 introduces a pilot test, which is designed for the evaluation of the VR system. Finally, chapter.6 includes the conclusion and future work.

Chapter 2: **Background Research**

2.1 Papers Research

2.1.1 VR in Medicine and Veterinary

How can virtual reality affect the education in medicine and veterinary. Nicholson el at [1] made an experiment to verify whether virtual reality can improve anatomy education. They reconstructed a fully interactive model of the middle and inner ear from a MR imaging scan of a human cadaver ear and used it for the test. By randomly separating 61 medical students into two groups, one learned ear anatomy from a website with interactive 3D model generated by computer, the other one just learned based on tutorials. The result showed significant improvement by learning through 3D models, while the mean score of the former group was 17 percent higher than the latter group. Different from traditional tutorial, 3D model could provide more details and active the motivation of leaning.

Lack of materials and live tissues would always be a big trouble in medicine and veterinary education as surgical students , especially some rare subject, may rarely get chance to practice. Sarah el at [2] presented a virtual reality based teaching tool - the Bovine Rectal Palpation Simulator - that has been developed as a supplement to existing students' training methods. During the process of using the simulator, students got feedback from a PHANToM haptic device, in which teachers followed the action from students and gave instructions. They also evaluated the performance of the teaching tool and the result was showed a significantly better performance. By using the virtual reality based teaching tool, the problems in veterinary education, for instance, lack of resources and welfare issues, restricting the amount of training available to students in learning procedure could be eased or even solved.

Burdea el at [3] presented a virtual reality-based simulator to address the problems in digital rectal examination (DRE) training for curing Prostate malignancies. For instance, the number of patients that students could practice on was limited, allied care personnel did not train in screening for prostate cancer and whether the student doing well or not was hard to evaluate. In addition, there is no objective way to follow the improvement in DRE skills for medical personnel. And the simulator improved the correct diagnosis rate of malignant versus nonmalignant cases for nonmedical students and urology residents. It was concluded that the simulator needs significant improvement in both model realism and haptic interface hardware for a better performance.

Richard el at [4] claimed that approximately 90 percent knowledge a physician needs could be gotten from electronic means. By using the Internet, a therapy can be effected electronically, regardless of the physical location of the patient, achieving remote therapy.And those are the major force of VR to change the medical field. "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." Students and surgeons can learn and practice surgical procedures in immersible environment for unlimited times.

Rebecca el at [5] developed a mixed reality simulator to complement clinical training as the practice subjects had a low tolerance to being examined. They used toy which had two PHANToM premium haptic devices on each side as the physic base, on what virtual models of the chest and some abdominal contents were superimposed. With the participation of seven veterinarians, the result seemed encouraging and practical. Using the simulator before examining live animals particularly as the instructor can follow the movements inside animals body. By using mixed reality tech, veterinary research, exam and education could be finished under a better environment before getting into live animals, which would reduce the welfare issues and concern more about lives.

During the development of virtual reality in medicine education, this new kind of teaching tool has been accepted generally. Alaraj el at [6] reviewed of current status of Virtual reality training in neurosurgery. Within ten years, the number of published literature discussing the application of VR simulation in neurosurgery training had evolved from data visualization, including stereoscopic evaluation to more complex augmented reality models. Some recent studies had shown the coloration of proficiency with those simulators and levels of experience in the real world. And in the future, more detailed augmented model would be used in neurosurgery as the simulation technique has been about to apply to the practice of neurosurgery. In this case, virtual reality in veterinary would also have potential to be applied in education and even in animal operation.

2.1.2 Current Medicine Support by VR

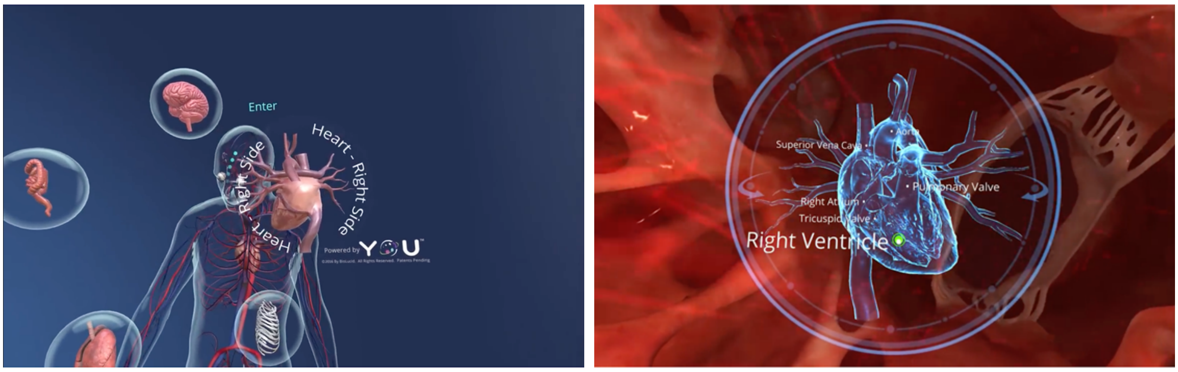

Figure 2.1: YOU

YOU [7] is a software platform that allows interactive exploration of a 3D virtual human body created by BioLucid, a digital health company which is aiming at Making Health Visual and providing solutions for effective visual communication 2.1. It is similar software as the one would be developed in this project, making user get ability to face the medicine volume closely in every angle and everywhere. What is more powerful is that they can simulate real biological phenomenon, for instance, the airflow happening in lungs or blood flow in heart. The company BioLucid also provides custom made option for specific patient case. Focusing on three aspects of target customer:

- Pharmaceutical Companies: YOU revolutionizes the way health, disease, and treatment are visualized and communicated globally.
- Health Systems and Healthcare Providers: YOU improves patient outcomes and satisfaction by increasing overall health literacy.
- Educational Institutions: YOU transforms medical education by creating an interactive learning experience leading to better knowledge retention and understanding.

It shows that when doing the education in virtual reality environment, there is no need to keep the medicine model same size as in real life. The power of VR is not stopped at simulating the real situation but expanding it and not only can serve education, but also the simulation for medicine.

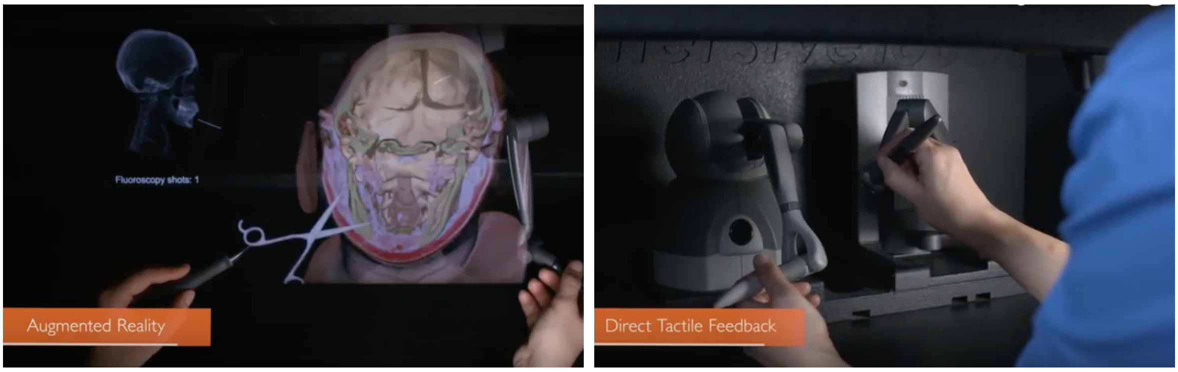

Figure 2.2: Immersive Touch

Immersive Touch 2.2 is a virtual reality platform for the Health-care Industry. It provides tactile feedback created by the surgical touch and medical device's interaction with patient anatomy for surgeons to experience a more immersible surgery simulation. By using Immersive Touch, not only the students can get more real practice in virtual environment, but also surgeons can communicate with their patients about their specific condition with personalized VR content. Alaraj el at [8] introduced Immersive Touch (IT) as an augmented reality (AR) system that integrates a haptic device and a high-resolution stereoscopic display, which also utilizes multiple sensory modalities, recreating many of the environmental cues experienced during an actual procedure. In this paper, they did not claim that the AR and virtual reality could produce a perfect neurosurgical resident, just like the ability to master a sophisticated flight simulator to the satisfaction of an FAA examiner does not mean the individual will be a good real-world pilot. Anyway, virtual and augmented reality environments would represent a crucial advancement toward enriching the training for neurosurgical residents as well as providing a platform for experienced surgeons to maintain their skills.

2.1.3 Similar Project

In order to understand a brief structure of what needs to be done, the learning of other similar project is quite important. During this process, you shall understand what's the general process, know what kind of software could be used for the project and get contact with other thesis.

Asma Almaksy el at [9] modeled novel vascular from CT DICOM data for Augmented Reality systems. It states the bad effect of the aorta aneurysm and the difficulty of Endovascular aneurysm repair (EVAR). First, it talks about segmentation and mask selection. It divided the CT images first while not in the 3D model, which can use several algorithms such as automatic, semi-automatic and manual segmentation. They tested free software including 3DSlicer, ImageJ and InVesalius then decided InVesalius was the best way. InVesalius is kind of software which can construct mask and select the wanted part of multiple masks. Then use Marching Cubes to construct 3D models by MeshLab. Although some holes need to be filled after the 3D modeling. Laplacian smooth algorithm is used to smooth the model. The final model was exported as STL into MeshMixer. The model needs to be fixed by software such as Blender, NetFabb and MeshMixer (most ideal) when it is initially imported into Unity3D.

Olivia de Oliveira Ranito el at [10] made 3D Stereo-lithographic models in Virtual Reality to assist in pre-operative planning. It states the bad effect of the heart disease and the importance of the preoperative planning then shows the increasing attention on 3D modeling. By using 3D model, they can make solid 3D model by 3D print technique, which can be used not only in pre-produce but also to solve the problems in education like lack of cadaveric material. And placing models into Virtual Reality is also a better way to teach students. The usage of ARToolKit makes Augmented Reality (AR) into Unity. Without using the same plug-in as ARTK, Oculus SDK is used to implement the Virtual Reality into Unity. Razer Hydra Controller is used as controller integrated with Sixense plugin. Quadric Edge Collapse Decimation (reduce half the numbers of mesh), Blender, Netfabb and Autodesk Meshmixer (divide mesh into sections) were the software involved. However, a problem arose when they tried to put mesh collider into Unity which is the polygons must be less than 255.

2.2 Other Research

2.2.1 Benefits of learning in VR Space

Nowadays, the world is stepping in to a generation called 'digital generation'. [11] Students are getting more and more familiar to new technology in a very young age and using this for every part of their life. This has become a teenager's lifestyle and teachers are aware of the reliance of technology. There's a lots of benefits of learning in Virtual Reality(VR) classroom:

- Active experience: students are able to approach the learning object actively while the active experience of learning can improve the enthusiasm of learner, comparing to passive experience.
- No distractions: The immersive environment can make learner focusing on the current stuff, which means they won't be distracted by their phones or other curious things.
- Immediate engagement: They can take part in the learning immediately, focusing on limited attention spans.
- Exploration and hands on approach aids with learning and retention.
- Helps with complex subjects: By simulating the experiment and observing in different angle, this can help learners understand the complex subject and theories.
- All types of learning styles: Visual, practical and theoretical learning can be easily handled by VR.

Because of all these reasons, using VR technology as part of learning might be useful and helpful for contemporary education system. By blending this new way of learning with several other approaches, a mix learning approach may be suitable for most of students and can be adjusted for their own learning style.

2.2.2 Meet with Professors

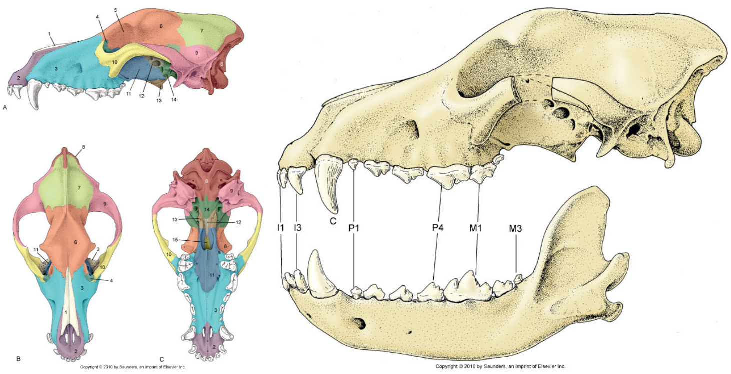

Figure 2.3: Three View of Skull

In order to get better experience of using the software, the conversation happened with professors in veterinary science subject helps a lot. Professors pointed out couples of aspects that can be considered.

- The function of slicing the model is quite important as this operation can show as much as details of data inside volume.
- Every part of the 3D model is linked to the specific content.
- The process of rendering the model could be part by part, for instance, first bone part, and then skin, vessels, brain, other tissues...
- As muscle is hard segmented from the bone, a better way to model this is creating muscle models and attaching them to the whole part.

As the canine anatomy needs some specific knowledge, processors provide me some materials for further function achievement and accuracy. Professor David Kilroy sent me a three view graph of dog skull for the segmentation of selection highlight system.

2.2.3 On-line Resource

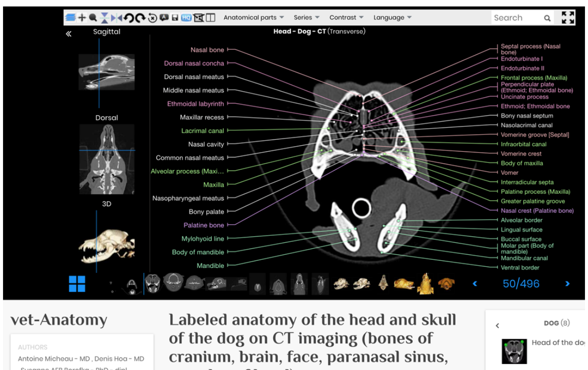

Figure 2.4: Labeled anatomy website

Antoine Micheau - MD el at [12] labeled anatomy of the head and skull of the dog on CT imaging (bones of cranium, brain, face, paranasal sinus, muscles of head) 2.4 and posted the result on website IMAIOS. You get the ability to view the DICOM data of canine head with details and also the 3D volume on the website, which would be really helpful.

2.3 Motivation

The motivation of this project is to deal with the problems that veterinary college currently have and optimize the education structure.

- Create immersive environment for veterinary education. Improving the teaching efficiency by help students learn the model in 3D space, focus on the study and understand the relationships between structures. By merging the teaching approach with other traditional method, a new type of mixed-approach of educating might be delivered, which can also be customized to many other occasions.
- No worry about autopsy material. As the leaning object is generated by computer, there's no need to mention about the waste of materials or limited resources of body. For the healthy of students, the virtual model is clean, won't change shape or infect bacteria and virus with the time passing by. Additionally, modeling in computer for a high quality volume is way much cheaper than creating a silicon model. Although the experience of feeling might not be as good as silicon model, the virtual model is more portable and customizable, which can simulating more disease's situation and improving the practical.
- Advanced operation can be achieved for research. Because all the functions in the immersive space would be implemented by programming, some extreme and unachievable operation in reality can be realized in virtual environment. For instance, user can slice the model in different directions, getting connection between cross-sectional anatomy and 3D volumes in real life. In the future, with the help of physic engine in Unity, an operation demonstration might be achieved under live calculation, which would be a huge step in the development of veterinary education.

Chapter 3: **Methodology**

3.1 Work-flow

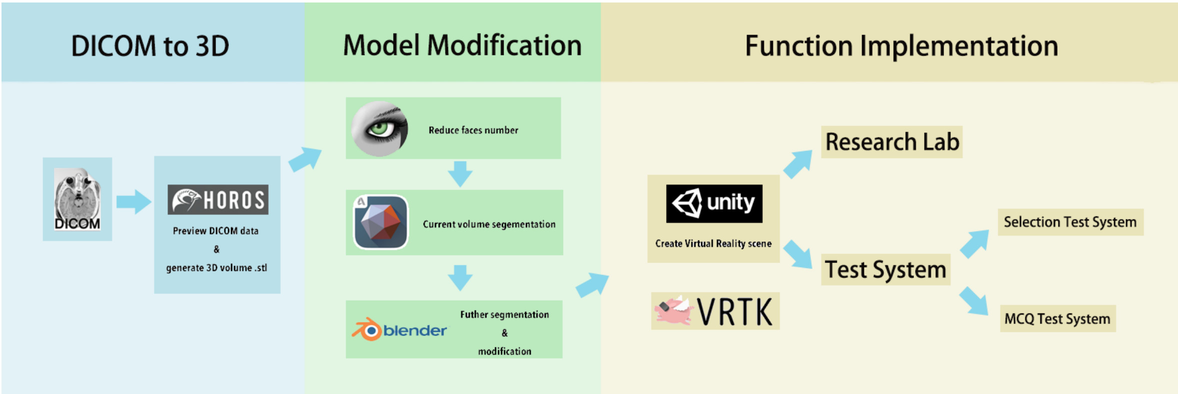

Figure 3.1: Work-flow

In this section, synopsis of the way working out the project solution is introduced 3.1, which is divided into three stages.

To get 3D data from DICOM data, the very first step is getting the DICOM data. The data is collected from college of veterinary and some relevant knowledge is retried through meetings with the professors David and Arun. After receiving DICOM data, the data is analyzed by Horos and volume is generated at the same time with based segmentation.

The models gotten from Horos still need some modifications. Use MeshLab to reduce the number of faces and then use MeshMixer to do some automatic segmentation. By using Blender, the final modification and further segmentation can be finished. The model in .fbx format is now ready for being imported into game engine.

The last stage is function implementation. With the help of Virtual Reality Toolkits, a VR environment scene called research lab with basic functions is created and some advanced operations are waiting to be added in queue. After basic scene is created, a test system that can be used for not only a function , but also for a pilot test is considered to be programmed. Think over the structure of questions offered by professor David Kilroy, another type of test system is also needed.

3.2 DICOM data and Engine Introduction

3.2.1 DICOM Data

Digital Imaging and Communications in Medicine (DICOM) is a standard for storing and transmitting medical images, which is created by CT or MRI. By using this standard medical image format, medical staff is able to communicate easily.

3.2.2 Unity Plus Edition

The game engine chose for build up VR environment is Unity engine. Unity 3D is an open source and cross-platform game engine, which mainly supporting 2D and 3D graphics. Based on C#, it is really convenient to implement the functions. For 3D games, Unity engine provides really powerful graphic performance by editing texture, material and lights. In Addition, it also supports VR and Augmented Reality (AR) development.

Unity provides free version that contains all the core functions for every programmer, however, the number of vertices is fixed below 65535 which may divide your model into may pieces. By choosing Plus version, the limitation is eliminated and the whole performance of the whole program is increased to some stage.

3.2.3 Virtual Reality Toolkit

As Unity is a open source editor, there is also a lot of useful plug-ins provided by assets store. Virtual Reality Toolkit (VRTK) is a collection of useful scripts like grabbing and teleporting and prefabs for building VR environment in Unity. It covers solutions for VR like interactions with object and UI canvas in space and some other advanced operations.

3.2.4 SteamVR

'The SteamVR SDK allows developers to target a single interface that will work with all major virtual reality headsets from seated to room scale experiences. Additionally, it provides access to tracked controllers, chaperoning, render models for tracked devices. SteamVR's compositor allows you to preview your content in VR using Unity's play mode, while leaving the normal game window to act as your companion screen on the main monitor.'

3.2.5 HTC VIVE VR Headset

The hardware device is HTC VIVE VR headset which is provided by my supervisor Abey Campbell.

3.3 DICOM Transfer

In order to create an application that can help with biological education, the research about how to create 3D model by DICOM data, such as CT, MR, seems to be really basic and important part of the whole project. Every tool has its own advantages and short parts. Trying each tool and then finding which is the most proper tool to create 3D model would be more time-saving in the future research.

3.3.1 DICOM Analysis Tools

ITK-SNAP is an interactive software application that allows users to navigate three-dimensional medical images, manually delineate anatomical regions of interest, and perform automatic image segmentation. (From Wikipedia) This software is quite handy, it can import DICOM data easily and show the details in 3 dimensions. The segmentation function is quite powerful among those old medical software, which providing auto-segmentation and user can easily control the process, limiting the range.

Seg3D2 is a free volume segmentation and processing tool, and thank for that we can segment model parts by parts and easy to see. I went through the same situation like ITK-SNAP that I cannot render the 3D model for DICOM data and it was really hard to find the tools for this. And the 3D model it provides now is just three images. The tutorial for Seg3D2 is really few on the Internet.

OsiriX (Lite) is an image processing application for Mac dedicated to DICOM images (".dcm" / ".DCM" extension) produced by equipment (MRI, CT, PET, PET-CT, ...).(From Wikipedia) According to my research on the Internet, this software might be most powerful among the medical image processing. With powerful engine, it can deal with 3D volume which is more spectacular. Whats more, the service is much more complete including tutorials, help center and plenty of resources. However, the functions of lite version seems to be too shabby to use - it cannot even create volume (since the software updated 3 years ago) while the formal version is too expensive for student.

Slicer 3D Slicer is an open source software platform for medical image informatics, image processing, and three-dimensional visualisation. (From slicer.org) Till then, I finally found a tool that can generate 3D model of DICOM and it is called Slicer. It is really handy and powerful, and can segment the DICOM data automatically, create individual model by different tissues and layers. It also provides some DICOM samples which is really delightful for me cause high-quality DICOM resources are hard to find on the Internet. I used Slicer to import a DICOM of CT human chest and segment the bone of it. Then export .stl file of 3D model to be processed in another tool. Slicer is also a expandable software that many users create their own plug-in for many other functions, like air-flow segmentation.

Horos is a free, open source medical image viewer, which is based upon OsiriX and other open source medical imaging libraries. As the formal body is OsiriX, Horos is nearly as powerful as OsiriX. After importing the DICOM data, user can generate 3D model by that and slice the volume easily. It can also generate exportable 3D model for specific part of data, skin and bone especially, which provides a lot of convenience for software engineer. Different view patterns are provided for medical residents.

3.3.2 Process

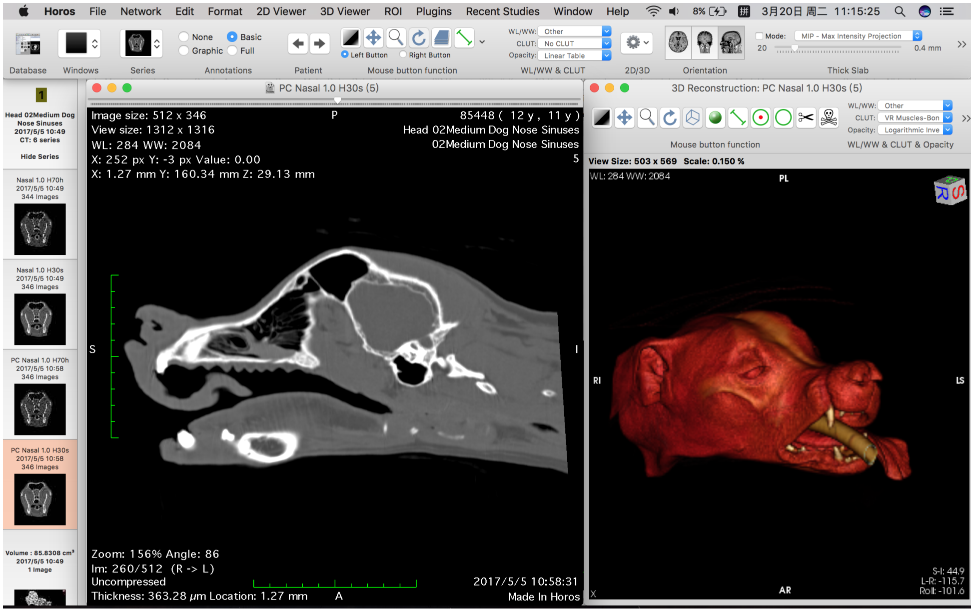

Figure 3.2: View DICOM and generate volume for previewing

With the help of college of veterinary, I got DICOM data for modeling. By using Horos, DICOM data can be viewed in details and generate some basic parts of the data like skull and skin 3.2, which is really convenient for the next modification.

Some customized segmentation like brain has been tried on Horos, however, the model is too rough to use and can not be exported. As the DICOM data of dog head is generated by CT, soft tissues like muscle, vein and artery can not show clearly on DICOM viewer, so, it is not possible to segment those soft tissues. Those segmentations can only be left for the future plan.

3.4 Model Modification

To increase the performance of the game engine and experience of user, the model exported from DICOM viewer still needs some modification, including remove noise, simplification and further segmentation before being imported into game engine.

3.4.1 Volume Process Tools

MeshMixer. After getting the .stl file from Slicer, I import it into MeshMixer to fix the details. It should be able to reduce the vectors and triangles of the volume, however, I did not figure out the specific way while my laptop runs too slow in this case. Whats more, the function of cutting off pieces is not that delightful cause its really hard to find.

MeshLab, The open source system for processing and editing 3D triangular meshes. It provides a set of tools for editing, cleaning, healing, inspecting, rendering, texturing and converting meshes. (From meslab.net)

Blender, a free and open source 3D creation suite that is quite powerful and handy tool after being learned. It is really convenient to use Blender to deal with the modification and inner segmentation of volume. By using Blender, user could even color the volume and attach texture on model.

3.4.2 Process

The first step is removing the noise. Because of the principle of generating DICOM data, the things that show same attenuation coefficient with main object can also be generated. For example. when we export skin volume form DICOM data, some noise from the blanket that is used for cover the live dog show with the main volume. In the editing mode of Blender, those noise can be removed easily.

Then is simplifying the model. The main purpose of this are increasing the performance of computer and avoid the limitation of free version Unity. Because the capability of graphic card has its own upper bounds, the model with full details would put too much pressure to the graphic cards then effect the frame rate of VR environment. If the refresh rate got lower than 120 Hz and the frames got lower than 120 frame per second, it would cause uncomfortable feeling to user, even sickness. Additionally, there's no need to show every single particulars while simplified knowledge may be easier to be accepted by learner. And the other reason why simplification is necessary is the limitation of free edition of unity, the vertices number of one model is fixed below 65,535, which means some complex models such as skull may be divided into may layers.

The last step is further segmentation. The skin model generated from DICOM viewer contains lots of other organs and tissues, so, it still need to be separated little by little. The skull model is far more complex as it contains so much details inside. By using Meshmixer, the segmentation of unlinked part can be finished automatically, which is much more accurate comparing to hand work. However, there's too many little noise involved in skull and they are all separated as individual parts, causing troubles of filtering them. After all these big part being done, the partition design needs to be finished on skull model for the selection test system. Following the image sent from professor David Kilroy to do the segmentation by using Blender is quite hard to ensure the accuracy for each part as some specific knowledge is needed. So the segmentation of highlight areas are rough, just used for guide the participants.

3.5 Research Mode

The main purpose of this software is to create an impressive environment for veterinary stuff to learn and research the autopsy of dog (head for now). So it really important to set up the Virtual Reality (VR) environment and implement necessary operation methods into the surrounding.

There are two main function mode in this program, one is research mode and the other one is test mode. Research mode is aiming at veterinary education and some research. User can interact with 3D volume, search knowledge points for specific organs and slice the model in VR space.

3.5.1 Basic Operation

As the aim is to create an immersive environment, setting up VR title and achieving some basic functions are the foundation of the whole program. These basic operations allow user to move around in immersive environment and get interaction with virtual objects. By using VRTK, some packeted scripts can be used directly in Unity to get this goal. After getting used to the rules and connections between each scripts, the VR space can be set up easily.

3.5.2 Advanced Operation

The basic operations are able to improve the efficiency of veterinary education to some degree. However, to get better performance, some advanced operations such as slicing model and drop zone are added into program.

The first one is slicing function. It provides user the ability to slice the model by very tiny offsets to see the crosssectional faces of model. In traditional way of veterinary subject, staff usually views CT scans to get three dimensional appreciation of body. To let them get a good understanding of the internal anatomy of the region, the slicing function provides user opportunities to study cross-sectional anatomy. The design and implementation details of slicing function would be delivered in the next chapter.

Another advanced operation is the Drop zone function. It is a place that can magnetically absorb the model to the zone which keeps the volumes in the fixed position. Because of this, user can easily see the connection between the parts in correct position. After dropping the models into the Drop zone, the information attached on the model would show on the screen if user need to learn the knowledge or confirm and enhance their current acknowledgment.

3.6 Test Mode

Test mode is designed for lecturer to host a exam in VR space and student to test their current knowledge level. Unlike traditional paper test, test system in immersive environment has some benefits: Students will not be distracted by other things, being able to fully focus on the test; Besides, the test combined with 3D volume can show all the details of some complex question, increasing participant's understanding of what the question is aiming at; Active operation can make the test more vivid and more practical, which benefits practical subject like veterinary a lot.

3.6.1 UI Based Test System

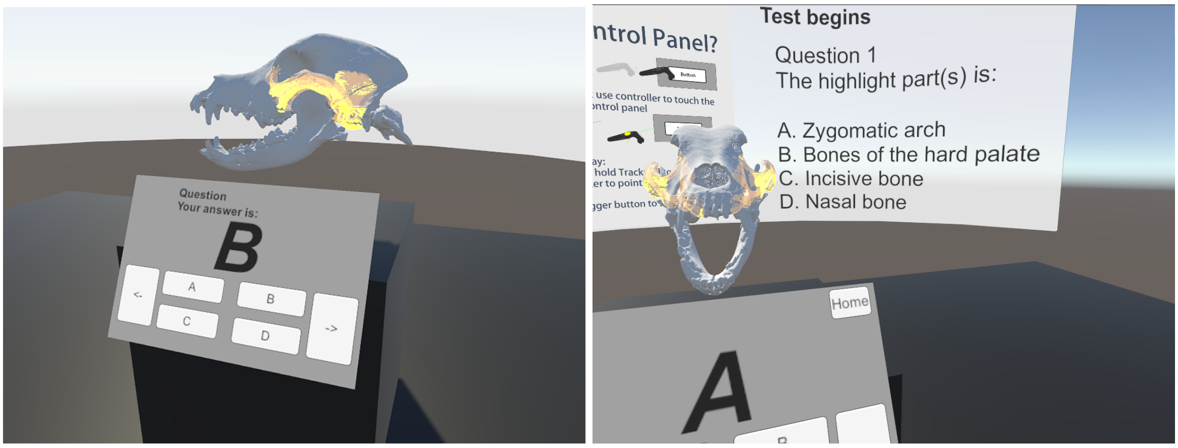

Figure 3.3: UI Based Test System

Because virtual reality is kind of new technique nowadays, people who do not get involve with this may not know how to use this. To make them get used to the operation quickly, one test system is simplified as much as possible 3.3. Just use controller to touch the basic user interface can get interact with the questions. All operations are finished on GUI which is nearly same as user interface on computer operating system.

Questions of the quiz will be showed on the big screen and there will be a control panel for user to touch. A skull model is segmented by the regions and those regions will be highlighted to give a hint to participants. For each question, there will be four buttons, representing four answers and waiting for being chosen. After user choose their answer, they are able to change the answer whenever they want before they submit the answer list. The result of the test would be showed on the screen and user will get a detailed list of how is their tests.

This system is quite straight forward to get answer from user, easy and high-effective. However, once you use multiple choice, some wrong choices must be applied to mislead the participants, making the quiz more challenging. On the other hand, the interaction between user and skull model is limited in grabbing and nothing more.

3.6.2 Volume Based Highlighting Test System

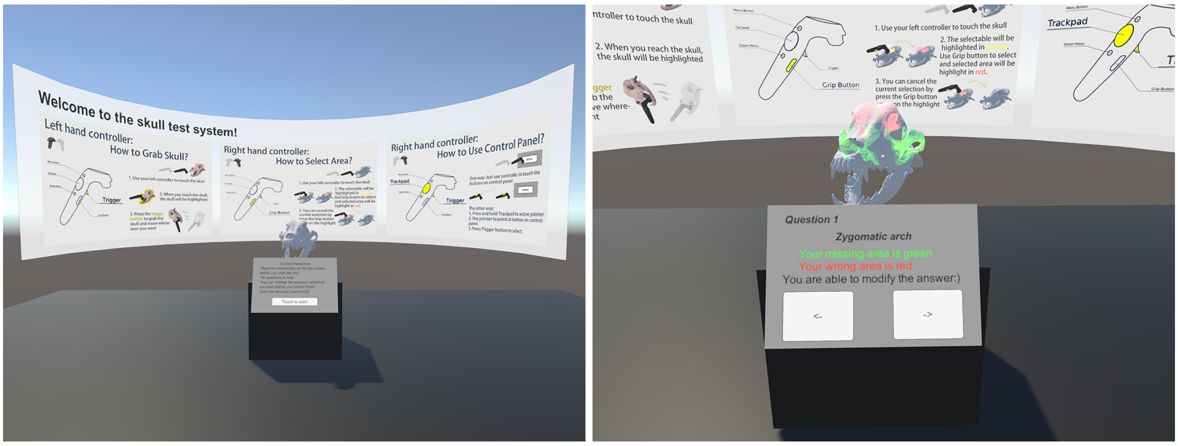

Figure 3.4: Volume Based Highlighting Test System

To make a better use of virtual reality and increase the immersible feeling of user, another testing system with complex operations 3.4. A better way to deliver the quiz is giving a name of a part of skull, and let participants select all the parts involved as one region group can have more than one region, for instance, Zygomatic arch contains Temporal Bone and Zygomatic bone. This test system require participants to use two controller at one time to achieve some operations. As the purpose of this test system is to ask candidates to select the area by the given structure's name, the test system is called selection test system.

Before the test starting, some guides will show user how to do the operation and provide tutorials for user to get familiar with it. By using left controller, user is able to grab the volume and take a closer look of it while right controller is mainly used for UI interaction and model highlighting. Then questions will be showed one by one, for each question, participant need to highlight all the parts involved to get a right answer. After the answer list is submitted, the result will show on the screen and user can check the details for every question they answered. The system will highlight the wrong answer area and correct answer area in different color, which would provide a more straight way for user to recognize at where they got the wrong choice 3.4. And users are able to modify the current answer to the correct one and enhance their memory of the knowledge in this process.

This system is little bit complex for new user, but once user is getting used to the operation method, the experiment would be way better than the UI-based test system.

Chapter 4: **Design Details and Implementation**

4.1 Test System Design

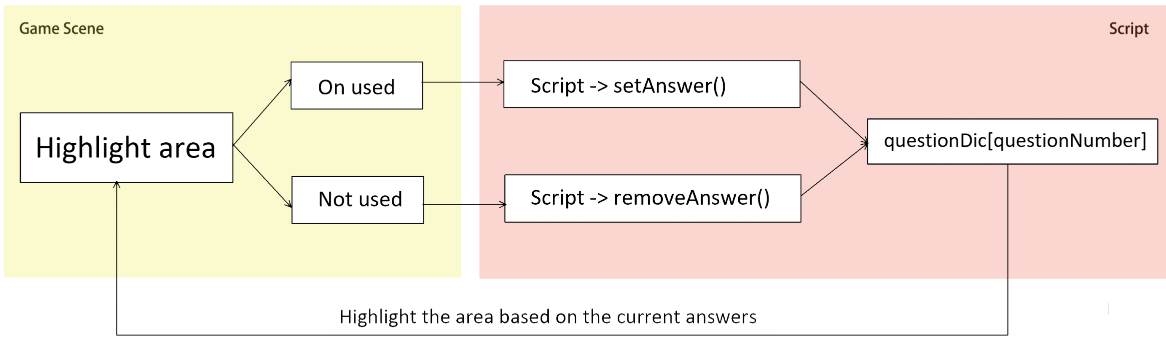

Figure 4.1: Selection Test System Logic

Because the test system needs have the ability to store the user current answers, correct answers and calculate a result, all the data are stored in a dictionary for a easy traverse. The functions could be easily implemented in MCQ test system, which is similar to the system on a laptop. Even though, it is hard to program the selection test system as the question becomes multiple choices and is linked with game object.

```
public Dictionary<int, Transform> GetVolumeDictionary(){
    selectVolume = GetComponentsInChildren<Transform> (true);
    volumeDictionary = new Dictionary<int, Transform> ();
    volumeNumber = 0;
    foreach (Transform child in selectVolume) {
        volumeDictionary.Add (volumeNumber, child);
        volumeNumber++;
    }
    volumeDictionary.Remove (0);
    return volumeDictionary;
}
```

To give the system the ability to store multiple answers, list structures are added as value for each key in dictionary, which makes it easy to compare the answers. By using the GetComponentsInChildren() function, there would be no need to create event for each game object.

The design of selection test system is showed above 4.1. When user press the use button, the area will become 'used' and duplicate a same highlighted area to show that this area is selected. If user press the use button on a 'used' area, the 'used' status would be canceled. 'Used' and 'not used' statuses would respectively active corresponding functions in a script, and add or remove the number of current area into/from the answer list. Furthermore, when user tends to go to the previous question to modify the answer, all the current 'used' status will be canceled and the 'used' status for the previous question will show.

4.2 Set Up VR Environment

To set up the operation environment, a prefab called SDK_setup need be added into the scene and configure SteamVR plugin into the prefab. Two empty objects are created as two controllers with scripts called controller_events and then added into SDK configuration. Till then, a basic VR environment is all built up.

Other basic operation methods like grabbing, teleporting, zooming, touching and using are done by the cooperation between game object and controller. For instance, to achieve grabbing function, the game object needs to change to interactive object by adding rigidbody and collider components and scripts. When an object is interactive object, the controller with interact_grab script is able to grab it.

To implement the drop zone in VR environment, a drop zone prefab is added. By tagging all the game objects in the scene, a policy list is created based on the tag, making drop zone have the ability to distinguish the identify of the entering object and show the corresponding model. Simultaneously, the UnityEvent script attached on the each game object would active a function to display the corresponding content when the game object has entered the drop zone.

4.3 Shader - Slice Function

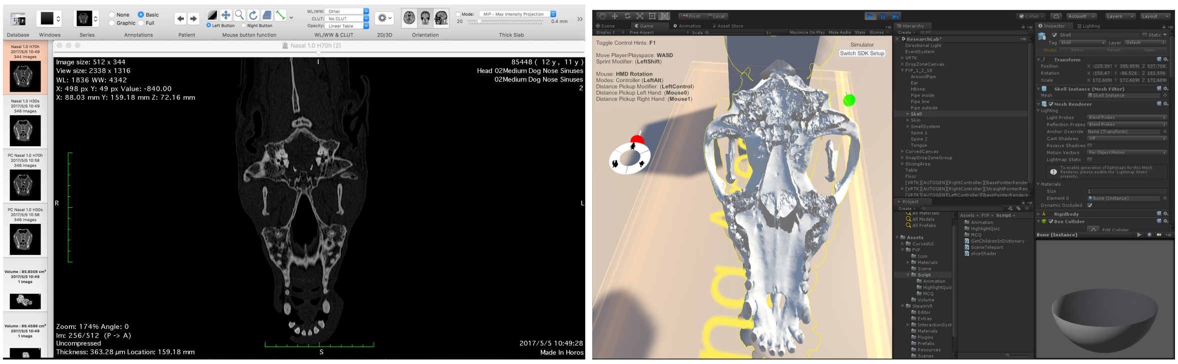

Figure 4.2: Slice Function in DICOM viewer (left) and in Unity (right)

Slice function gives veterinary participants a chance to view DICOM data in 3D space. Because the DICOM data is usually viewed in 3 directions, people from vet subject has gotten used to view the object in cuts. The slice function would provide a clear way of seeing models cut, combining the DICOM data with 3D volume. When students realize the connection between those two, it would be easier for them to hands on the real body. Professor David Kilroy explained the reasons in details:

- Anatomy teaching is still highly reliant on the use of cadaver material which does permit the student to get a three dimensional appreciation of the body. Using a slicing function on a virtual reality (VR) model gives the user extra opportunities to study cross-sectional anatomy which mimics the technique of CT scans. The correct interpretation of CT images requires a good understanding of the internal anatomy of the region being examined.

- Cross sectional anatomy knowledge is also required in order to interpret ultrasound images, which produce a thin slice of the body region being examined. While cadavers help with 3D appreciation, a VR model can be used outside the laboratory setting and is more realistic in that the original scans are from live animals, so the organs/tissues are not embalmed and static.
- For surgery of deep structures, VR with a slicing function can enable the student/clinician to do an in depth study of the area or structure to be operated on, giving a better understanding of the local anatomy.

To achieve slice function, a lot of researches have been done. Like such function is rarely used in Unity Engine, while some other functions are mainly focus on cutting object into two parts but not slicing. Then I found a video on the Internet which is mostly close to the slice function veterinary subject needs. After that, I realized that there is no need to focus on achieving this by modifying the model, a new shader is enough for this.

A surface shader example called 'Slices via World Space Position' [13] is included in Unity 2017b documentation. The shader slices the game object by discarding pixels in horizontal rings by using the clip() Cg/HLSL function based on the world position of a pixel. This shader can achieve slice function beautifully, however, it still needs some modifications as there is only one layer needed and can not be world position based.

The standard shader has been modified from world position based to object position based. The slice shader has been showed as following:

```
// Use clip() function to slice the game object in 3 directions
      void surf (Input IN, inout SurfaceOutput o) {
      if(_direction == 0){
              clip (frac((IN.objPos.y+_Offset) * _frequency) - 0.5);
      }else if(_direction == 1){
              clip (frac((IN.objPos.x+_Offset) * _frequency) - 0.5);
      }else{
              clip (frac((IN.objPos.z+_Offset) * _frequency) - 0.5);
      }
      o.Albedo = _color.xyz;
          o.Alpha = _color.w;
      }
```

More attributes are added for changing the properties of the shader, which are also providing interface for scripts in Unity. The attribute called offset is the main one that achieves the dynamic slice process, so user is able to change the offset to see more details. Then the properties are changed by a C# script in Unity:

```
//get renderer attached
    public Renderer rend;
    public GameObject clipArea;

//those two value need to be changed in slider,
      so make them dynamic by adding {get;set;}
```

```
public float shaderOffset{ get; set; }
public float isParallel{ get;set;}

void Update() {
    rend.material.SetFloat("_Offset", shaderOffset);
    rend.material.SetFloat("_direction", isParallel);
}

void OnTriggerEnter(Collider area){
    if (area.gameObject.name.Equals (clipArea.gameObject.name)) {
        rend.material.shader = Shader.Find("FYP/Slices");
        rend.shadowCastingMode = UnityEngine.Rendering.ShadowCastingMode.Off;
    }
}
```

As the slice shader is different from the standard shader, there is still a demand for standard shader. Because of this, a clip area is created to trigger the change of shader. When the game object enters the area, the shader attached would be changed into slice shader and turn off ShadowCastingMode to ease the effect of shadow. After connecting two properties to a slider, and change the value with frame, user is able to use slice function fluently.

4.4 Highlighting in Test System

In test system, the function of highlighting the parts involved in the given name is really important. In MCQ test system, it can show the question area which is much better than show the separate parts one by one. In selection test system, it gives user the ability to recall the area of the name and select all areas involved.

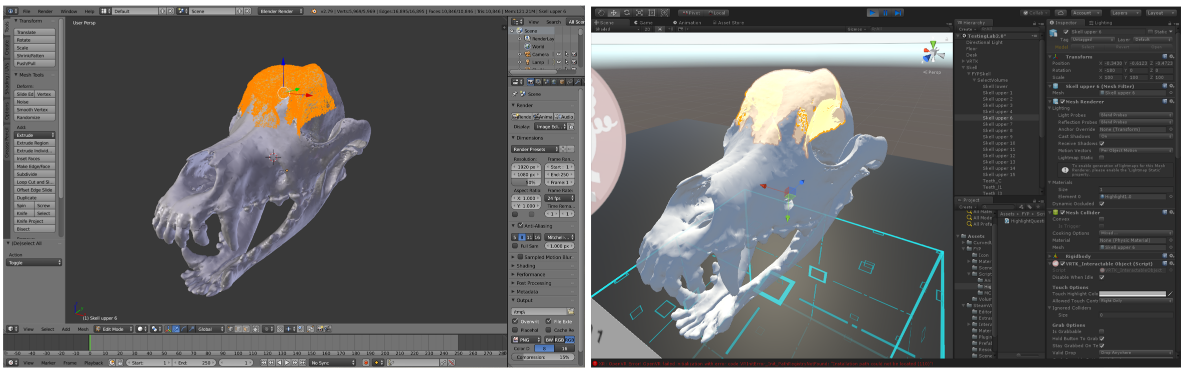

Figure 4.3: Segmentation in Blender (left) and in Unity (right)

After getting the dog skull image and teeth image, the very first step is do the segmentation of current skull model. By using Blender, the process of modifying model seems to be handy 4.3, however, for every part of the skull, there are 3 images in only 3 directions to be based on, which means the unseen area can only be segmented by space imagination - exactly the issue of education in veterinary subject. Because of this reason, the segmented part is not the actual area but a signal of the specific space. Students from collage of veterinary should be able to give the right answers relying on those signals.

As the highlight areas should be attached on the main object, script Outline Highlight in Virtual Reality Toolkits is not ideal for highlighting. And the original highlight script is disabled when the game object is a child of another object with the script. I have considered to use drop zone to replace the highlight area because of the good effect of drop zone. But in fact, the transparent model of drop zone is one side model, which means the model can only be seen from one direction. At last, a shader called highlight is found and solves the problem of highlighting. After attaching a script called VRTK_Material Color Swap Highlighter, adding a new material with highlight shader into custom material can finally achieve the touching highlight function. 4.3

To keep the highlight area after selection, a bunch of copies of current game objects is created with a different color material, only appearing when current game objects is On-used. At the same time, the answer would be added into a list based dictionary. If participant canceled the selection, the answer would be removed. Because the correct answer is multiple choice, they are stored in a list for each questions and those lists are stored in a dictionary with their question number being their keys. Based on the correct answer dictionary, the involved part would be highlighted when participant wants to check the previous answer and change them.

Chapter 5: **Testing/Evaluation**

5.1 Pilot Test

5.1.1 Propose

As the software is designed for veterinary relevant people to use, to get a more straight feedback from them about how this software work, a Pilot test is raised. I create a test system in the software which is used to test veterinary student's knowledge about dog skull. The test has two versions, one is UI based test system while the other one is Volume Based Highlighting Test System, and those two systems provide more options for participants.

5.1.2 Process

Ten students from college of veterinary were invited to the pilot test. When the students came, the precautions and introduction of the project were told to them. While a student was experiencing the device, the rest of students were allowed to be the guest, watching the test going on. During this process, they could express whatever they think about the system and had discussion with others. Professor David Kilroy was on side all the time, answering students' questions about vet knowledge and helped the test running within the whole process.

Student was told to play in Research area first, getting familiar with the immersive environment and trying the advanced operations. Move around in VR space to explore the immersive environment; Grab the object to get the basic idea of VR environment and feel the distance between the controller and object in virtual space; Take the model and move into slice area to slice the model and change the offset of the slicing; Zoom the model in and out to experience the feeling of being surrounded by the model. After playing in the research lab, participants were able to be aware of the basic operations in VR and know how to use the user interface, which was helpful for the tests showing next.

As there were two modes of test system (one was UI based MCQ test system, the other was highlighting selection test system), students were divided into two groups with different testing order to eliminate the effect from previous test system. There were 10 questions in each test system, when it came to some unclear questions, professor David was there to describe the question and correct the answer for participants. After answering all the questions, they were told to active the see details button and check their result.

After experiencing the whole program, participants needed to fill up three questionnaires with their feelings. For each test system, participants were told to rate their experience by marking once sections. The ratings were from the far left to the far right, marked within the 9-point range what they consider was the closest feeling they had about the media experience. The last paper was about some basic information like gender, age and current VR experience.

5.1.3 Result

Num	Gender	Age	Have you used Virtual Reality before?	Did you feel the test was easier in VR?	If so why do you think that was?
1	Female	18-25	no	yes	it was a 3d visual rather than just a diagram.
2	Female	18-25	yes	yes	easy to pick up and manipulate the skull
3	Female	25-35	no	I don't understand the question Easier than what?	
4	Female	25-35	yes	yes	ability to move the object around for proper orrentation
5	Female	18-25	no	yes	Being able to interact with the structures and see from all angles. I think it is also a lit easier for education perpose to understand relationships between stuctures
6	Male	18-25	no	no	I feel like the selection blocks made it harder as you try and translate your mental image of the anatomy onto the exam.
7	Female	25-35	no	yes	more interactive
8	Male	18-25	no	yes	having model in front of you made visualising easier
9	Female	25	no	yes	I was able to pick up the skull & look in 3D

Figure 5.1: Degree of test difficulty in VR and why

Num	Did you think selection method of testing was better than the MCQ?	If it was/not why?	Do you think this is a better way of testing Anatomy than a paper based MCQ?
1	Yes, I prederred the selection test	I thought it was a better learning experience	Yes, it is v. practical
2	yes	Harder to find bones when given the words than than guess names	yes, very practical and quick
3	yes	option to select more than one section	yes
4	yes	arrows identification of anatomy in real life	yes, especially with visual warners
5		I think it si a more thorough method of testing (testing knowledge better) but technically slightly more difficult (selecting objects)	yes definitely, a lot more interactive and students will take more away from it, much more useful in terms of surgery
6	yes		yes, each has drawbacks but I think that this is more open ended which reflects the real world better
7	yes	looked more at the skull and was more active in my selection	100% - it seems like a would be learning during the exam
8	no	highlighting all parts for each question was difficult from knowledge stand point	yes
9	yes	be ability to point & see which areas were selected was useful	yes! More hands on - more similar to be lab

Figure 5.2: Comparison between Selection, MCQ and paperwork

When it came to the question about degree of test difficulty in VR 5.1, 7 of 9 students gave positive feeling while one student did not get the question and one thought the test was harder in VR. The reason why the majority of participants thought the test easier was the 3D visual was more interactive than a 2D diagram, which made visualizing easier. Except one who did not answer the question, the one who thought the test harder commented that it was hard to translate mental image of anatomy onto the exam. This was possibly caused by the inaccurate segmentation of the model. Overall, the result was really good in this question.

Aspacts	(Positive/Negative)	(Inside/Outside)	(Excited/Calm)	(Lack of control/In control)	(Far away/ Beside)
t-text	0.346593507	0.346593507	0.622383329	0.799485207	0.346593507
Result	0.05 Would be Selection better, very slightly just down to one person putting 2 and 1 in the other	0.05 would be a result, Felt they where more inside slightly in MCQ	Result looks like Selecton is more excited , again results need 0.05 to be real	slighly more control on selection but again 0.5 result is as good as random	MCQ actually seemed close but again a result of 0.33 means you would get this result running the experiment randomly 3 times

Figure 5.3: Result from T-Test

When participants were asked about the experience between selection test system and MCQ test system 5.2, again 7 of 9 thought the selection was better than MCQ as it was more active and option to select more sections. However, the stats leaned a bit to MCQ, and my supervisor said that the graph showed there true feelings the selection was more interesting but perhaps. He guessed the cognitive load e.g how much thinking participants have to do was harder, better for testing, but deep down humans were lazy and wanted the easier approach. After I handed all the questionnaires' data to my supervisor, he did the t-test [14] towards the data and got a basic trend of how this performed 5.3. Because the number of the sample was too small to get results, we could only get a trend. It was said that only when the output of t-test was less than 0.005, the output would be a result.

When comparing the VR test system to paper MCQ 5.2, 7 over 9 participants thought selection method of testing was better than the MCQ while one thought the selection method could test the knowledge better but hard to operate, and the last one thought highlighting all parts for each question was difficult from knowledge stand point. Which meant the selection method could get mostly positive comments from veterinary students. All the students agreed VR test system was a better way of testing anatomy than a paper based MCQ. Comparing to the paperwork, the test in VR was more practical and quick process. The approach was more active which made the the exam vivid and reflect the real world.

In conclusion, we did not get specific result based on the limited sample resource, but, the comments made from participants were mostly positive with supporting attitude.

5.2 Evaluation

A demonstration has showed to Professor David Kilroy and Arun Kumar from college of veterinary and they gave positive comments to the project: The VR space shows all the details much clearly and the slicing function is really helpful to crosssection anatomy.

All participants in pilot test thought it was enjoyable and great experience. With time and work, the program will be a very good education tools and benefit vet college. And they were all looking forward to see more functions and additions of other body systems.

Chapter 6: **Conclusions and Future Work**

6.1 Conclusions

To solve the problem of a lack of anatomy material problem and increase the efficiency of veterinary education, a VR system is developed.

The DICOM data is obtained from the college of veterinary and successfully transferred into 3D models. Next, the models are modified to be less computationally expensive for the Graphical Processing Unit (GPU). The noise of the volume is removed and the organs such as skull, skin and ear canal are separated from the whole part. Further segmentation was done on the skull for the selection test system. Moreover, basic VR immersive environment was created, which could achieve basic human behaviors such as grabbing and moving. User was able to grab the organ model, zoom into it and slice the model in three different directions and even change the slicing offset at the same time. Besides, user is welcome to use the drop zone to gain more knowledge about a specific organ/tissue.

The MCQ test system and the selection test system are implemented for the lecturer to give the tests in the VR space. Both test systems can record the results and show the candidates the right answer for each question. A pilot based on those two test system test was implemented to get the big picture of how this software performed from the vet staffs' point of view. Professors and relevant staff from college of veterinary were invited to experience the software as well, and they were all showing interests and giving positive feedbacks about it.

6.2 Future Work

6.2.1 Model

For now, the models created for the program are just some main parts including skull, skin, tongue, smell system, hear path of a dog head, and those parts can only be used for demonstration, which are little bit limited for further study and research.

So there are lots of soft tissues needed to be added into program, such as brain, vein, artery and muscle. Because of the limitation of CT, those soft tissues are hard to be segmented. To get soft tissue, a more detailed data source is needed, DICOM data generated by MRI. As MRI can create DICOM data with soft tissues particularly, this is the quickest and most suitable way to sort this problem out. However, consider to the price of getting a MRI DICOM data, a back up method is modeling the soft tissues by using modeling software. The shortage of this way is quite obvious: time consuming and lack of accuracy.

Another aspect is expending to the whole body. Only a dog head is absolutely too shabby for a canine autopsy software. So for the future, the model in program can be expended to whole dog and even add other animals. This future plan does not have any technical problem as every part modeling is same as dog head. However, this is a really time consuming process and also needs some veterinary autopsy knowledge.

6.2.2 Function

The function of VR canine autopsy system can affect the immersive experience of user and the richness of program.

Some current functions can be updated for a better performance. For instance, there's a lot of improvements can be achieved in slice function. Firstly, more dimensions of slicing can be running at the same time, which may provide user a totally different angle to observe the model. Secondly, the thickness of the slicing piece and be optimized by user within millimetres, showing the crosssecional anatomy in 3D model. Finally, a slicing surface can be created for user to handle, by using which, user would be able to slice the model in any different angel they want. And some little changes to increase the user's experience like changing the offset slider into controller.

Furthermore, the current drop zone function is designed for showing the information of specific parts as a education mode. To achieve a better experience, a education mode might be implemented in the future. In education mode, the touched part will be linked to a UI panel describing the parts. At the same time, it will show the page number connected to learning material.

New functions like simulating the autopsy operation can also be added in the future. With live physic calculation, a whole autopsy process can be simulated to mimic the reality. When knife cuts the skin, blood will come out and flow; cutting skin and bone would give different feedbacks by shaking the controller. Once this function is achieved, before fresh learners gets a real anatomy operation, they can practice in VR space, which may decrease the error rate when it comes to real one.

6.2.3 Hardware

In the future, if we could get chance to customize a new controller that is shaped like a operation knife with some seniors equipped, the immersive experience must get better and the autopsy process would become more similar to this in real life.

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