Programming in Virtual Reality

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Exeter Mathematics Certificate Report

EXETER MATHEMATICS SCHOOL
SERVING CORNWALL, DEVON, DORSET AND SOMERSET

Abstract

As virtual reality becomes evermore prominent in the modern day, we aim to investigate its exciting limits and prove just what is and may be possible as VR continues to grow. Incorporating mathematics into our project, one of our goals was to create an apparent four-dimensional Klein Bottle in virtual reality, using Unity 3D, Steam VR and the HTC Vive to make this possible.

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Introduction

Our report aims to investigate the use of virtual reality, using a cross-platform game engine to explore and test some of the ideas we had. We chose to undertake this project as virtual reality is such an exciting prospect for the world in the future, in addition to this we tried to incorporate our love for mathematics into this virtual world.

1.1 Our aims for this project.

Initially our main objective for the project was to model and create a Klein Bottle, where it could visualised in virtual reality. We hoped that it would be possible to use a method of movement to walk over the surface. The surface would be modelled using an external program outside of Unity, called Blender and then imported. One of the main appeals of VR is the movement around seemingly large spaces, and so we would also aim to implement different modes of movement, such as touch-pad walking and controller teleportation over the three-dimensional representation of the 4D object.

Literature Review

2.1 Unity 3D

Unity 3D is a free to download gaming environment, which would be the basis for our project. We chose Unity over other programs due to the vast range of assets, including SteamVR Plugin which could be used to run the Vive and simulate the environment we had created. Although neither of us had experience using this software before the user interface was straightforward and easy to use. A simple example of the environment is shown in Figure 1; in-game testing is shown in Figure 2 throwing a ball using the controllers.

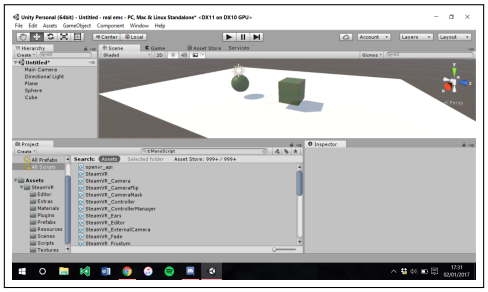

Figure 1: Unity 3D Environment

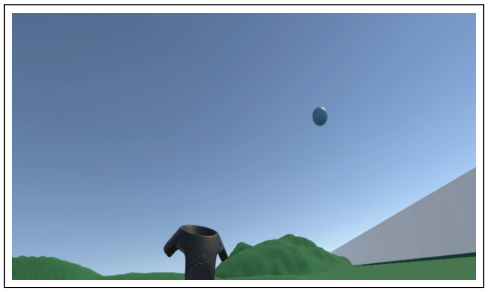

Figure 2: Throw Test

2.2 Klein Bottle

A Klein Bottle is defined as a non-orientable surface that is closed, this means it technically has no inside or outside. An idea is that walking on a Klein Bottle means that you will always travel the length of it and never encounter a boundary. It was first theorised by Felix Klein in 1882, whereby two Möbius strips could be glued together. A Möbius strip is a surface (shown below) with only one edge and one continuous length, like a Klein Bottle this surface is non-orientable but some versions of this band can be modelled in Euclidean space.

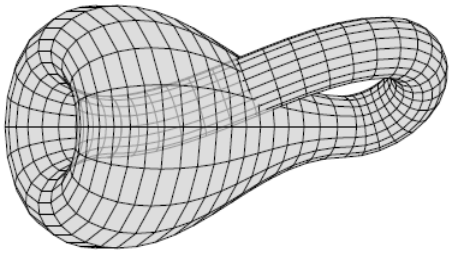

Figure 3: Klein Bottle [1]

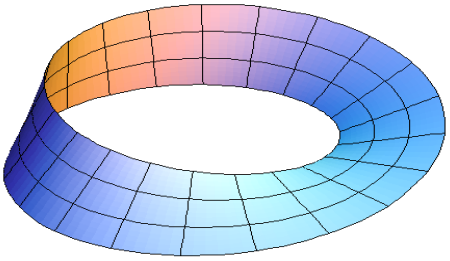

Figure 4: Möbius Strip [2]

A Klein Bottle and a Möbius Strip have an Euler characteristic 0. [5] As stated if you were to walk along the Klein Bottle you would never encounter a boundary this is due to the fact that a Klein bottle is a four dimensional object meaning there are no intersections. In a 3D representation of a Klein bottle there is an intersection which is why one appears in our model.

2.3 Uses of Virtual Reality

2.3.1 Military Training

Virtual Reality has seen wide uses in the training of military personnel from flight simulators to combat training. These methods of training both cut down on resources used to train each person and provide more repetition in shorter periods of time. It also reduces the length of training for pilots going from ground training to flying the aircraft much sooner and more safely.
There are hopes to branch out more from the military with all fast response vehicle drivers being trained by virtual reality simulators, this has already started in Belgium where firefighters are taught to drive in a way preventing as much damage as possible, this is much more convenient and safe to do in a virtual reality.

2.3.2 Education Doctors

Recently Virtual Reality has started training medical personnel. It has helped medical students to gain basic skills in a repetitive environment. In an experiment to test whether Virtual reality improves training 16 surgical students were set the same operation and on average student who had received the VR training on average were 29% faster than those who had received traditional training.

2.3.3 Engineering

Virtual Reality has improved the field of engineering greatly. Virtual prototyping has improved the design phase allowing the engineer to see their finished product from any angle and test it against many elements such as the weather. It allows investors to view the products long before any physical prototype are available. Before 3D computer-aided design was limited by paper printouts and physcially two dimensional computer monitors. Now companies like VRcom and ICIDO have pioneered modelling techniques with the introduction of multi-surface projection units and 3D tracking.

2.3.4 Gaming

One of the biggest improvements in gaming is virtual reality, it allows the players to become the the controller adding a whole new layer of immersion. It first started simply

with a few consoles incorporating narrow VR, such as the Wii and Xbox 360 (with the kinect). These only allowed motion tracking as was still played on a normal television or computer monitor. More recently VR headsets have been created for PC and PlayStation 4. They incorporate a head-mounted display and headphones, really taking the user into a virtual reality. As hardware improves and becomes cheaper soon headsets like these could become the gaming norm.

2.4 History of VR

The concept of virtual reality has been around in science fiction for over 80 years but the first machine to deliver a VR experience was first developed in the 1950s. The sensorama was pre-digital programming and showed five short films which also engaged other senses. The first true Virtual Reality was the "The Sword of Damocles" it came with a head mounted display (HMD) so heavy it had to be mounted from the ceiling. It was designed in 1968 by Ivan Sutherland and a student Bob Sproull to lead the way for extensive innovation of this technology.

After the initial inventions other good developments were made but due to computing powers and general unpopularity in the field, many of the new inventions were never released to the public. It wasn't until the 1990s when VR became more popular with a few arcade machines implementing the feature. Machines like Sega VR and "Virtuality" led the way for VR with the later being the first mass-produced Virtual Reality entertainment system. These were still expensive with a multi-pod virtual reality system costing up to $73,000 around £104,000 in 2017.

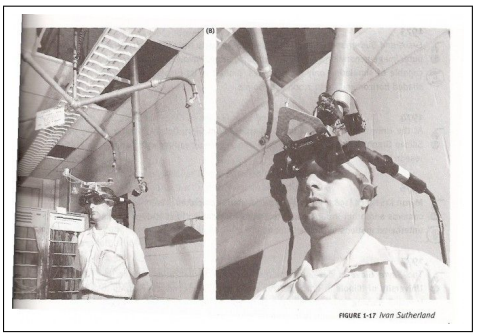

Figure 5: First VR Headset [3]

It was not until 2010, the first modern virtual reality headset was developed, with rotational tracking and a 90-degree field of vision the first prototype of the Oculus Rift was born laying the groundwork for future headsets to be created. March 2014 was the next big development for virtual reality with Facebook purchasing Oculus VR, Sony announced Project Morpheus later to be known as PlayStation VR, a headset to be used with the PlayStation 4 and Google revealed Cardboard a simple VR headset that uses certain phones as its screen. [6]
The Virtual Reality headset we used in our project would not be unveiled until 2015 when HTC joined with Valve Corporation and created the HTC Vive. It came with handheld controllers and sensors, known as "base stations". These stations provided improved

tracking allowing the player to move more. This combined with the controllers give the user a complete VR experience compared to previous designs only providing a different way of viewing.

Methodology

3.1 Steam VR and HTC Vive

Steam VR is a virtual reality environment, with a headset made jointly by HTC called the "Vive". The Vive itself only became commercially available in April 2016. In contrast to its largest competitor, the Oculus Rift, the Vive aimed to reduce motion sickness by incorporating even more interactivity to simulate a more 'real' experience. The headset consists of two LCD screens [1080 x 1200 resolution] behind the lenses. Steam VR was the ideal system for our project as the movement and data from the base stations and headset tracking system could be interpreted by Unity via the Steam VR plugin.

3.2 The Virtual Environment

After deciding that we wanted to create our own virtual environment, it was apparent that we needed to create a method of movement and interaction with the world. Whilst the Vive could track small movements relative to the area enclosed by the base stations, this was not sufficient to move over larger distances, for example the Klein Bottle. Therefore we came to a conclusion that teleportation using pointers from the hand-held controllers would reduce motion-sickness, something experienced more prominently using touch-pad movement, as well as quicker and much more simple to use.

3.3 Unity Assets and Scripts

Whilst neither of us had any experience in using Unity or programming in C#, the language primarily used to code scripts in Unity, it was evident that we could not program these scripts manually. However during an attempt at learning this environment we found tutorials and pre-made scripts by the YouTube user: 'thestonefox' [7] which were compatible with Unity 3D.
This included teleportation scripts using simple pointers. It also meant that we could copy these scripts across onto the controllers of the Vive, so that in a basic plane in virtual reality, we had a simple and suitable method of movement.
Teleportation is great and we had fully intended to use it, however using the scripts we had meant we couldn't teleport onto the surface of the Klein Bottle. Therefore we had to find a different movement system. We went with a simple flying script created by

Unity 3D forum user 'Chillfire'. It's a very simple system, that at a basic level, provides as force in the direction you are looking allowing the user to fly. Another advantage is that flying provides more freedom to move about the environment and view the model from a variety of different angles not available by teleportation alone.
We also decided to create a more interactable environment by using 'interactable object' scripts so that an object in the environment could be picked up, or even thrown as in Figure [2].

3.4 Klein Bottle Equations

Given that a Klein Bottle is a fourth-dimensional object it is seemingly difficult to represent it in three-dimensions. The set used in our project are shown below.

3.4.1 Parametric Equations

$$\mathbf{X:} -\left\{\tfrac{2}{15}\cos(\alpha)\left[3\cos(\beta)-30\sin(\alpha)+90\cos^4(\alpha)\sin(\alpha)-60\cos^6(\alpha)\sin(\alpha)+5\cos(\alpha)\cos(\beta)\sin(\alpha)\right]\right\}$$

$$\mathbf{Y:} -\left\{\tfrac{1}{15}\sin(\alpha)\left[3\cos(\beta)-3\cos^2(\alpha)\cos(\beta)-48\cos^4(\alpha)\cos(\beta)+48\cos^6(\alpha)\cos(\beta)-60\sin(\alpha)+5\cos(\alpha)\cos(\beta)\sin(\alpha)-5\cos^3(\alpha)\cos(\beta)\sin(\alpha)-80\cos^5(\alpha)\cos(\beta)\sin(\alpha)+80\cos^7(\alpha)\cos(\beta)\sin(\alpha)\right]\right\}$$

$$\mathbf{Z:} \left\{\tfrac{2}{15}\sin(\beta)\left[3+5\cos(\alpha)\sin(\alpha)\right]\right\}$$

$$\Rightarrow \textit{where } 0 \leq \alpha \leq \pi \textit{ and } 0 \leq \beta \leq 2\pi$$

Figure 6: Klein Bottle Equations [4]

In fact there are many different versions of an equation represented in a parametric form.

3.5 Importing to Blender and Unity

In order to create a Klein bottle for unity we had to use Blender, a program in which you can create complex 3D models. Using the equations shown in Figure [6], the program creates a 3D version of a Klein bottle. It is not quite perfect with the bottom being too much like an edge but it does look very good. After we created the model it was simple to import it into unity by saving the file in the assets folder. When imported we dropped

it into the scene and thus have a 3D Klein bottle in unity. Images of the Klein Bottles are shown below in Unity and Blender.

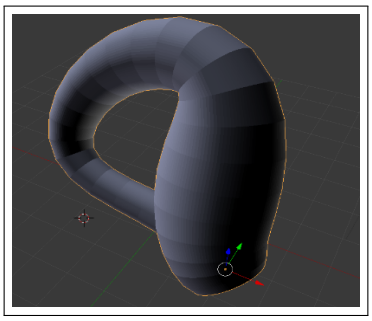

Figure 7: Klein Bottle in Blender

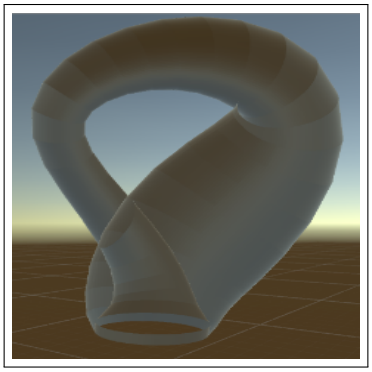

Figure 8: Klein Bottle in Unity

Conclusion

To conclude Virtual Reality is an impressive piece of technology due to the vast range of applications in the near future; yet is only beginning to emerge from its infancy, despite major developments over the last decade. Our project has been tough with multiple setbacks, including asset incompatibility and software updating. With the realisation that programming for this purpose was particularly challenging, especially being novices to begin with. We now hope to bring together all the work we have done to create a tour of the Klein Bottle in virtual reality.

References

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