Creating an immersive virtual reality application for ski jumping

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Sammendrag

Virtuell virkelighet (VR) har i løpet av de siste ti årene blitt anvendt i ett stort spekter av domener. VR gir muligheten til å utføre oppgaver i ett kontrollert og trygt miljø. I denne rapporten presenterer jeg en virtuell skihoppapplikasjon. Applikasjonen ble implementert i Unity3D. Et LIDAR-system ble brukt til å skape en nøyaktig punksky av hoppbakken i Granåsen. Punktskyen ble omgjort til en mesh ved å utføre Poisson Surface Reconstruction. Applikasjonen har en forenklet fysisk modell basert på Marasovic [2003]. Applikasjonen bruker akselerometer i en Wiimote til å måle vinkelen på overkroppen til spilleren under hoppet. Vi utforsket også muligheten for å bruke Kinect og Wii Balance Board til å detektere hoppet. Applikasjonen ble testet av det norske hopplandslaget, og av elever på videregående skole. Det viste seg at applikasjonen har potensiale til å bli brukt til å trene på timingen på hoppkanten. Den kan også være ett verktøy for å inspirere unge skihoppere.

Abstract

Virtual reality(VR) has been successfully applied to a broad range of training domains. VR provides an opportunity to train in a safe and controlled environment, with support for accurate performance measurement. In this report I present a prototype of a VR application for ski jumping. The goal for this project is to explore if such an application can be used to teach the basics of ski jumping, and if it can be used as a training tool for athletes. The development process is thoroughly described in the report. Through user testing and an expert evaluation it was concluded that the application has potential to be used as a tool for practicing the timing of the jump. Improvements for the prototype is proposed, which should enable the prototype to also evaluate the jumping technique.

Acknowledgments

I would like to thank my supervisor Ekaterina Praslova-Førland for her useful comments and engagement throughout the whole year. Furthermore I would like to thank Håvard Aas from Blinken Nord, who helped me by creating the point cloud of Granåsen. The project would not have been the same without you. Also I have to express my gratitude to Christian Meyer, Steinar Bråten and the Norwegian national ski jumping team, who have willingly shared their precious time during the evaluation, and have given me valuable feedback on the system.

Contents

Chapter 1

Introduction

1.1 Motivation

Virtual reality has been pursued for some time, and it has been successfully implemented in several domains such as military training [Bowman and McMahan, 2007], sports training [Komura et al., 2002] and education [Seymour et al., 2002]. It is believed that the first attempts at virtual reality started back in the 1860s when artists started to paint three dimensional panoramic murals. However the modern virtual reality did not really start before 1957 when Morten Hellig invented the Sensorama, a simulator that projected 3D images combined with smell, wind and sound to create an illusion of reality. Traditionally the technology used in virtual reality applications has been expensive, which is one of the explanations for why virtual reality has not become mainstream yet. With the release of the Oculus Rift in 2012, for the first time there was a reasonably priced head mounted display accessible for the general public. This has opened up for building VR applications for a reasonable amount of money.

Jonathan Steuer defines VR as "a real or simulated environment in which a perceiver experiences telepresence" Steuer [1992]. Where telepresence is defined as "a mediated perception of an environment". Today there are a wide variety of VR technologies with varying degree of immersion, spanning from regular computer screens, to head mounted displays such as the Oculus Rift, and the more advanced CAVE systems. Other VR technologies such as haptic, and gesture recognition are contributing to increase immersiveness in virtual reality applications.

Educators and researchers have also been drawn to virtual environments after they appeared.

The VR technology has several traits that makes it interesting to be used for educational purposes such as low cost, and high safety, and it can provide interaction in simulated context with high immersion [Cram et al., 2011]. Today there are many different educational environments that define themselves as "Virtual Campuses" or "Virtual universities". These environments started out as applications for distance learning in the early 90's of the 20th century [Carswell, 1998] Modern virtual campuses have adopted several different technologies which ranges from simple web-based systems to immersive 3D Virtual environments. Many of the virtual campuses attempts to create a familiar atmosphere for the students, and acts as a framework around the educational content, and learning activities at the educational institution they represent [Fominykh et al., 2008]

Virtual cities has also become increasingly popular. The virtual cities often has higher requirements for the design quality of the environments and the level of detail are often of high importance [Dokonal et al., 2004]. The virtual cities can have different purposes such as geographical navigation(Google Earth), heritage perservation (Rome Reborn, Forbidden City), socializing(Cybertown) and tourism (VirtualNYCTour). Virtual reality also has the possibility to offer tourism useful applications within several areas such as planning and management, marketing, entertainment and education accessability and heritage preservation. Virtual reality can create virtual experiences that tourists may accept as substitutes for real visitations to threatened sites Guttentag [2010] .

In Norway ski jumping is popular, and many tourists come to visit the ski jumping hills. This project is done in cooperation with Visit Trondheim. Visit Trondheim is interested in using virtual reality to promote Trondheim to tourists. In earlier projects parts of Trondheim has been modeled and implemented in the virtual 3d-world Second Life. The goal for this project is to create a prototype for a real time 3D ski jumping simulator, based on the hill in Trondheim, Granåsen. Furthermore we want to see how emerging technologies such as the Oculus Rift, Kinect and Wii Balance board can be used to improve the user experience in an application like this.

The simulator may have several applications: Teaching the basics of ski jumping to the general public, be a tool for recruiting aspiring young ski jumpers, promote Trondheim and Granåsen as a tourist destination, and be used by ski jumpers in a training situation. A simulator like this gives the possibility for everyone to experience a ski jump without the risk that is involved with real ski jumping.

1.2 Research questions

Much of the research in this project will be about developing the prototype and exploring the possibilities of building a reasonably priced immersive virtual reality ski jumping simulator. Moreover I will explore how the system can be used. The research question is as follows

R 1: *To what extent can an immersive virtual reality application support the understanding of ski jumping for amateurs?*
In order for the application to be able to achieve this goal, the application has to be a realistic simulation of a ski jump, and let the user emulate the different techniques involved in a ski jump. This will be evaluated by letting representatives from the general public test the application

R 2: *Is it possible to use an immersive virtual reality application as a training tool for ski jumpers?*

This puts higher requirements on the system, as the athletes demand a higher level of realism to be able to use it in a training situation.

R 3: *How would such an application be developed*
Which tools, methods, and algorithms are required for developing such an application

1.3 Research Method

Literature research
This project required research on virtual reality, 3D-modeling, Computer Graphics,Blender, Unity, and ski jumping. It proved helpful too read about how virtual reality has been applied earlier, and specifically how it has been implemented in sports. Literature and web materials on 3D-modeling, Blender and Unity was necessary to enable me to develop the prototype. The literature on ski jumping gave insight in how the physical model could be implemented.

Questionnaire

The prototype was tested by the general public at NTNU and Vitensenteret. After the test the users answered a questionnaire. We had to limit the number of questions, as we did not want it to take the average user more than 5 minutes to complete the survey. The questions is is designed using the proven Likert scale, focusing on the realism, presence, and learning. Measuring the presence is based on [Usoh et al., 2000].

Expert evaluation

The expert evaluation was done with professional ski jumpers from the Norwegian national team. The evaluation was conducted as a semi structured interview where the prototype was presented, tested, and discussed. The interview focused on the realism of the prototype, the physical model, and how it could be used as a tool in training.

Chapter 2

Background

2.1 Virtual Reality

The goal in Virtual Reality is to create an immersive experience for the user. The reality it presents is a synthetic 3D-world which is often presented to the user on a stereoscopic head mounted display, and some applications also offers haptics, or tactile feedback to enhance the reality. Users often show a strong reaction when experiencing immersive virtual reality for the first time. It is a different experience than interacting with regular 3D applications on a desktop PC or a gaming console. This is supported by Meehan et al. [2002] , which confirms that users behave and feel differently in immersive Virtual Environments. The terms immersion and presence are often interchangeably used in Virtual Reality community. In Slater [2003] it is claimed that they are distinct concepts and defines the terms this way:

- Immersion refers to the objective level of sensory fidelity a VR systems provides.
- Presence is the user's subjective pshycological response to a VR System.

Slater uses an analogy to colour science where immersion is analogous to wave distribution as it can be objectively assessed and presence is analogous to the perception of colour. In other words presence is a humans reaction to immersion, and given the same immersive system different people may experience different levels of presence. This means that a VR systems level of immersion is only dependent on the systems rendering software, display technology, audio, and tactile feedback technology. In Usoh et al. [2000] the following list of factors that impacts the level of visual immersion was proposed:

- Field of view - The size of the visual field(in degrees) that can be viewed instaneously.
- Field of regard - the total size of visual fields (in degrees) surrounding the user.
- Display size
- Display resolution
- Stereoscopy - The display of different images to each eye to provide an additional depth cue
- Head-based rendering - The display of images based on the physical position and orientation of the user's head (head tracking)
- Realism of lighting,
- Frame rate
- Refresh rate

2.2 Areas of applications for virtual reality

2.2.1 Military training

Virtual reality has several applications in military training. The US Military has been a primary supporter of real time simulation ever since the Link Flight Instrument trainer in late 1930s, which is shown in figure 2.1. Flight simulation was first invented to support carrier landing training, in-flight emergency training and air-to air combat [Rolfe and Staples, 1988]. The development of these simulators was originally motivated by safety and cost, and lack of suitable training areas. Virtual reality applications also ranges from flight simulators used in pilot training to urban combat simulators training infantry in combat tactics. Virtual reality training can provide the user with an accurate simulation of real events in a safe, controlled environment. And in many cases it has reduced cost in comparison with real-world exercises.

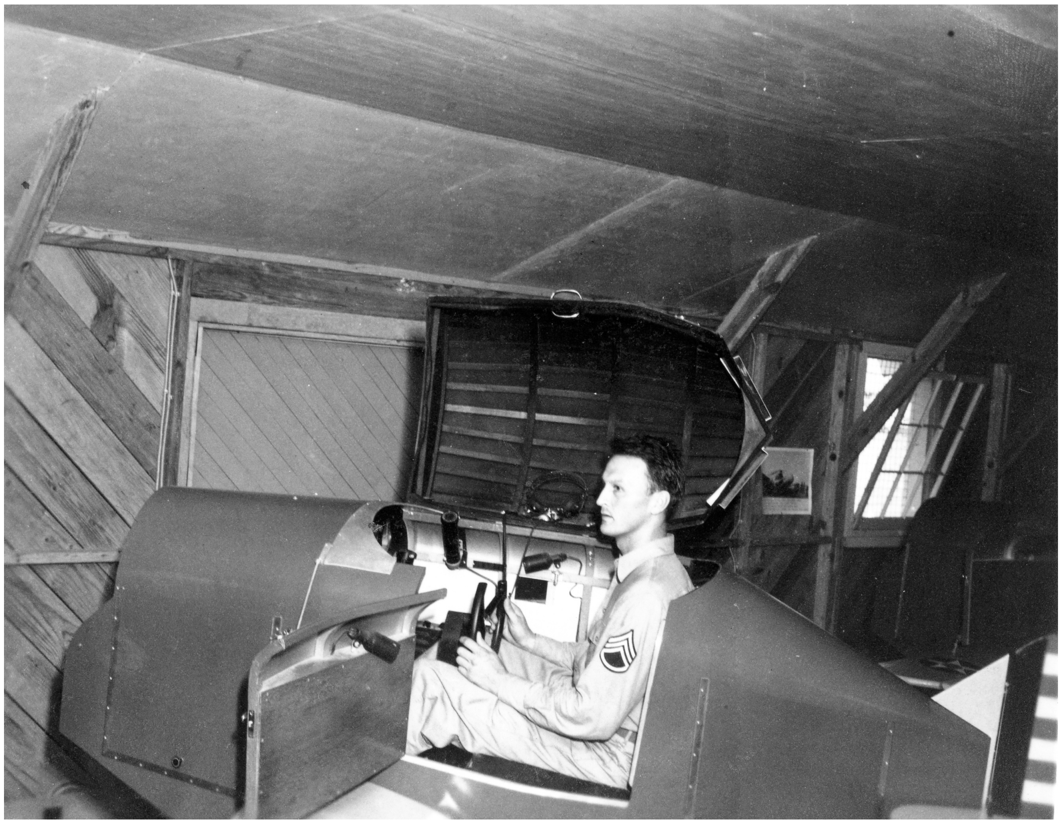


Figure 2.1: A link trainer at Freeman Field in Seymour Indiana

2.2.2 Entertainment

Entertainment or games has a big potential in Virtual reality. However up until now it has been more limited than some predicted, most probably due to the system's high cost. It is likely that the release of Oculus Rift will lead to a resurgence for virtual reality games as it is a reasonably priced head mounted display, targeted at the video game market. Even though it has not yet officially been released we are starting to see commercial games with support for Oculus Rift such as Half Life 2, and Team Fortress 2.

2.2.3 Education

As mentioned earlier the virtual campuses acts as a framework around the educational content, and learning activities at the educational institution. In addition to the virtual campuses we are also seeing potential for custom applications for specific educations. For instance in education of surgeons. Haluck and Krummel [2000] explores how virtual reality can be applied in education of surgeons: Technological advancements have drastically changed how doctors diagnose and treat disease. But surgeons are still being trained using the 100 year old Halstedian apprenticeship model. This means that in today's surgical programs most education is surgical skill takes place in the operating room. Some have argued that the Operating Room(OR) is the best environment for surgical education. However there are several possible weaknesses with using the OR as the classroom. There are numerous distractions, the learner may arrive exhausted or unprepared, or the mentor may not be a good instructor. Furthermore the specific case may not be suited for the learner. One must also take into the consideration patient safety. A virtual environment for surgical training could be a useful supplement in the education. The trainee could participate in real-life events without significant risk, as there are no patient who might suffer. The tasks could be repeated as many times as necessary, and the operation could be abandoned at any time.

In [Seymour et al., 2002] a randomized double blinded study was peformed on VR and operating room performance. Sixteen surgical residents had baseline pshychomotor abilities assessed, and where randomized to either VR training or control non-VR Training. They then performed a laparoscopic cholecystectomy with an attending surgeon blind to training status.

There was no difference in the baseline assessment between the groups. The gallbladder was 29 % faster for VR-trained residents and the non-VR-trained residents was nine times more likely to transiently fail to make progress, and five times more likely to injure the gallbladder or burn non-target tissue.

2.2.4 Sports training

There are several potential advantages to a sports training Virtual Environment. [Miles et al., 2012] lists the following:

- A VE allows standardised scenarios to be created by coaches
- Extra information can be given to players to enrich the environment and guide their performance
- It is possible to quickly and randomly change the environment to match any competative situations.

In sports athletes has to react to their environment that provides them with information. Especially for duels between two players the opponents react with anticipation by using this information. Traditionally these situations was analyzed by showing a film on a wide-screen, and stopping at strategic time events, and the subjects would than guess the remainder of the sequence. In Bideau et al. [2004] it is suggested that virtual reality could be an alternative for this. The environment is under control and enables fine tuning of parameters, and measure the parameters effect on the subject's behaviour. They develop a system where they are testing how handball goalkeepers acts in a virtual scenery. The study shows that the proposed model enables to carry-out virtual experiments without modifying the natural gestures of the subject.

An other example of virtual reality is shown in Chong and Croft [2009], where the rugby player sees a full-sized projected video of a player jumping, and the goal is to throw the rugby ball to that player. A device called TAM (Throw accuracy measurement) was created, compromising of 28 lasers forming two grids. As the lasers is intersected the data is sent to an MATLAB application, which calculates the parabolic flight of the ball. Tests with players with different experience-levels showed that inexperienced players made more than twice as many errors as experienced players.

Virtual reality has also been applied successfully in other sports, for instance Komura et al. [2002] introduce a prototype for a virtual batting cage, which enables batters to face a variety of baseball pitchers. There are no real baseball thrown, but a virtual ball is rendered over the screen in different trajectories depending on which pitcher the player is facing. The player is swinging a bat with reflectors attached to the sweet spot. Photoelectric sensors are analyzing the trajectory of the bat when the player swings, and calculate the balls movement accordingly.

In Park and Moon [2013], it is presented how virtual reality can be used in order to teach beginners the basic of snowboarding. The system is able to teach 5 basic snowboarding exercises. It is detecting the players movement and center of gravity, and giving instant feedback on the players performance. Both these papers are good examples on how virtual reality can be implemented as tools for sports training. In Stinson and Bowman [2014] it is shown that a VR sport-oriented system can induce increased anxiety compared to a baseline condition. Which indicates that there are potential for useful VR sports psychology training systems. And ski jumping is a sport where mental fortitude plays an important role in an athletes performance.

2.3 Ski jumping applications

Over the years there has been several ski jumping games. Deluxe Ski Jump 4 is by many considered to be the best ski jumping game on the market in 2015, mainly because there are not any real competitors. Deluxe Ski Jump has 24 accurately modeled ski hills, and the game is based on real physics. There has not been published any papers about how the physics in Deluxe ski jump is implemented. The game controller on the other hand is quite simple, as it uses a computer mouse for all the phases of the jump. The player can choose between 12 different camera angles when jumping, and one of them is a first person camera angle. However from that viewpoint it is really hard to get good results, because it is hard for the player to judge the how the skiers body is positioned.

Wii fit ski jumping is also an interesting ski jumping game. The game uses the Wii Balance Board, so the user is using his body to control the jump. Simulating body movement in this fashion can improve the users perception of the game, and will probably result in a more realistic experience than if you are only pushing a button on a controller. Although game has nice controllers, the game itself is simple and does not seem to have any real physics.

In 19 November 2014 the Alf Engen Ski Museum in Park City, Utah opened a new virtual ski jump exhibition called "Take Flight". It seems like the game is displayed on a TV-monitor, and it also looks like it using some kind of a force scale for the jumping, similar to the Wii fit jumping game. At the moment there is not much information about the system, but based on EngenMuseum [2014] this may be one of the better virtual ski jumping simulator at the moment. And in March 2015 the Slovenian insurance company Triglav created the "Planica 2015 Virtual ski flying" Sporto [2015] which is a virtual reality ski jumping application based the real ski jumping hill Planica, which is one of the largest ski jumping hills in the world with a hill record of 248.5 meters. The application is using the Oculus Rift Devolopent Kit 2, and it seems like it only uses the head tracker of the Oculus for controlling the ski jump. This is probably the best virtual reality ski jumping application using a head mounted display.

2.4 Serious games

There are several definitions of video games and serious games. [Zyda, 2005] offers the following definitions *video game:* "A mental contest, played with a computer according to certain rules for amusement, recreation of winning a stake". *Serious game:* "A mental contest, played with a computer in accordance with specific rules that uses entertainment to further government or corporate training, education, health, public policy, and strategic communication objectives." In other words a serious game is a game where the main objective is to educate users, and not to entertain them. The games need to be engaging but not necessarily fun. Serious games can be many different game genres and like virtual reality it can have a broad area of applications. Americas Army US-Army is a round based team tactical shooter game where the player can experience how it is to be a soldier in the US army. It was first deemed to be a good recruiting tool but there "was insufficient fidelity in the game for it to be any use in training". Later it turned out that the game also had been incorporated in the training for soldiers who e.g. struggled in the rifle range Zyda [2005]. The earlier mentioned experiment in [Haluck and Krummel, 2000]

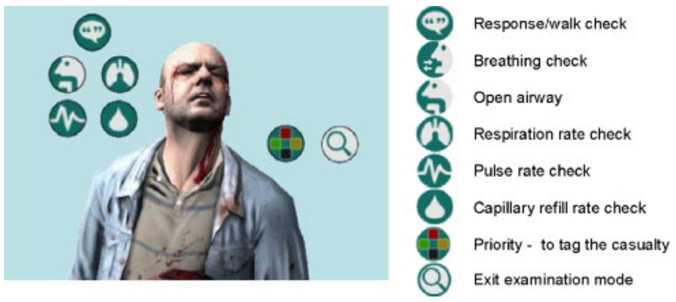


Figure 2.2: The triage trainer

is an example of a combination of a serious game and virtual reality. An other interesting application is the triage trainer Knight et al. [2010]. The study showed that the tagging accuracy of participants who used Triage trainer was significantly higher than those who undertook the traditional card-sort exercise. Triage is the process of prioritizing patients based on the severity of their conditions.Serious games are also incorporated in business corporation and commerce. In 2009 IBM estimated that between 100 and 135 of the fortune 500 companies would use serious games in 2012. IBM also has their own Serious game called "CityOne: A smarter planet game" which focuses on making energy banking, water and retail systems more efficient. The use of serious games in formal education is still limited, this may be related to issues around using leisure games. That is concerns about physical and cost barriers having enough hardware, licenses, sufficient access, IT support and confidence in using the game, which includes having had time to read the manual, understand ho the game relates to the curriculum goals and an understanding of how learning will be assessed [Mary Ulicsak, 2010]. Games may also not be a an effective learning tool for all students. In a study using the game Civilization to teach history and geography, roughly 25 % of the students withdrew from the study as they found it too hard, complicated and uninteresting. While another 25 % of the students (particularly academic underachievers) loved playing the game and thought it was a "perfect way of learning history" Squire [2005]

2.5 Natural User interface

In the last decade Natural User Interfaces have seen an rise in popularity. A natural user interface lets the user interact with the system in a natural way that mimics the real world. Touchscreens(Microsoft Surface), and gestural interactions(Kinect) lets the user interact with systems in new ways. Natural user interfaces is of particular interests for virtual reality. In virtual reality applications the user often has a head mounted display (HMD), which prevents the user from seeing the keyboard and mouse. Natural user interface is considered as an requirement for a sport-themed virtual reality application in [Miles et al., 2012]

2.6 Ski jumping

Ski jumping is a form of Nordic skiing in which athletes descend a take-off ramp, called the in-run, jump and fly as far as possible. During the in-run the athlete tries to gather as much speed as possible by having favorable aerodynamic body position. While in flight the athlete attempts to hold a favorable body position and avoid landing as long as possible. In competitions points are awarded both for style and length. The skis are 11 cm wide and can be up to 146% of the total body height of the skier.

The ski jumping hill consists of two main parts: the in-run, and the landing slope. The in-run typically starts with an angle of 38-36 degrees which then curves into an transition often called the take-off radius or the R1. The transition is then followed by the take-off ramp, which typically has an angle of 7 and 12 degrees downhill. The landing slope has a smooth curve that follows the profile of the jump, because of this the skier is never more than 6 meters above the ground. The steepest point of the hill is called the K-point or the critical point. The K-point is used in the calculation of distance points in competitions, as a jump to the critical point grants 60 points. Further down the slope lies the hill size point, which is calculated based on the technical data of a hill based on radius, angle of inclination and record distance. Since 2004 this has been the official measurement for the size of hills.

2.7 Requirements

In this section we will describe the requirements for the prototype. The requirements was set through reviewing the literature.

- The hill should be similar to the ski jumping hill in Trondheim, Granåsen. This means that the hill have recognizable visual elements from the hill. It should also have the same structural dimenensions as the real hill.

- The prototype should be physical correct. The prototype should model the physical properties of a ski jump correctly, including speed, jumping, and flying.
- The application should be able to run in real time on a mid-range computer.
- The system should provide a realistic ski jumping experience for amateurs.
- The prototype should have a natural user interface

Chapter 3

The first prototype

This project is a continuation of the prototype made in Staurset [2014]. In this chapter I will describe the design and implementation of the original prototype. I will only describe the most important part of the development process. For a more detailed explanation please see [Staurset, 2014].

3.1 Modeling

A 3D model consists of vertices, edges and faces in 3D-space. It is usual to start up with a simple mesh(e.g a cube) and shape it by doing operations on said mesh. I used the the graphics software Blender to create the models. A model consists of vertices, edges and faces in 3D-space. It is usual to start up with simple mesh(e.g. a cube) and shape it by doing operations on the mesh. In Blender you have many different operations that can be applied to the model such as translate, rotate, scale, mirror,extrude and duplicate. These operations can be applied at mesh ,face, and vertex level.

I used the official FIS hill certificate(Appendix A) as a reference when I created the hill. The hill certificate provides the basic measurement and metrics of the hill. The in-run was divided into 3 parts: the straight, the transition (or radius) and the take-off ramp. The straight part of the in-run was created by shaping a cube. At first it was scaled and rotated so the cube had correct dimensions and orientation. Then the cube was subdivided into a finer mesh. Next the ski tracks was made by extruding down two of the rows on the cube. The radius was created by

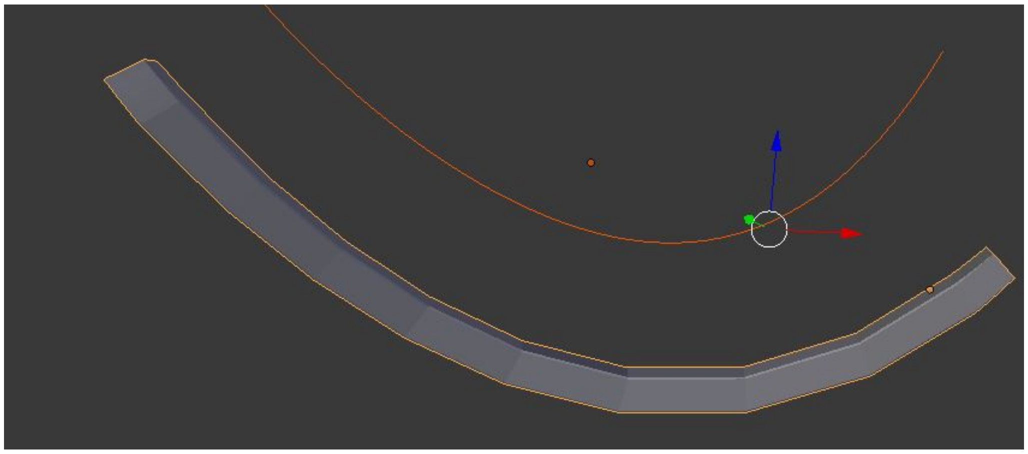


Figure 3.1: This figure illustrates how the curve deforms the cube

duplicating the straight part and applying the curve modifier to the mesh. This modifier curves the mesh according to a NURBS curve with the approximate shape of the radius. A NUBRS curve is a Non-uniform rational B-spline used to represent curves and surfaces. The curve is defined by a set of control points and a knot vector. The curve is intuitive to use and offers great flexibility. The radius and straight ramp was then joined into a single mesh. It turned out to be difficult to join the two parts into a smooth mesh, as it was especially easy to see if the ski tracks was not properly joined. The take-off ramp was created in a similar fashion and scaled, rotated, translated and join to create the complete mesh. Figure 3.2 shows the in-run seen in profile.

The landing was modeled using a NURBS curve. The hill certificate was used as a reference, but it only offered a rough approximation to the slope. The curve was approximated using the K-point and 3 different values from the certificate: h, n and β_K. H and n is the vertical and horizontal length between the K-point and the start of the slope, and β_K is the angle of the slope at the K-point. I then drew the curve so it ended up with a correct angle at the K-point. After the landing slope was approximated, I used a straight line as a bevel object for the curve. When setting a bevel object for a curve combines the two object into a solid mesh.

From the evaluation done in [Staurset, 2014] it was clear that this model had several faults. First of all the straight part of the in-run was too long and the transition was to short. This was not something that the general public would recognize, but an experienced jumper would notice it at once. The landing slope was also not sufficient, and especially the transition was to "steep",

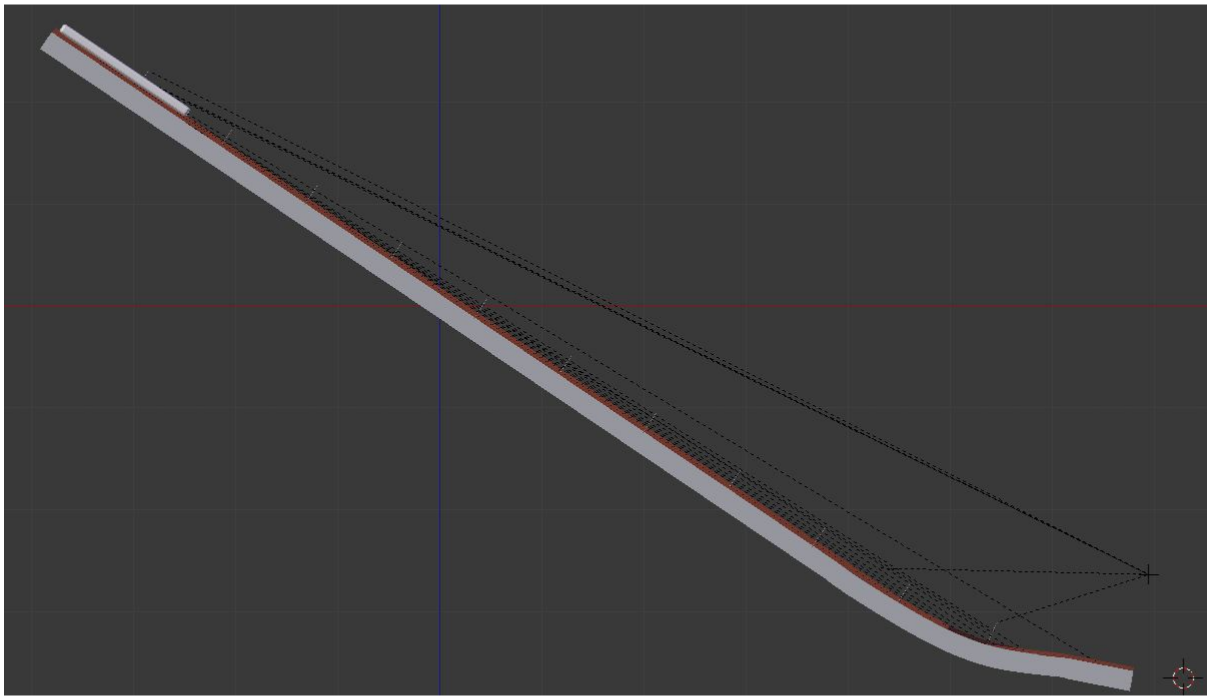


Figure 3.2: This figure shows the in-run profile

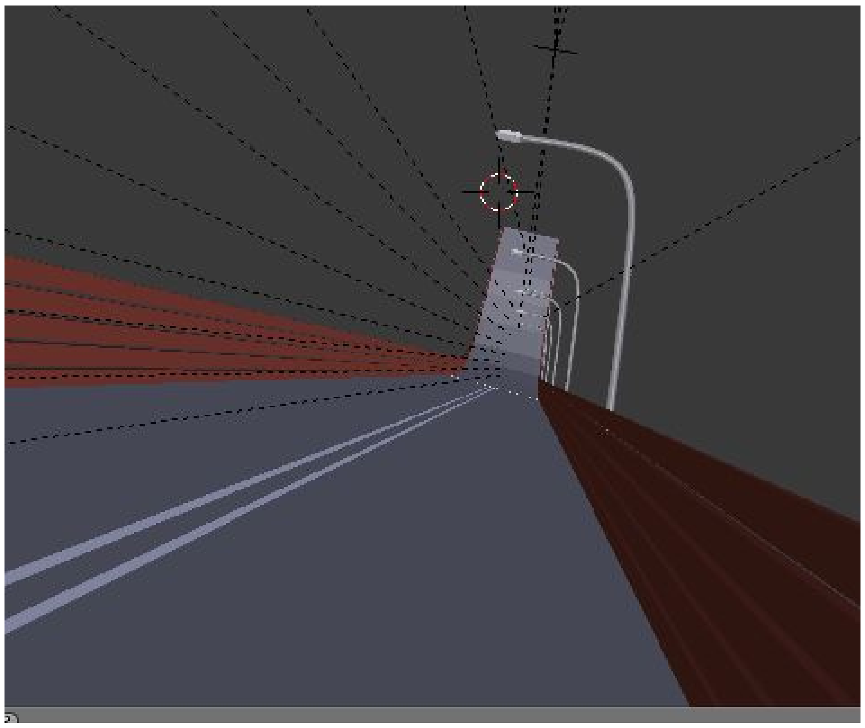


Figure 3.3: This figure shows the in-run closer up. Both the fence and lamp post are visible

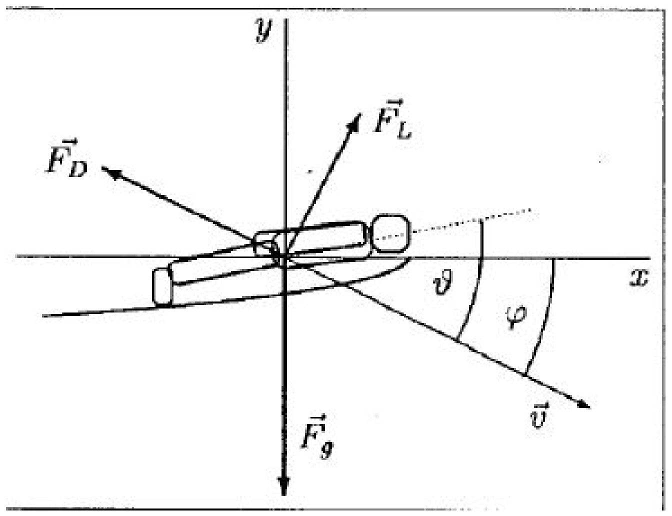


Figure 3.4: This figure shows the forces acting on the skier while he is in the air. The figure is from Marasovic [2003]

3.2 Physical Model

A ski jump is a mathematical complex and computationally expensive process. The state of the art aerodynamic computations using computational fluid dynamics is too complex to be computed in real time. Hence it was necessary to device a simplified physical model describing a ski jump. I decided to implement the model proposed in Marasovic [2003], which describes the forces acting on the ski jumper while in flight. It takes a simplified Newtonian approach to the problem where only two forces acts on the skier: The gravitational force F $_g$, and the dynamic fluid force. The magnitude of the dynamic fluid force is proportional to the air density (ρ), the surface area A (an intersection of the plane perpendicular to the relative jumper's motion and his body and the square of the jumpers velocity v relative to the air. The equation for the fluid force can be expressed as follows:

$$F = \rho A v^2 \tag{3.1}$$

The dynamic fluid force can be divided into two components, namely F$_D$ and F$_L$. F$_D$ is the drag force acting in the opposite direction of the velocity. F$_L$ is the lift force and acts perpendicular to the jumper's velocity. This is illustrated in figure 3.4. The magnitude of the drag force and lift force can be expressed as follows.

$$F_D = \frac{1}{2} C_D \rho v^2 \Big(A_\perp + A_\parallel \sin^2(\vartheta) \sin(\vartheta) \Big) \tag{3.2}$$

$$F_L = \frac{1}{2} C_L \rho v^2 A_\parallel sin^2(\vartheta) cos(\vartheta) \tag{3.3}$$

Where A$_\perp$ is the area of the frontal surface of the skier, A$_\parallel$ is the area of bottom surface of the skier. For simplicity these are assumed to be constant during the jump. C$_D$ and C$_L$ is the drag and lift coefficient. And ϑ is the angle between the body of the skier and the velocity v, also known as the angle of attack. By decomposing the drag and lift force I can derive the forces F$_x$ and F$_y$ which is the sum of forces acting on the skier in the horizontal and vertical direction respectively.

$$F_x = \frac{1}{2} C_L \rho A_\parallel \sin^2(\vartheta) \cos(\vartheta) \sin(\phi) - \frac{1}{2} C_D \rho v^2 \Big[A_\perp + A_\parallel \sin^2(\vartheta) \sin(\vartheta) \Big] \cos(\phi) \tag{3.4}$$

$$F_y = -mg + \frac{1}{2} C_L \rho v^2 A_\parallel \sin^2(\vartheta) \cos(\vartheta) \cos(\phi) + \frac{1}{2} C_D \rho v^2 \Big[A_\perp + A_\parallel \sin^2(\vartheta) \sin(\vartheta) \Big] \sin(\phi) \tag{3.5}$$

here ϕ is the instantaneous angle between the velocity and the x-axis, m is the mass of the ski jumper and g is the acceleration of gravity. By using Newton's laws of motion I were able to express the acceleration and instantaneous velocity in both vertical and horizontal direction by the following equations

$$\frac{dv_x}{dt} = \frac{F_x}{m} \tag{3.6}$$

$$\frac{dv_y}{dt} = \frac{F_y}{m} \tag{3.7}$$

$$\frac{dx}{dt} = v_x \tag{3.8}$$

$$\frac{dy}{dt} = v_y \tag{3.9}$$

According this model the parameters that changes during a ski jump is F_X, F_Y, the skiers velocity, position and angle of attack. And the only thing the jumper can impact while he is in the air is the angle of attack. The prototype used the following values for the constants: $A_\perp = 0.15\ m^2$, $A_\parallel=1.2\ m^2$, m = 58, g = 9.81 m/s^2, ρ =1.0 kg/m^3, and $C_D = C_L = 1$.

3.3 Implementing in Unity

The application was developed in Unity 3D. Unity is a cross-platform game creation system, including a game engine and an IDE. Unity also has its own integration package for Oculus Rift, which makes it relatively easy to create a VR-application compatible with Oculus rift. When creating an application in Unity the game is organized in scenes. Each unique scene can be thought of as an unique level. The scenes can contain numerous GameObjects. GameObjects is the basic building block in Unity. Everything you see in the game is a game object. The GameObjects themselves does not do anything, but it is a container for components that can be attached to the object. The components can be several different things such as a mesh renderer, a collider, a rigid body, and a script among others. Scripting in Unity is also an important part in developing in Unity. The scripts can be created in JavaScript, C# and BOO. Through a well documented API you can access and manipulate the Gameobjects and other components via the code.

The first thing I did was importing the 3D-models from Blender, and place them in the scene. In this context the imported model will be the GameObject and by default it has two components attached to it: the transform, and the animator. The transform keeps track of the position, rotation and scale of the GameObject, while the Animator lets you manipulate the behaviour of the object by providing setup for state machines and blend trees. The terrain was created by using the built in terrain creator in Unity. This gives you three different tools for manipulating the height map of the terrain: raise/lower terrain, paint height, and the smooth height. The terrain creator also has a tree creator, which lets you place trees in a chosen radius with a chosen density. These tools make it quite easy to to create a varied scene.

After importing the models into Unity, colliders was added to them. Unity provides 4 different colliders: box, sphere, capsule, and mesh collider. The first 3 are often called primitive colliders as they are less computational expensive than the mesh collider. The colliders can both be used to prevent the player from falling through the objects and as an action trigger. However a collider cannot be used for both at the same time. Due to the complex shape of the in-run and out-run both had to use the mesh collider. The in-run also has a trigger box collider which to keep track of when the player is in the in-run. The out-run also needed a collider to trigger when the player landed. A box collider was not accurate enough, and the existing collider could not be used. Therefore the out-run was duplicated, where the duplicated out-run has a trigger mesh collider that triggers when the player landed. This trigger mesh was translated 0.3 meter in the Y-direction to make sure that the collider got triggered when the player landed.

The player behaviour used the standard Unity First Person Controller as a starting point. This is a out of the box controller which make you able to walk around in a unity scene. It has a sphere collider which prevents the player from falling through the terrain, and it has a standard camera that can be rotated with the mouse, and several parameters that enables you to fine tune the behaviour of the character. The player object has a capsule collider which prevents the player from falling through the terrain and other colliders. It also has 3 scripts attached: MouseLook, CharacterMotor and FPSInput Controller.

The FPSInputController handles the input from the keyboard/mouse and passes it on to the CharacterMotor and the MouseLook scripts. The MouseLook Scripts handles the mouse input and rotates the camera based on it. While the CharacterMotor is responsible for calculating the movement of the player based on the input. By default the motor has implemented walking, jumping, gravity and sliding. This was the script where much of the work was done. The script is quite complex but I will give a brief explanation on how it works. The update function is called every frame and have two different modus operandi: fixed or "when available". When doing fixed update the function is called at a fixed interval of 0.02 seconds, while the "when available" is called immediately after the last frame was done calculated. The fixed update tends to perform better in physical simulations, so that is what we chose. The Algorithm 1 shows the main steps in the update function. ApplyInputVelocityChange updates the velocity according to input from the keyboard and the current velocity. ApplyGravityAndJumping handles the jumping and also implements gravity(without air resistance) . In MoveCharacterAndUpdatevelocity the position of the player is updated, taking collisions into consideration, and updates the velocity based on the distance the player actually moves.

Algorithm 1 Pseudocode for the original update function

```
1: procedure UPDATEFUNCTION
2:     velocity ← ApplyInputVelocityChange(velocity)
3:     velocity ← ApplyGravityAndJumping(Velocity)
4:     MoveCharacterAndUpdateVelocity
```

To implement the players behaviour in the in-run i created a function called ApplyInrunVelocityChange, which is accelerating the player to a max forward speed of 28 m/s. The function is similar to ApplyInputVelocityChange but makes sure that the player does not have to press any keys to accelerate down the in-run, and also that he only moves straight forward. This function is called while the player is in the in-run. I also added a boolean to make it so that the player does not start accelerating down the in-run immediately, this Boolean is switched by pressing the "0" button.

The physical model is implemented in a function called ApplyGravityAndFluidForce. This function calculates the horizontal and vertical forces, F_x and F_y according to equation 3.4 and 3.5. It is then calculating the velocity change in x and y-direction by assuming that $\Delta v_x \approx \frac{dv_x}{dt} \Delta_t$ and $\Delta v_y \approx \frac{dv_y}{dt} \Delta_t$. The ApplyGravityAndJumping function is changed so that it does not apply gravity, but calls ApplyGravityAndFluidForce when the player is in the air. As mentioned in section 3.2 the angle of attack is the only parameter the skier can influence while in the air. The default value chosen is 35 degrees on the velocity. While the skier is in the air is body is rotated so that the body will rotate with the velocity and the angle of attack remains constant until the jumper lands. When the jumper lands his body is rotated back, so his body is normal to the ground. The rotation happens insantly and has a unnatural feel to it.

The initial thought when implementing the skis was to let the player be parenting the skis. That did not work as because the skis should be independent of the rotation of the player. To achieve this, the skis instead have a script called followPlayer. This script is moving the skis according to the player, and is rotating the skis into the well-known v-style while the skier is in the air.

Chapter 4

Modeling

In the second iteration we used a Lidar system to create an accurate model of the hill. LIDAR is a remote sensing technology that accurately measures distances to a target by illuminating it with a laser and analyzing the reflected lightSANGAM [2012]. The LIDAR system was attached to a drone that flew over a large area around Granåsen. The output from the Lidar system is a point cloud in the form of a LAS-file. A point cloud is a set of data points in 3D space. With the system it is possible to choose the granularity of the point cloud down to one point every 5 cm. After some initial testing I found that I got the best results 10 cm granularity, this is of course a trade off between file size and accuracy of the point cloud. As mentioned in section 3.1 a 3D model consist of vertices, edges and faces in 3D-space. The point cloud is only raw data points and has to be converted into a triangulated mesh before it can be used in Unity.

I did not have software that could read the LAS-file, so the first step was to convert the LAS-file into the more manageable XYZ format. In this format each point is written in ASCII separated by comma. This conversion was done by using the LAStools las2txt program, which provides an easy and intuitive way to convert LAS files.

With the new XYZ file I was able to edit the point cloud using Meshlab. Meshlab is an open source 3D mesh processing software with many useful tools for processing point clouds. The file size of the original point cloud was ~ 75 MB, which seems a little excessive for our use.

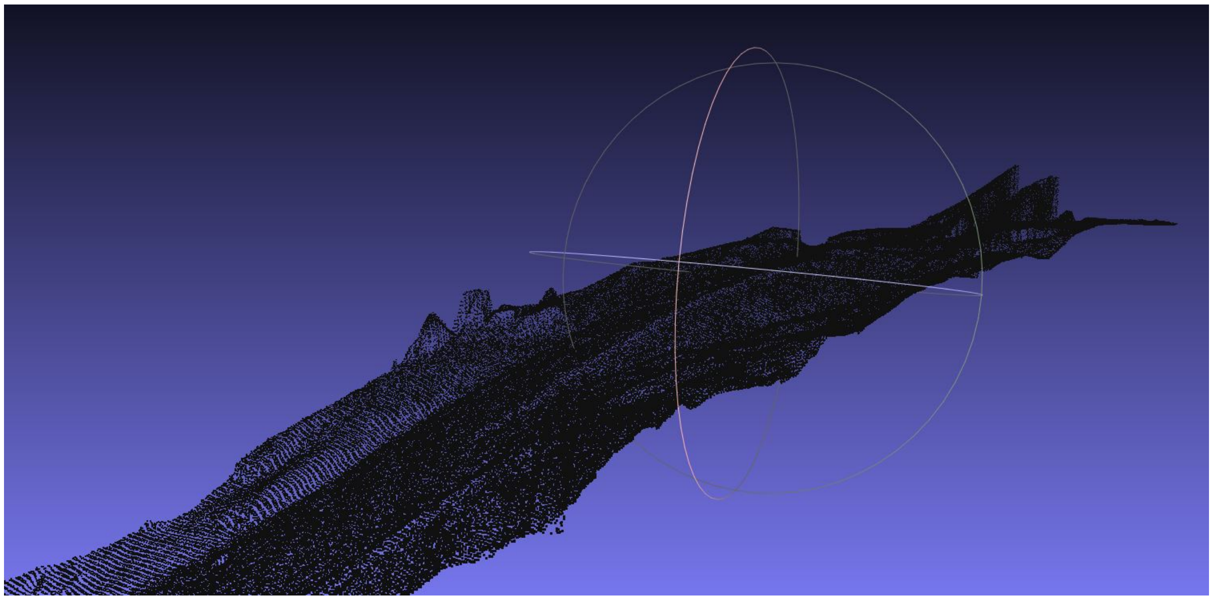


Figure 4.1: This figure shows how the results from Poisson-disk subsampling with 1 million samples.

4.1 Surface Reconstruction

The first task was to reduce the data set. This was accomplished by using the Poisson-disk sub sampling algorithm. This algorithm is well suited for sub sampling surfaces. It is similar to the algorithm described in [Cline and Wonka, 2009]. It divides the surface *S* into a set of fragments called the active fragment set and also instantiates an empty point set. Next it randomly selects an active fragment *F* with probability based on its surface area. It then "throws a dart" at a random point *p* in the fragment, and checks if this point is covered by the point set in which case the fragment will be discarded. If *p* is not covered by the point set, the parts of *F* not covered by *p* is split into a number of child fragments which are added into the active fragment set, and *p* is added to the point set. The algorithm runs until the active fragment set is empty. This should result a surface that is neither undersampled or oversampled. In 4.1 you can see the result from running Poisson-Disk subsampling with 1 000 000 samples.

The next step is to reconstruct the normals. Meshlab uses the nearest neighbours of a vertex to approximate its normal. The algorithm also offers the possibility to smooth the normals over several iterations. Figure 4.2 shows the result from a normal reconstruction with the 30 nearest neighbours and with 3 smoothing iterations. It is now easy to recognize the shape of

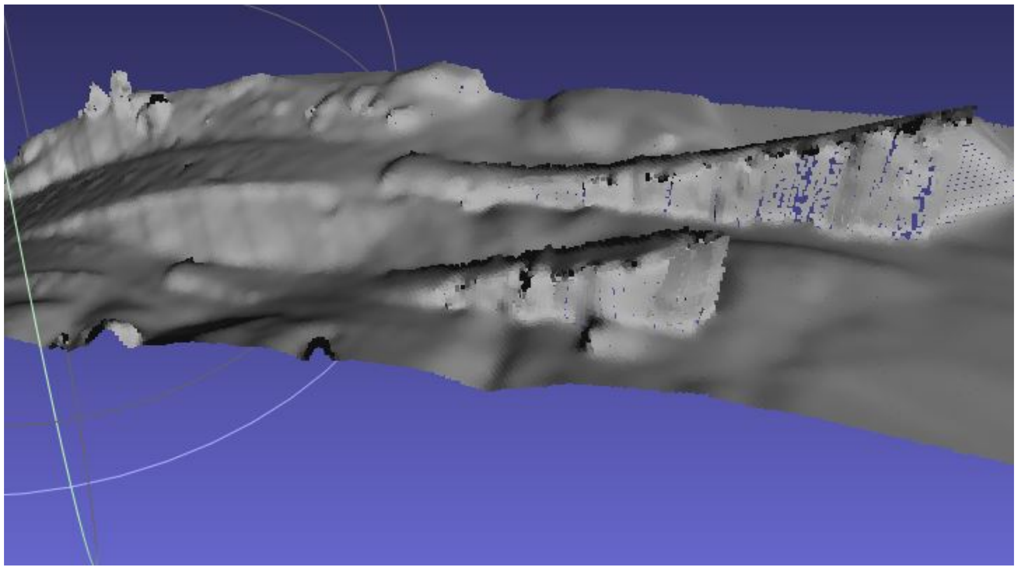


Figure 4.2: This figure shows how the results from running normal reconstruction with 30 nearest neighbours and 3 smoothing iterations.

the ski jumping hill. At this point we have a set of vertices with normals, and the next step is to reconstruct the surface. I tested 3 different surface reconstruction methods: Marching Cubes, Ball Pivoting and Poisson Surface Reconstruction. The methods are described in the following sections.

4.2 Marching Cubes(RIMLS)

The Marching Cubes algorithm was introduced in Lorensen and Cline [1987] . The algorithm passes through the scalar field looking at eight neighbor locations at a time. The eight locations forms an imaginary cube. The algorithm then determines the required polygons for representing the isosurface passing through the cube. This is done by checking if the corners of the cube is inside or outside of the object. There are 256 possible polygon configurations for the cube, and these are stored in a look-up table. Furthermore due to rotations and mirroring there are only 14 different triangulations for these 256 configurations. Next each vertex of the generated polygons is placed along the cubes edge by linearly interpolating the scalar values that are connected by that edge. The implementation in Meshlab is the Robust Implicit Moving Least Squares algorithm as proposed in Öztireli et al. [2009]. This algorithm uses the marching cube for a coarse extraction of the surface followed by an accurate projection onto the Moving Least Squares and an extra zero removal procedure. Meshlab offers the following parameters for tweaking the output:

- **MLS - Filter scale:** The scale of the spatial low pass filter relative to the local point spacing of the vertices
- **Projection - Accuracy:** Threshold value for stopping the projection step.
- **Projection - Max iterations:** Specifies the number of iterations of the projection step.
- **MLS -Sharpness:** Width of the filter used by the normal refitting weight. Typical values are ranging between 0.75(sharp) and 2.0 (smooth)
- **MLS - Max fitting iterations:** Max number of fitting iterations.
- **Grid resolution** Resolution of the grid that marching cubes are ran on.

The algorithm was tested with several different parameters, and it turned out that the grid resolution was the parameter with most impact on the outcome. When running with the default resolution of 200 the algorithm is only able to reconstruct 319 vertices of the surface, which amounts to less then 1 % of the surface. When the grid resolution is increased to 600, much more of the surface is reconstructed as is shown in figure 4.3. The rectangular holes in the mesh most probably comes from a line in the grid where the cube is to large extract the surface. When increasing the grid resolution to 1200 the surface starts to look very good, but there are still a few holes in the surface, but this can be solved by manually filling the holes in the surface. However the resulting mesh ended up having a file size of roughly 22 MB with 412 000 vertices and 819 000 faces. Having such a large model could heavily impact the performance when running the application on a reasonably priced computer. Therefore the mesh had to be reduced. This is usually done by decimating the mesh. Meshlab offers a method called Quadric Edge Collapse Decimation. This is a very robust and easy method for reducing the number of faces of a mesh. It achieves this by using quadric error metrics to determine the optimal edges to collapse in the mesh. The only parameters the function needs is the desired number of faces or percentage of the mesh to decimate. However the mesh did not respond well to the decimation, and ended

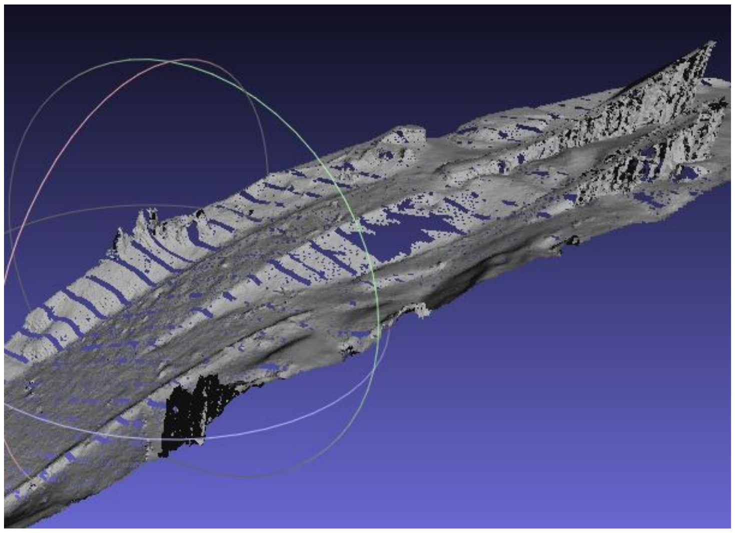


Figure 4.3: This figure shows the in-run reconstructed with the Marching Cube algorithm with grid resolution of 600

up looking very noisy when decimating only 10 % of the faces as can be seen in figure 4.4. Furthermore it is worth mentioning that although the method is able to reconstruct the shape of the in-run it is not detailed enough to be used directly in the application.

4.3 Poisson Surface Reconstruction

This approach was introduced by Mikael Kazhdan in Kazhdan et al. [2006]. It requires a point set with oriented normals. The indicator function is used in the reconstruction of the surface. It is a function that is zero everywhere except near the surface. The gradient of this function is first approximated using the normal field, and then the function itself is derived from this gradient. Next the Marching Cubes algorithm is used to build an octree representing the surface. An octree is an tree data structure where each node has exactly 8 children are used for partitioning the 3 dimensional space. Meshlab offers several parameters that can impact the reconstruction:

- **Octree Depth:** This is the depth of the octree created in the reconstruction. The default value is a depth of 8.
- **Solver divide:** This specifies at which depth a Gauss-Seidel is used to solve the Laplacian equation. This parameter can impact the memory usage during reconstruction.

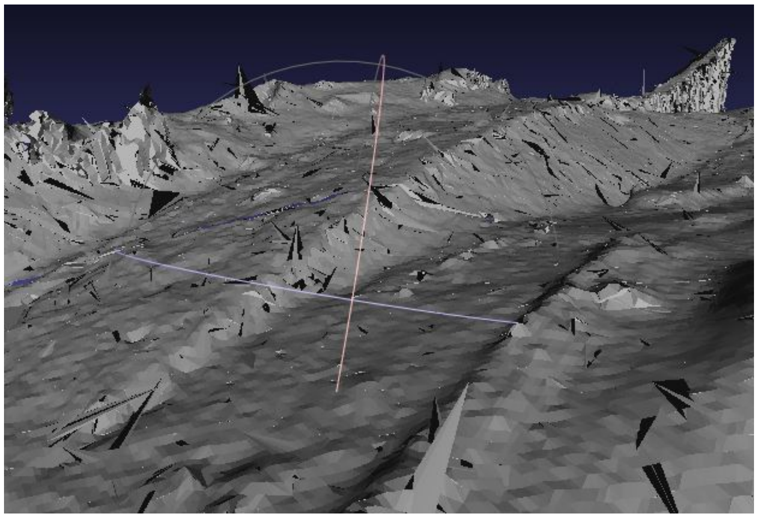


Figure 4.4: This figure shows the the results of running Quadric Edge Collapse Decimation on the Marching Cubes surface

- **Samples per Node:** Specifies the minimum number of sample points that should fall within an octree node as the octree construction is adapted to sampling density. This can be helpful when dealing with noisy data.
- **Surface offsetting:** Specifies a correction value for the isosurface threshold that is chosen. Default value is 1.

Figure 4.9 shows a closer look at a mesh reconstructed with an octree depth of 12. As can be seen in figure 4.10 the reconstructed surface assumed a spherical shape. I was not able to figure out why this was the case. The top half of the sphere would have to be removed if I would chose this approach for the final model.

4.4 Ball Pivot Algorithm

The ball pivot algorithm was introduced in Bernardini et al. [1999]. The main concept underlying the algorithm is actually quite simple. Basically it pivots a ball of radius p around the surface. The ball starts in contact with a randomly selected triangle. The ball is than pivoted around until it touches another point. It then forms a new triangle with this point, and the new triangle is added to the mesh boundary. The process continues until all reachable edges have been tried. The Meshlab implementation offers the following parameters for the Ball Pivot Algorithm:

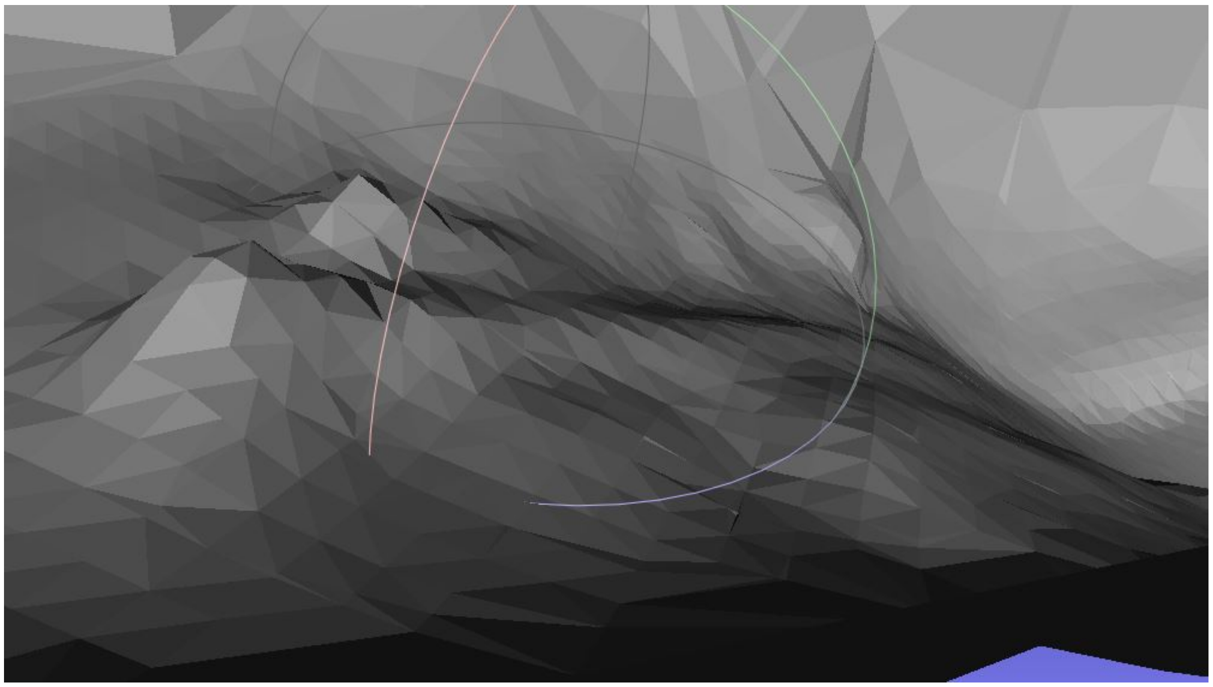


Figure 4.5: This figure shows the in-run reconstructed with an octree depth of 6. The in-run is not recognizable

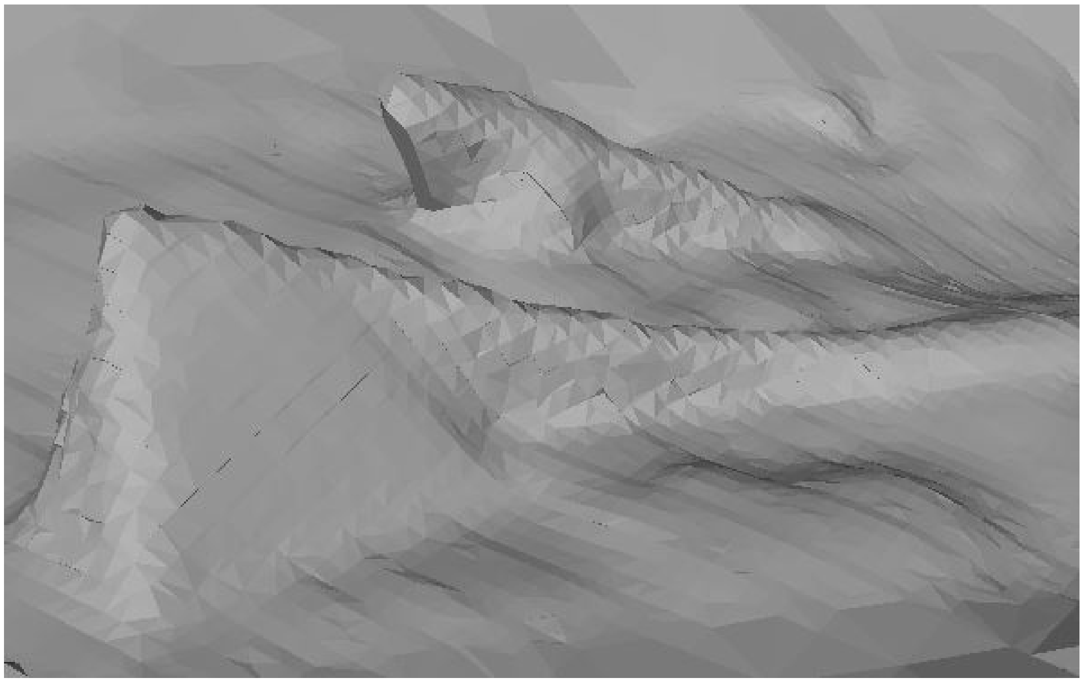


Figure 4.6: This shows the in-run reconstructed with an octree depth of 8. The shape of the in-run is now clear, but the mesh is not very detailed.

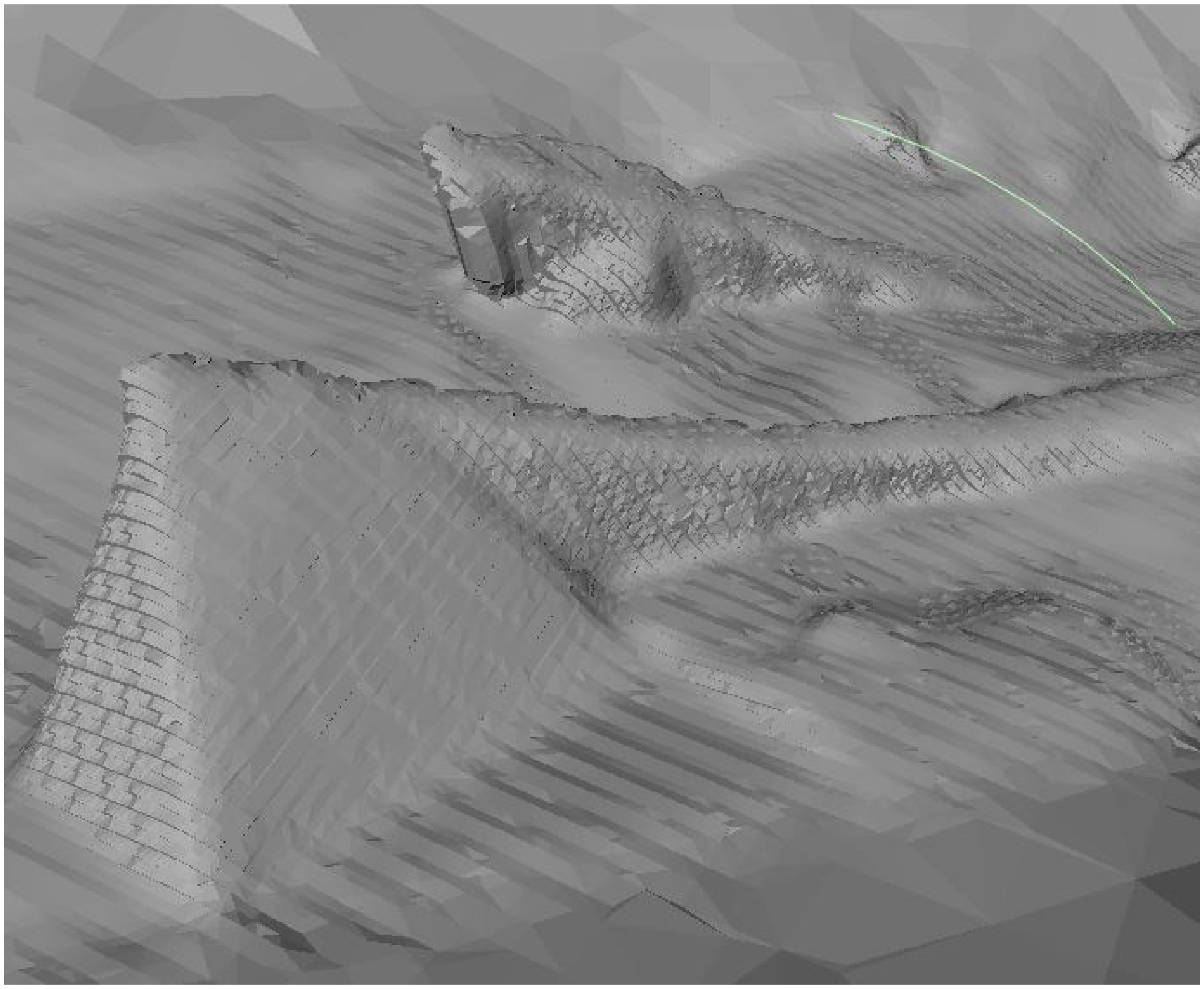


Figure 4.7: This shows the in-run reconstructed with an octree depth of 10. The mesh is more detailed

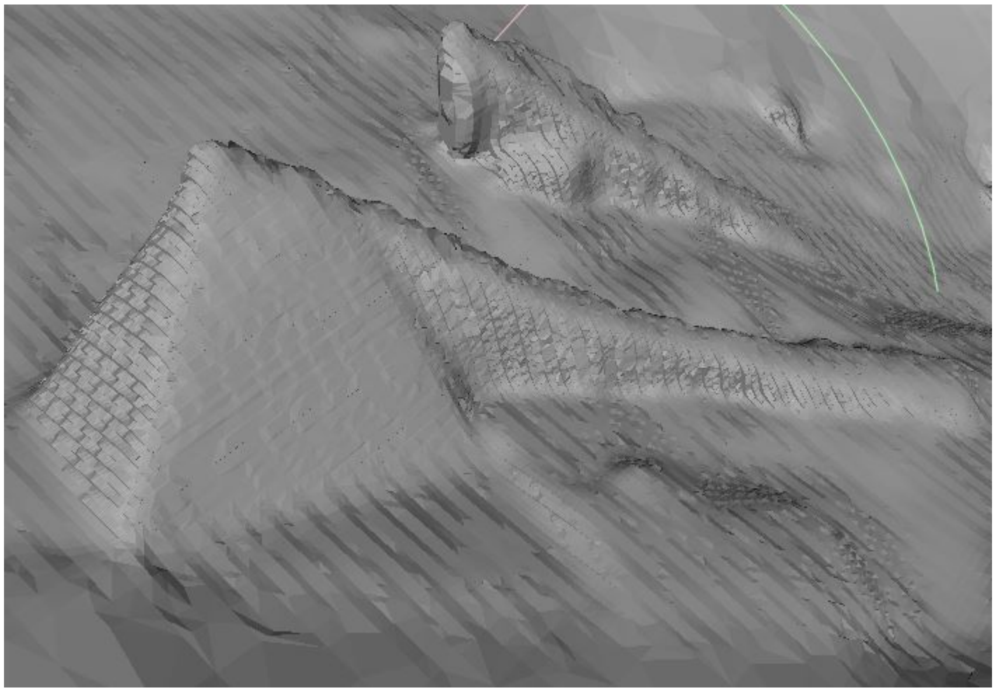


Figure 4.8: This shows the in-run reconstructed with an octree depth of 12. Looks similar to one with octree depth of 10

- **Pivoting Ball Radius:** Radius of the pivoting ball. Can be specified in world units. If no value is set the algorithm auto guesses a radius
- **Clustering Radius:** Threshold value for clustering points that are close to each other. Used to reduce number of triangles. Parameter is specified in percentage of the ball radius.
- **Angle Threshold:** Threshold for at what angle the ball shall stop rolling.
- **Delete initial faces:** Specifies if the initial faces should be deleted or not.

It is obvious that the radius p of the ball have much impact on how the mesh ends up. For instance holes in the point cloud that are bigger then the chosen radius will not be filled. Also this property makes the algorithm perform better on uniformly sampled point clouds. The LIDAR data is uniformly sampled with a 10 cm spacing between each point. However the original point cloud seemed to be too large and Meshlab crashed when reconstructing the surface with the original data. For that reason the data set had to be subsampled using the poisson disk sub sampling. A clustering radius of about 40 % of the cube seemed to give decent results. But this is of course dependent of the ball radius of the iteration. Moreover the angle threshold had to be

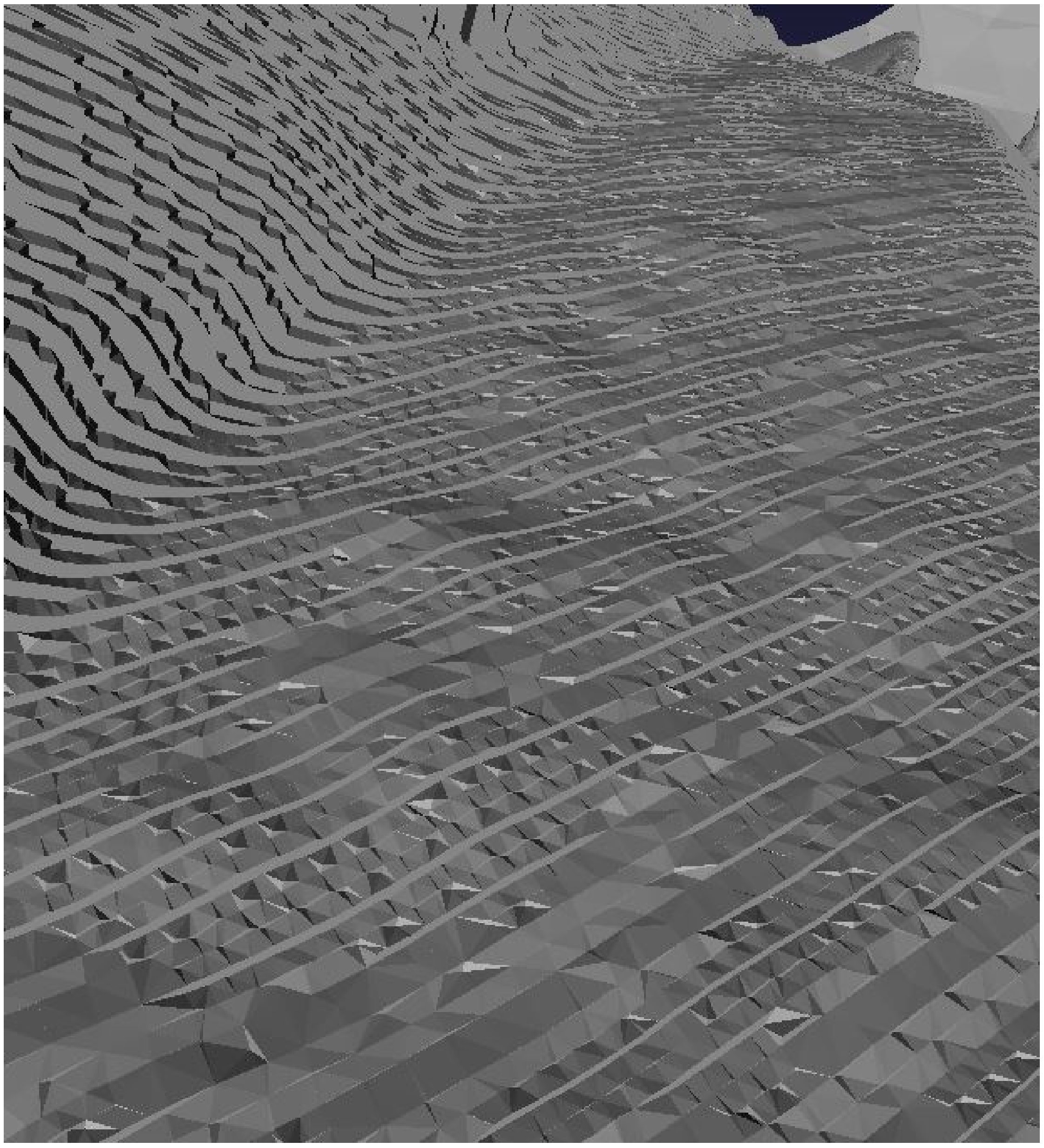


Figure 4.9: This figure is a closeup of the hill before decimation.

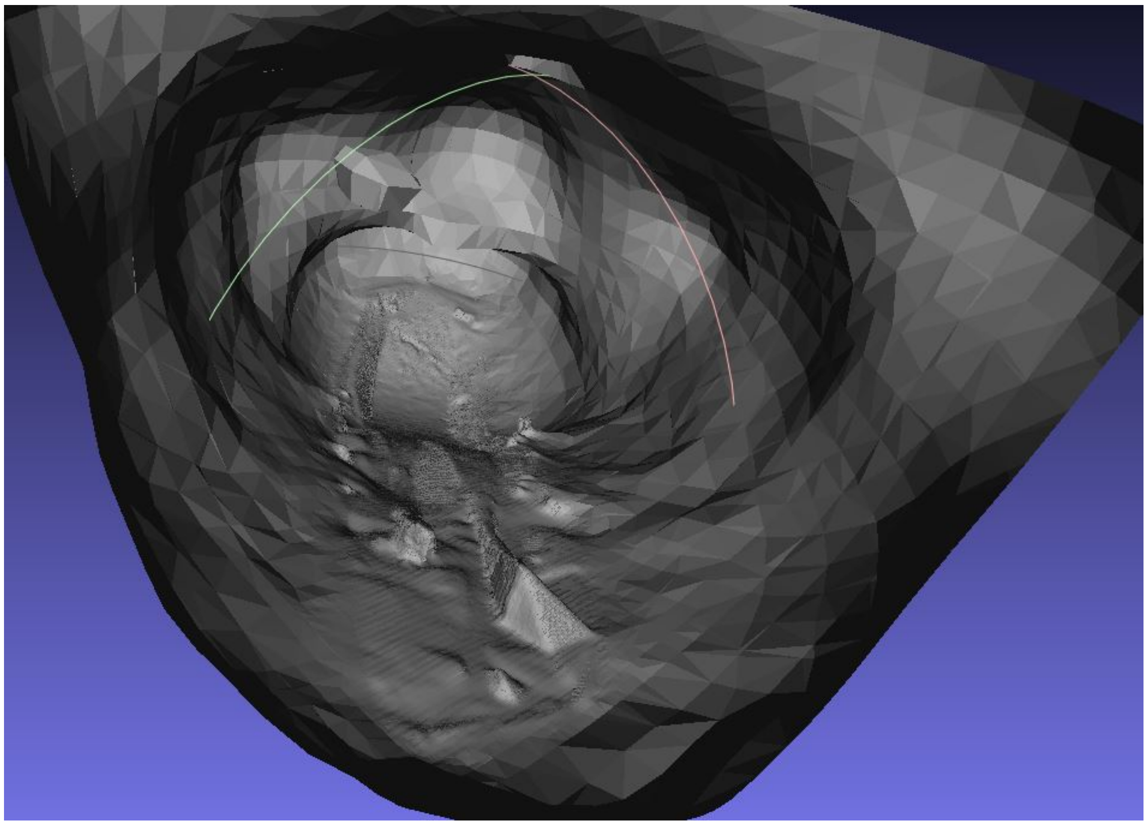


Figure 4.10: The spherical shape of the reconstructed surface

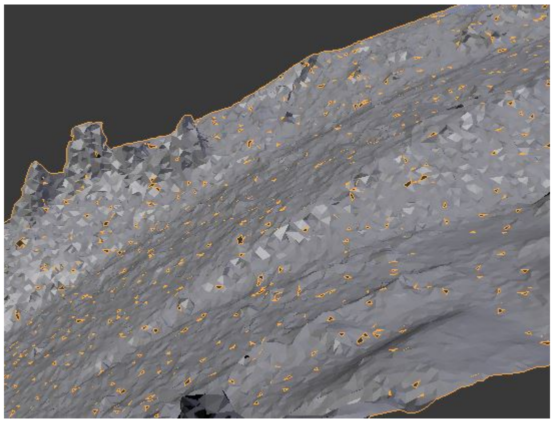


Figure 4.11: This figure shows a mesh reconstructed with a ball of 100 cm. The orange parts of the mesh are holes.

adjusted from the default value of 90 degrees. Since the ball starts pivoting at a random triangle the in-run was not reconstructed at all because the ball stopped rolling when it reached it. An angle threshold of 120 ensured that ball reached the in-run independent of where it starts. Also the deletion of initial faces provides a nice way to run the algorithm in an iterative manner. The idea is that you start out with a (possibly subsampled) point cloud with normals, and runs the algorithm with a small ball radius. The resulting mesh will then have many small triangles and holes. You then run the algorithm again with a slightly larger radius and clustering threshold, and deletes the initial set of surfaces. Repeat this until you have an acceptable mesh. However for some reason I was not able to get good enough results with the ball pivot algorithm. The file size tended to become very large ~ 50 MB and still the mesh ended up having many holes. Meshlab has a function for closing holes, but even when applying this the mesh had an unacceptable amount of holes. This is illustrated in figure 4.11 where the mesh is reconstructed from a ball with a radius of 100 cm. The mesh is both low detailed and have numerous holes. There are several possible reasons for the holes. It may be a result of the nonuniform subsampled point cloud, or it may be because of noise in the data set, or due to the topology of the terrain.

4.5 Which reconstruction method?

The Marching Cubes Algorithm and the Poisson Surface Reconstruction were both able to reconstruct the mesh fairly well. The main difference between them is how well they responded to decimation. And that is an important factor because a too detailed mesh will impact the performance of the application. For this reason the Poisson Surface Reconstruction mesh was chosen for this application. It is also worth noting that none of the algorithms was able to reconstruct the in-run in such a detail that it could be used directly in the application.

4.6 Post processing the mesh

The next step is to process the mesh to make it ready to be imported into Unity. I started out with a mesh from Poisson Surface Reconstruction. When the mesh is imported into the Blender scene it is located far away from the origin of the scene, actually it is placed at the point (-2397,-22316,-37). I believe this position comes from the LIDAR data. To move the geometry to the center of the scene I first snap the 3D-cursor to the origin, than the Origin of the mesh is moved to the 3D-cursor and then the geometry is moved to its origin. As shown in 4.10 the mesh has a spherical shape, where the top half of the sphere is basically noise. The noise was removed manually by using the Circle Select tool to select the noise and then delete the vertices. Figure 4.12 show the mesh after the removal of the noise. Still the mesh is quite dense and has ~ 620k faces. So I applied the decimate modifier to the mesh. This modifier is very similar to the quadric edge collapse decimation in Meshlab. The mesh was reduced to 10 % of its original face count, and visibly it was not much of a difference as can bee seen in figure 4.13. However the surface still look kind of rough and unsmooth. This was solved by applying the smooth modifier with factor 1 on the mesh. The modifier smooths the angle between adjacent faces in the mesh. In other words it smooths the mesh without subdividing it, and the number of vertices stays the same. The result from the smoothing can be seen in figure 4.14. By now the hill itself is ready to be exported to Unity. However there still is work to do on the in-run, as it is not detailed enough. Nevertheless the mesh has the profile and dimensions of the in-run and can be used as a reference for building a new in-run. Which is ultimately what I decided to do. I started out with a simple cube. The cube was subdivided so it had a more detailed mesh. Next the ski tracks was created by simply extruding two rows of the cube down in the z-direction. Then the cube was translated to the top of the in-run and rotated so it had the same orientation as the in-run mesh. Next I selected the front of the cube and switched into right orthographic view.

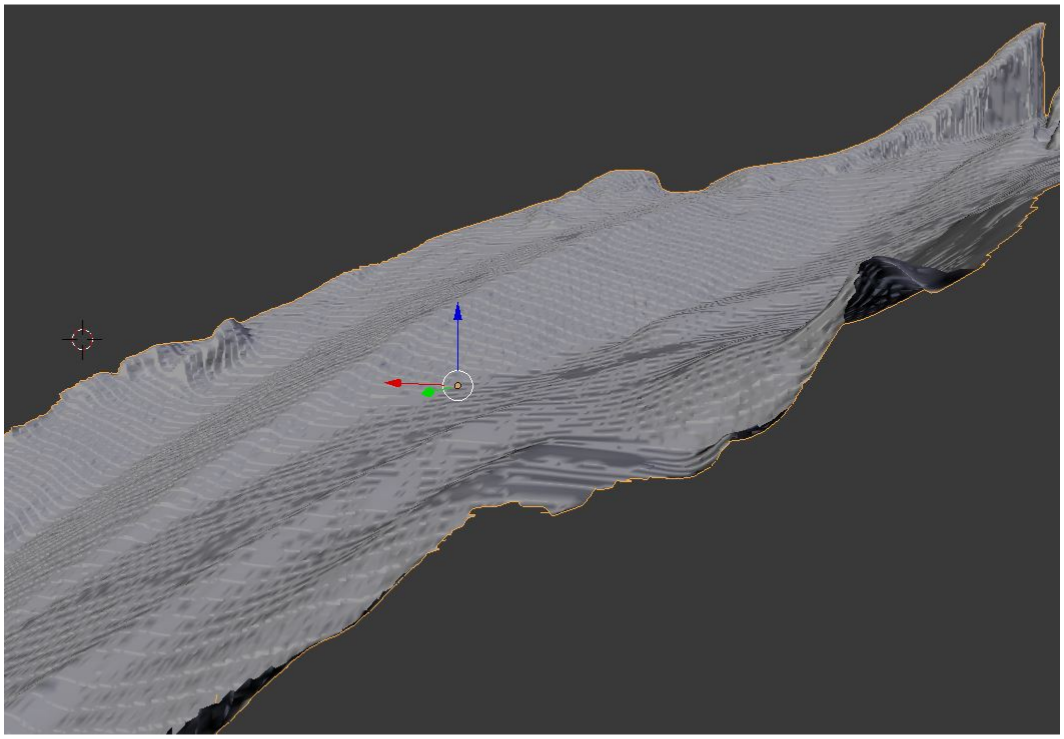


Figure 4.12: This figure shows the mesh where the top half of the sphere is removed

Now it is possible to extrude the cube along the reconstructed in-run. This process is illustrated in figure 4.15. Since we can use the reconstructed mesh as a reference we are not dependent on the hill certificate for creating the in-run. Moreover you do not have the problem with joining the different parts of the in-run, which was a tedious process. In other words this is both easier and faster than the process described in Staurset [2014].

Next task was to add more detail to the in-run by creating the fence and the lamp post. They are too small to be picked up by the LIDAR. So the models has to be made manually. The fence also started out as a cube, which was scaled until it was approximately the size of a plank, 10 cm high and 3 cm wide. It was then translated to the top of the in-run, and rotated so it had the same orientation as the start of the in-run. The front of the cube was then extruded along the in-run seen from right orthographic view in a similar fashion as the in-run. After creating one plank, the array modifier was applied to it. The array modifier generates an array of the chosen element in a chosen axis, with a chosen offset. In the case of the fence the array modifier is applied in the local Z- axis with a relative offset of 0.02. The mirror modifier was then used to mirror the fence on the other side of the in-run. The modifier mirrors a mesh a long a local axis

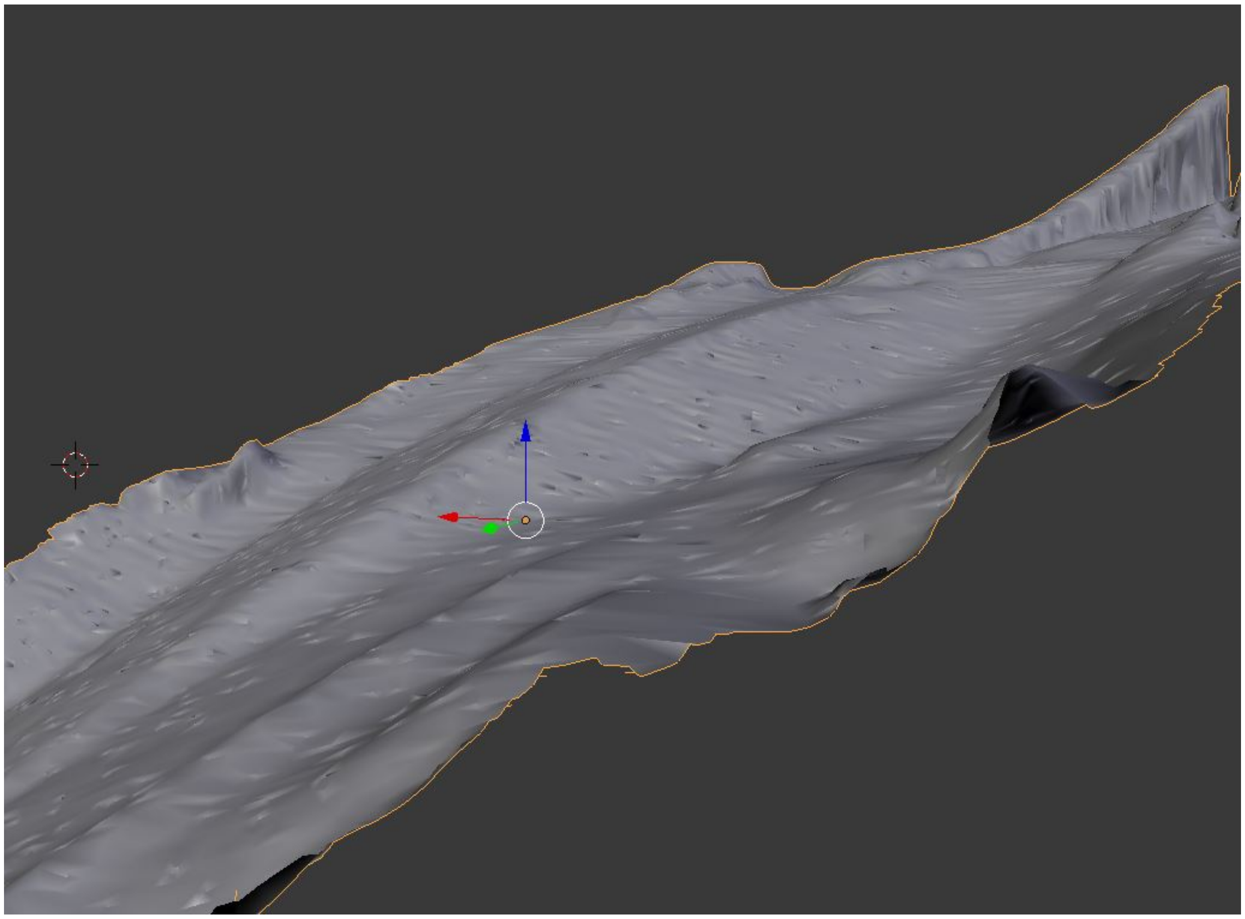


Figure 4.13: In this figure you can see the decimated mesh with only 10% of the original vertices

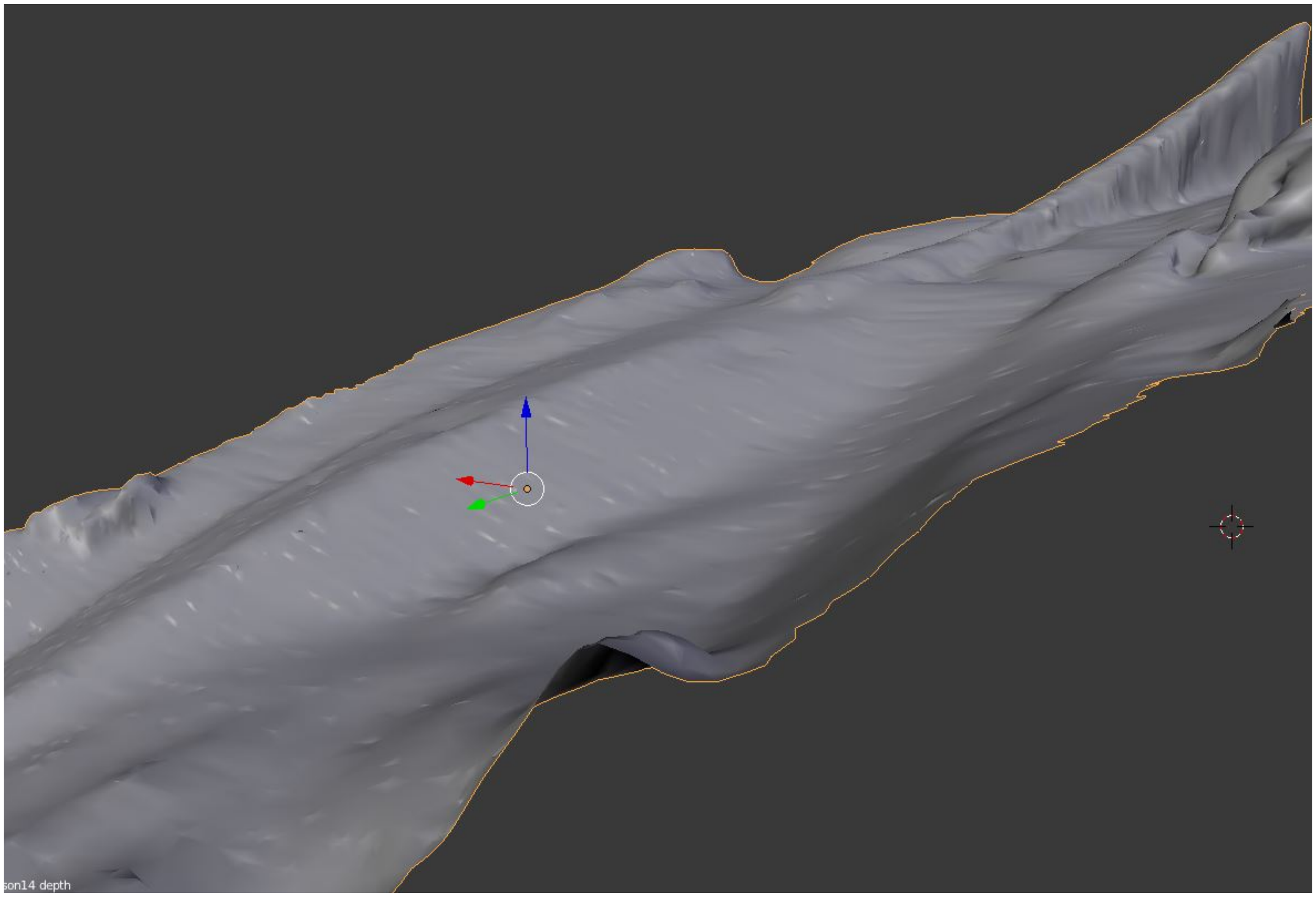


Figure 4.14: The mesh after applying the smooth modifier

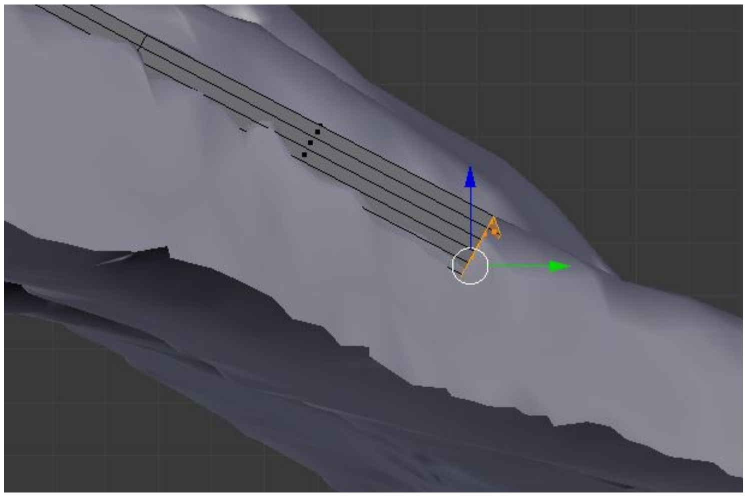


Figure 4.15: Here the process of extruding the in-run is shown.

of a chosen mesh. In this case it was mirrored around the local x-axis of the in-run. Finally a material was created for the fence. The material created is a basic red diffuse Lambertian with a low intensity specular Cook-Torrence component.

There was another approach used to model the lamp post. It started out with a NURBS-path with the shape of a lamp post. Then a small NURBS-circle was used as a bevel object for the NURBS-path. When adding a bevel object for a line, it combines the two objects into a solid mesh. So the result of the beveling is a solid lamp post. Next the lamp head was created using a cube which was scaled, and rotated so it had the dimensions and orientation of a lamp head. Then the bevel modifier was applied to the lamp head. The bevel modifier must not be confused with the bevel object for lines, it is a modifier that smooths the edges of a mesh. The material for the lamp is a gray Lambertian with a more intensive specular Cook-Torrence component. Next the lamp post was duplicated and manually placed so that the in-run had in total 10 lamp posts. To make the lamp post easier to handle, I also created an empty object as a parent for all the lamp post. That makes it possible to treat the lamp post as a single object, and apply basic operations such as rotation, translation to all lamp post at once.

The next thing that was created was the indicator lines. There are in total 5 lines. The first line is a line to assist the player to find the optimal place to jump. The other 4 are placed in the out-run and are indicating the distance of the jump. The first line is placed at 100 meters, and then there is one line every 10 meters They are created as basic planes, which are scaled down to 5x5 cm. Then the array modifier is applied to them with a relative offset. There are 3 different materials for the lines, they are all Lambertian with same intensities but have different colors. The jump indicator is green, and the distance indicators are blue and red. The first 3 lines are blue, and the last red indicating the hill size.

Then the flood lights was created. The pole started out as a circle with 10 cm in diameter. The circle was first filled, so that it is a solid circle. Next it was extruded 8 meters in the z-direction creating an 8 meter high cylinder. Then the top of the light was added. This is basically a cube that is scaled down, rotated and placed on top of the cylinder. The lights itself is also a cube that is scaled down. It is subdivided into a more detailed mesh. Then the center faces of the front is translated into the cube. And the center faces on the opposite side is translated outwards of the cube. Then the subdivision surface modifier is applied to the cube. This modifier is a method

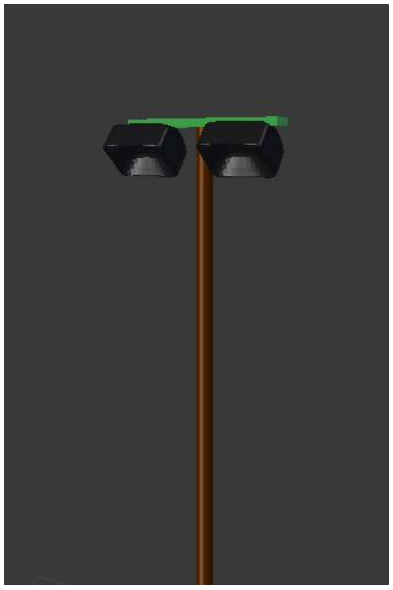


Figure 4.16: This figure shows the model of the flood light

of subdividing the faces of the mesh, giving it a complex smooth appearance with relatively few vertices. Then the light was duplicated and attached to the top of the light. The flood light can be seen in figure 4.16. Then the flood lights was duplicated and manually placed at a regular interval down the hill. The flood lights was probably not the most visible element in the scene. But it helps providing more reference points for the viewer while in the air.

Lastly I created the fence in the out-run. As always it started out as a cube, which was scaled, and translated to the top of the out-run. The cube was then extruded in a similar way as the fence of the out-run. It was very important that the fence followed the ground in a precise manner. Because it was easy for the player to see if this was not the case. The fence is also supposed to have a circular white sign attached to it, measuring the distance of the jump. This sign was modeled by a circle which was filled and extruded the same way as the flood light. The circle also has a text attached to it as can be seen in figure 4.18. This sign was to be duplicated at a regular interval along the fence. My first thought was to apply the array modifier on the sign. But this did not work as it was not possible to find an offset that made the array of signs follow the fence. So in my first approach I placed the signs manually by duplicating the sign, and place it on a tentative regular interval down the fence. The problem with this approach was that the player could perceive that the signs was not placed at a regular distance, so I had to do better. In my next approach I decided to combine the array modifier with the curve modifier. The curve

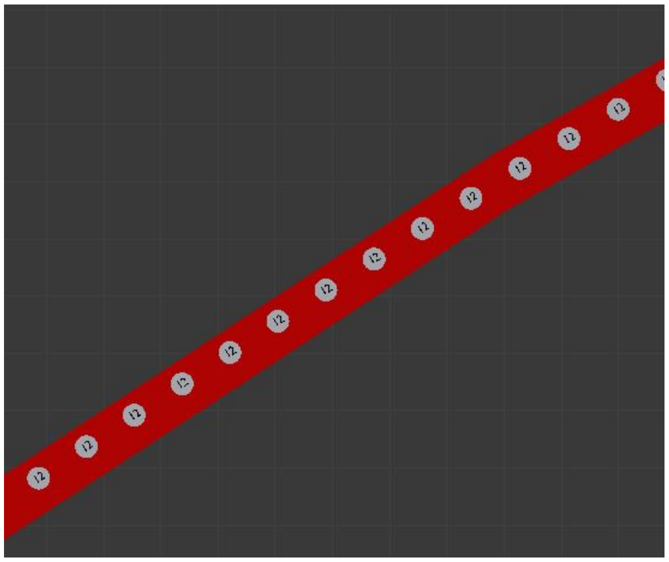


Figure 4.17: This shows a section of the fence in the out-run

modifier deforms the chosen mesh along a line. First a NURBS-path was created. Then it was rotated so it followed the direction of the fence, and next it was extended so it followed the center of the fence the whole way down. Then the modifiers was applied to the sign and the text. There seemed to be a problem with applying modifiers to both object at the same time, so they had to be applied to the text and the sign individually. First the array modifier was applied to the sign with a constant offset of -5.0000 in the x-axis. Then the curve modifier was applied to the sign, and the signs was rotated and translated so that it followed the fence closely. Then the same modifiers was applied to the text object. However the constant offset had to be tweaked a little bit. This is because the text object is just a little bit smaller than the sign. So the final constant offset for the text was 5.0940. In figure 4.17 you can see how the fence ended up looking. It is also worth mentioning that all the text objects have the same text. This is due to the array modifier being applied to the text object, which makes all the text objects a copy of the original text object, so they cant have individual texts. A possible solution to this would be to manually add a text object to each sign. Which would be a very time consuming process. Also the player is not able to read the number of the signs because of the distance and the speed that the player moves with. Hence I decided that it was acceptable that the text was the same for every sign.

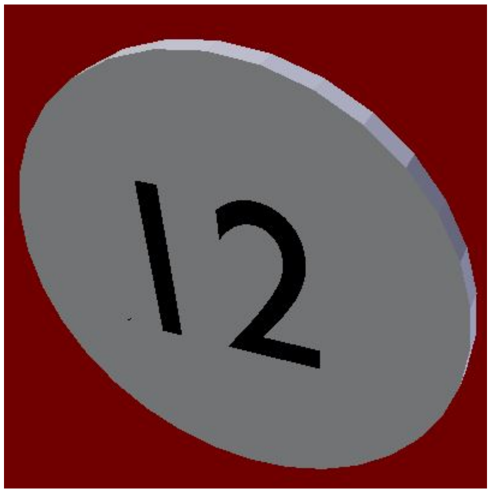


Figure 4.18: This figure shows the sign for measuring distance attached to the out-run fence.

Chapter 5

Implementation in Unity

In this chapter the implementation in Unity will be described thoroughly.

5.1 The player object

The project is a continuation of the project in Staurset [2014], so I used the same Player GameObject as a starting point. This is an extension of the standard Unity First Person Controller. There has been done several improvements and extensions to the original object. In the following section these changes will be explained.

5.1.1 Head rotation

In the original version there was a problem that the camera was rotated around the x-axis when the player was in the air. This made it so that the player had to look upward when flying down the hill. This is because the camera is a child of the player object, and in Unity every transform applied to the parent is also applied to every children of that object. E.g if the player object moves 10 units along the x-axis the camera will also move 10 units in the same direction. In the same way when the player is rotated along the x-axis when flying the camera would rotate the same amount. This is undesirable, hence we need to find a way decouple the rotation of the players body, and the camera. One possible solution would be remove the parent relationship between the camera and the player. But then the camera has to have another way of following the player. This would could be done with a script which updates the cameras position for every frame. One problem with this approach is that the camera no longer has access to broadcasted messages within the player object. Another possible solution is to add a new object as parent of the camera and child of the Player object. This new objects only task is to decouple the rotation of the player object with the camera. It has a script attached to it called headManager. This script only has one function: Update. Update is called for every frame, and in this function it resets the heads orientation. By doing this the camera can now rotate independent on player rotation, and it is still a child of the player, so it can receive broadcasts within the player object.

5.1.2 Body orientation

As mentioned in section 3.2 the jumpers angle of attack is an important factor when calculating the drag and lift forces acting on the jumper while he is in the air. The angle of attack is the angle between the velocity and the body of the ski jumper. Algorithm 2 shows pseudo code for how the body orientation was implemented. In this implementation the ski jumper will rotate as velocity changes. As an example, lets say that the angle of attack is 10 °. At the start of the jump the velocity is about 5 °on the x-axis. Then the skiers body will be 15 °on the x-axis. Then the skier will rotate with the velocity, and at the ending of the jump the velocity is about -45 °on the x-axis. This will result in the skier being -35 °on the x-axis. So the body of the skier is rotating 50 degrees on the x-axis during the jump. In reality the skiers body angle on the x-axis does not change much while he is in the air. So I needed to find a new approach on the rotation of the players body.

Algorithm 2 Pseudocode for the original body orientation of the ski jumper

```
1: procedure PLAYERINAIR(VELOCITY)
2:     newRotation ← Vector(velocity.eulerAngle.x + angleOfAttack, velocity.eulerAngle.y, velocity.eulerAngle.z)
3:     player.rotation ← newRotation
```

In the new approach I do not store the angle of attack, but the jumper's body angle on the x-axis. Then the player can have a constant angle on the x-axis while he is in the air.That leads to the new algorithm 3. The reason that 90 is added to the x value is so that the body is aligned with the x-axis before subtracting the body angle. As long as the body angle is unchanged the skiers body rotation will now remain constant throughout the the jump.

Algorithm 3 New algorithm for handling body rotation.

```
1: procedure PLAYERINAIR(VELOCITY)
2:     newRotation ← Vector(90 - BodyAngle, 270,0 )
3:     player.rotation ← newRotation
```

Since we no longer are storing the angle of attack, we have to be able to calculate it. We have the velocity of the skier, and his body's angle on the x-axis. The first thought was to get the vector of the skiers orientation and use the dot product of the orientation and velocity to calculate the angle between them. However the orientation in Unity is represented using Quaternions, and I had problems with getting a direction vector from the quaternion. Algorithm 4 solves the problem. The algorithm takes the velocity and the body angle as arguments. It then finds the velocity's angle on the x-axis. So then we have both orientations angle on the x-axis, and we want to find the angle between them. There are four different cases:

1. The velocity angle is positive, and the body angle is positive: The angle between them is bodyAngle - velocityAngle
2. The velocity angle is negative, and the body angle is positive: The angle between them is bodyAngle - velocityAngle
3. The velocity angle is positive, and the body angle is negative: The angle between them is bodyAngle - velocityAngle
4. The velocity angle is negative, and the body angle is negative: The angle between them is bodyAngle - velocityAngle

So in all cases the angle between them can be expressed as bodyAngle - velocityAngle.

Algorithm 4 Calculating the angle of attack

```
1: procedure CALCULATEANGLEOFATTACK(VELOCITY, BODYANGLE)
2:     velocityAngle ← getVelocityAngle(velocity)
3:     angleOfAttack ← bodyAngle - velocityAngle return angleOfAttack
```

The calculation of the velocityAngle is shown in Algorithm 5. The algorithm uses the built in Unity function Vector3.Angle, which returns the absolute angle between the two vectors. In this calculation we also need to be able to find negative angles, so I use the cross product of the vectors to determine the polarity of the angle by checking the z-value of the cross product. If it is positive the angle is negative. The negative x-axis is used because the models in the scene are oriented so that "forward" is in the negative x-axis.

Algorithm 5 Calculating the velocity angle

```
1: procedure CalculateVelocityAngle(velocity)
2:     $angle \leftarrow Vector3.Angle(Vector3(-1.0, 0), velocity)$
3:     $cross \leftarrow Vector3.Cross(Vector3(-1, 0, 0), velocity))$
4:     if cross.z > 0 then
5:         $angle \leftarrow -angle$
       return angle
```

An other problem in the original prototype was that the body of the skier was rotated immediately after he jumped, and rotated back when he landed. People who tested it claimed thiss sudden rotation made it feel less realistic. The solution for this was spherical linear interpolation, or slerp as it is often called. As mentioned earlier Unity uses quaternions to represent rotations. Quaternions are based on complex numbers and can be thought of as a vector augmented by a real number, or a a point on a 4D unit sphere. So when interpolating between two quaternions you are basically moving around on this 4D sphere. We want equal incrementation along the arc connecting the two quaternions on the spherical surface. Equation 5.1 shows the equation for the spherical linear interpolations between two quaternions where q_1 is the starting quaternion, q_2 is the ending quaternion, and u is the interpolation parameter (a number between 0 and 1). Algorithm 6 shows the pseudo code for how the skiers body rotation is slerped in the transition between the jump and flying phase. The fromQuaternion has to remain the same during the interpolation, or the interpolation will be inconsistent. That is the reason we have the conditional check in line 5. If the quaternion is set we increment the slerpClock. The toQuaternion is allowed to change if the bodyAngle is changed. This is because that the function is responsible for the body orientation until the skier starts the landing. And if the bodyAngle changes, so does the rotation of the body. However it will only be interpolated once, when the interpolation parameter is greater than 1.0 the orientation will automatically be set to the toQuaternion.

$$slerp(q_1, q_2, u) = \frac{sin[(1-u)\theta]}{sin\theta} q_1 + \frac{sin[u\theta]}{sin\theta} q_2 \tag{5.1}$$

Algorithm 6 Spherical linear interpolation to air

```
1:  $hasSetSlerpToAir \leftarrow False$
2:  $rotationSpeed \leftarrow 2.6$
3:  $slerpClock \leftarrow 0.0$
4:  procedure SLERPROTATIONTOAIR()
5:      if not hasSetSlerpToAir then
6:          $fromQuaternion \leftarrow Player.rotation$
7:          $hasSetSlerpToAir \leftarrow True$
8:      else
9:          $slerpClock \leftarrow slerpClock + \Delta time * rotationSpeed$
10:     $toQuaternion \leftarrow Quaternion.Euler(90 - bodyAngle, 270, 0)$
11:     $player.rotation \leftarrow slerp(fromQuaternion, toQuaternion, slerpClock)$
```

The landing also needs a similar function to handle the rotation when transitioning from flying to landing. The pseudo code for the landing algorithm is shown in Algorithm 7.The first thing the algorithm checks is if the player has fallen. If he has fallen the algorithm should not do any thing, because that is handled by another script. An other difference here is that the bodyAngle is updated according to the rotation, so that if the player lands too early it will impact how far he jumps. The change in rotation is calculated from the change in the euler angles in the x-axis. This can be done because that we know that there are no rotation in the y- and z-axis.

Algorithm 7 Spherical linear interpolation from air to landing

```
1:  $hasSetSlerpToLand \leftarrow False$
2:  $rotationSpeed \leftarrow 2.0$
3:  $slerpClock \leftarrow 0.0$
4:  $toQuaternion \leftarrow Quaternion.Euler(0, 270, 0)$
5:  procedure SLERPROTATIONTOLAND
6:      if not playerHasFallen then
7:          if not hasSetSlerpToLand then
8:              $fromQuaternion \leftarrow Player.rotation$
9:              $hasSetSlerpToLand \leftarrow True$
10:         else
11:             $slerpClock \leftarrow slerpClock + \Delta time * rotationSpeed$
12:         $previousAngle \leftarrow player.Rotation.eulerAngles.x$
13:         $player.rotation \leftarrow slerp(fromQuaternion, toQuaternion, slerpClock)$
14:         $newAngle \leftarrow player.rotation.eulerAngles.x$
15:         $bodyAngle \leftarrow bodyAngle + (newAngle - previousAngle)$
```

So this leads to the simplified ApplyGravityJumping function shown in Algorithm 8. The doLanding variable is set by a button listener in the FPSInputController, which broadcasts to the player. The ApplyGravityFluidForce function is similar as discussed in section 3.2. The base jump height decides the vertical starting speed of the jump, which is deduced from the base height and and gravity.

Algorithm 8 Apply gravity and fluid force

```
1:  $jumpingDirection \leftarrow Vector3.Up$
2:  procedure ApplyGravityAndFluidForce(velocity)
3:      if Grounded then
4:          if Jump then
5:              $velocity.y \leftarrow 0$                    ▷ cancel vertical velocity first
6:              $velocity \leftarrow velocity + jumpingDirection * calculateJumpVerticalSpeed(JumpHeight)$
7:      else
8:          $velocity \leftarrow ApplyGravityAndFluidForce(velocity)$          ▷ Player is in the air
9:          if not doLanding then $slerpRotationToAir()$
10:         else if DoLanding then
11:             $slerpRotationToLanding()$
```

The update function is similar to the one discussed in section 3.3 but there are some subtle differences. Both the in-run and the out-run has their own mesh colliders keeping track of when the player is in contact with the meshes. ApplyInrunVelocityChange will be called as long as the player is touching these colliders. To prevent the player from going on forever I added a deceleration cube. When the player passes the cube the skier starts to decelerate. The cube is just a trigger box collider with a script attached to it that broadcasts when the player enters through it. Since the coordination system is swapped and the player is moving in the negative x-direction we are adding to velocity.x

Algorithm 9 changes to the update function

```
1:  procedure UpdateFunction()
2:      if PlayerHasEnteredDecelerationCube then
3:          $velocity.x \leftarrow Min(0, velocity.x + 0.7)$
4:      else if $PlayerInInrunOrPlayerInOutrun$ then
5:          $velocity \leftarrow applyInrunVelocityChange(velocity)$
        return
```

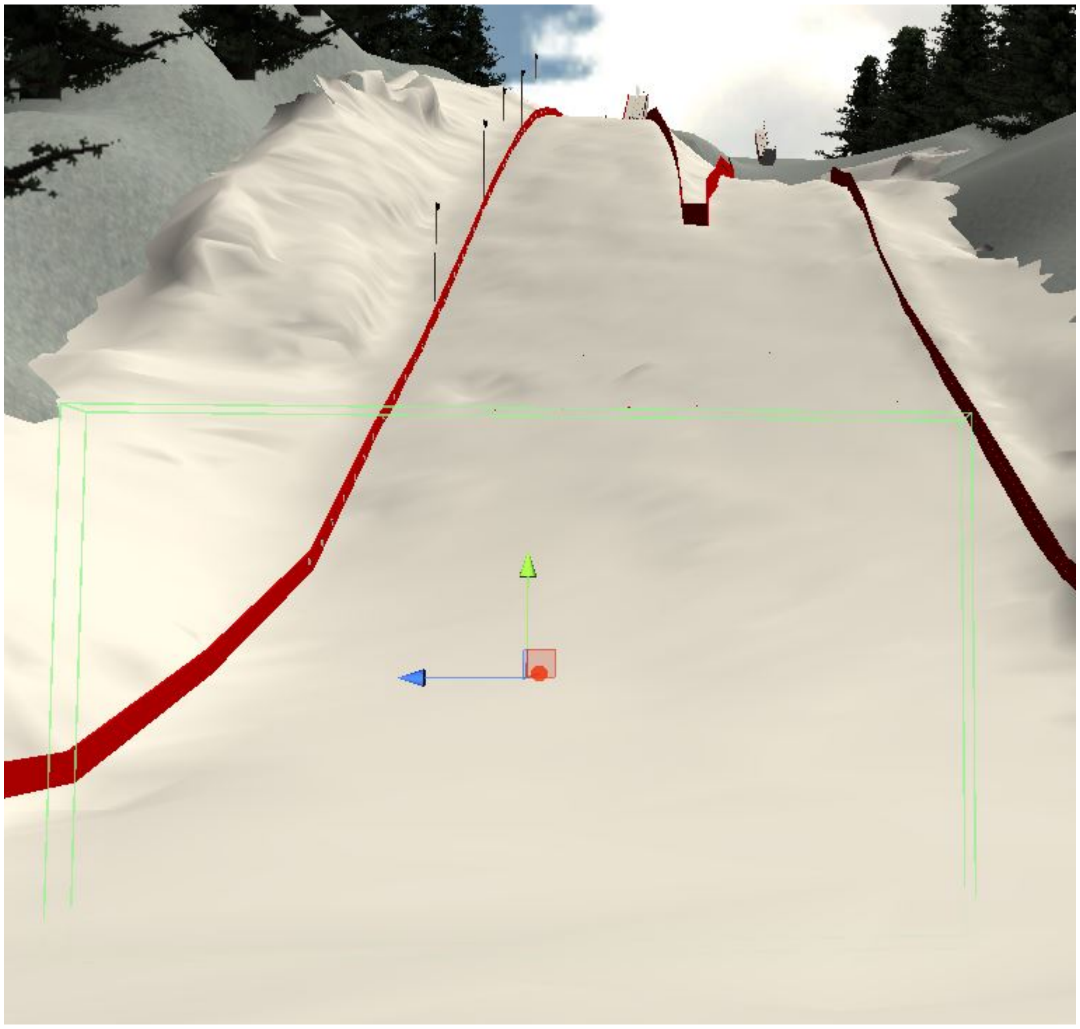


Figure 5.1: This figure shows the decelerationcube.

5.2 Jumping

There was also done some changes to how the jumping was done. Initially it was implemented so that the jump was the same regardless of position. But in reality this changes with how well the skier is able to time the jump. So the plan was to add differentiated jumping, so that the force the jump generated depended on how well timed it is. I solved this by creating 8 different cubes, which should act as reference points. These cubes were placed on the edge of the take-off ramp as shown in figure, and each of the cubes has a script. This is a simple script with only one function called calculateDistance. It takes the position of the skier as argument and returns the distance from the cube and the player position, using the built in Vector3.Distance. I also added an empty object called JumpingCubeParent which is parent to the jumping cubes. JumpingCubeParent has a script called JumpingManager. This script gets called when the player jumps, it iterates through its children jumping cubes, and calls the calculateDistance method to find the closest cube. It then returns the jumping multiplier of the closest cube to the player.

Figure 5.3 shows what is happening when the player is pressing the jump button. First the FPSInput controller sets the jump boolean to true in the character motor. This is done directly as the input controller has direct access to the variables in the character motor. Then the next time the update function is called in the character motor this Boolean is true. So when ApplyGravityAndJumping is called, the CalculateJumpVerticalSpeed function gets called. This function calls the JumpManager's GetJumpMultiplier function. The jumpManager then iterates through all the children to find the closest JumpingCube and returns the proper jumpMultiplier to CalculateJumpVerticalSpeed which in turn updates the velocity accordingly.

The player does not get instant feedback on how well timed timed the jump was. The reason for this that the player should not be distracted from the rest of the jump, he still have to concentrate on finding the correct angle of attack and landing. However the player is able to review the jump after the jump is finished. To achieve this I created a new Unity scene called JumpEvaluation. This scene is a copy of the ski jumping scene, with some modifications. The player object is deleted, and a regular camera is added. This camera is zoomed in on the take-off ramp. 6 cubes are placed on the in-run representing the different jumping cubes, and they have a color code symbolizing the jump multiplier. Furthermore a yellow cube is placed at the location of the last

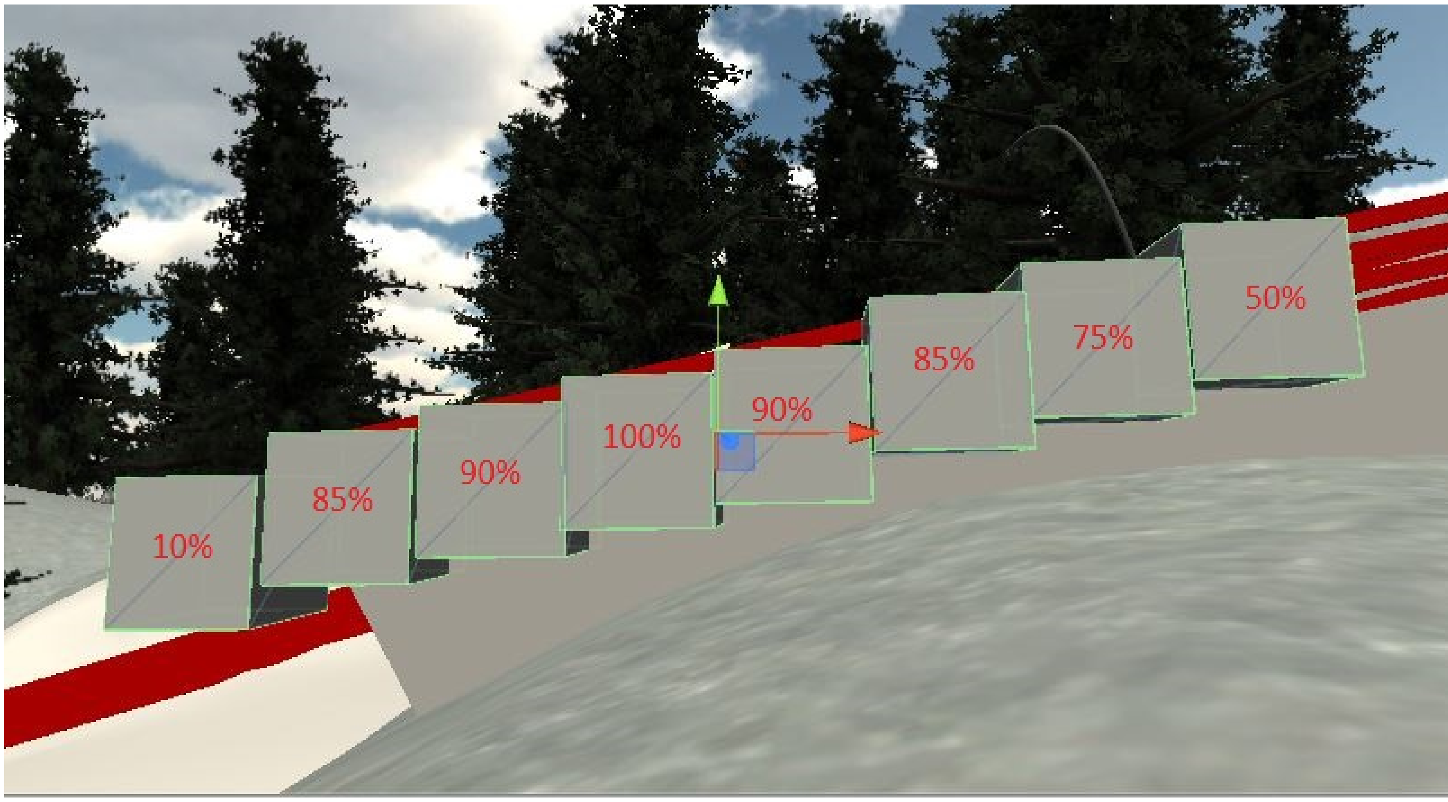


Figure 5.2: This figure shows the Jumping cubes.

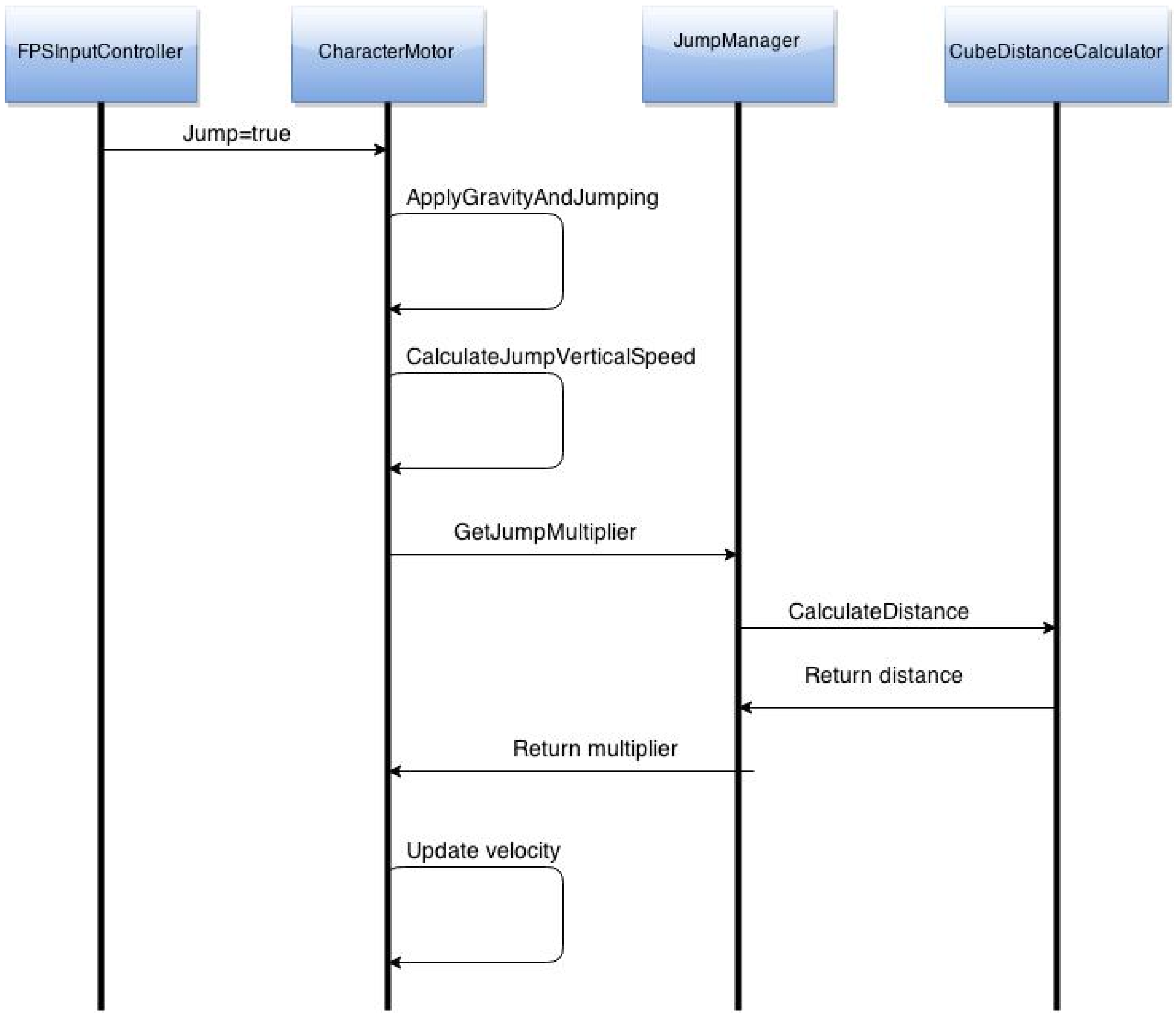


Figure 5.3: This diagram shows the how the scripts interacts with each other during a jump..

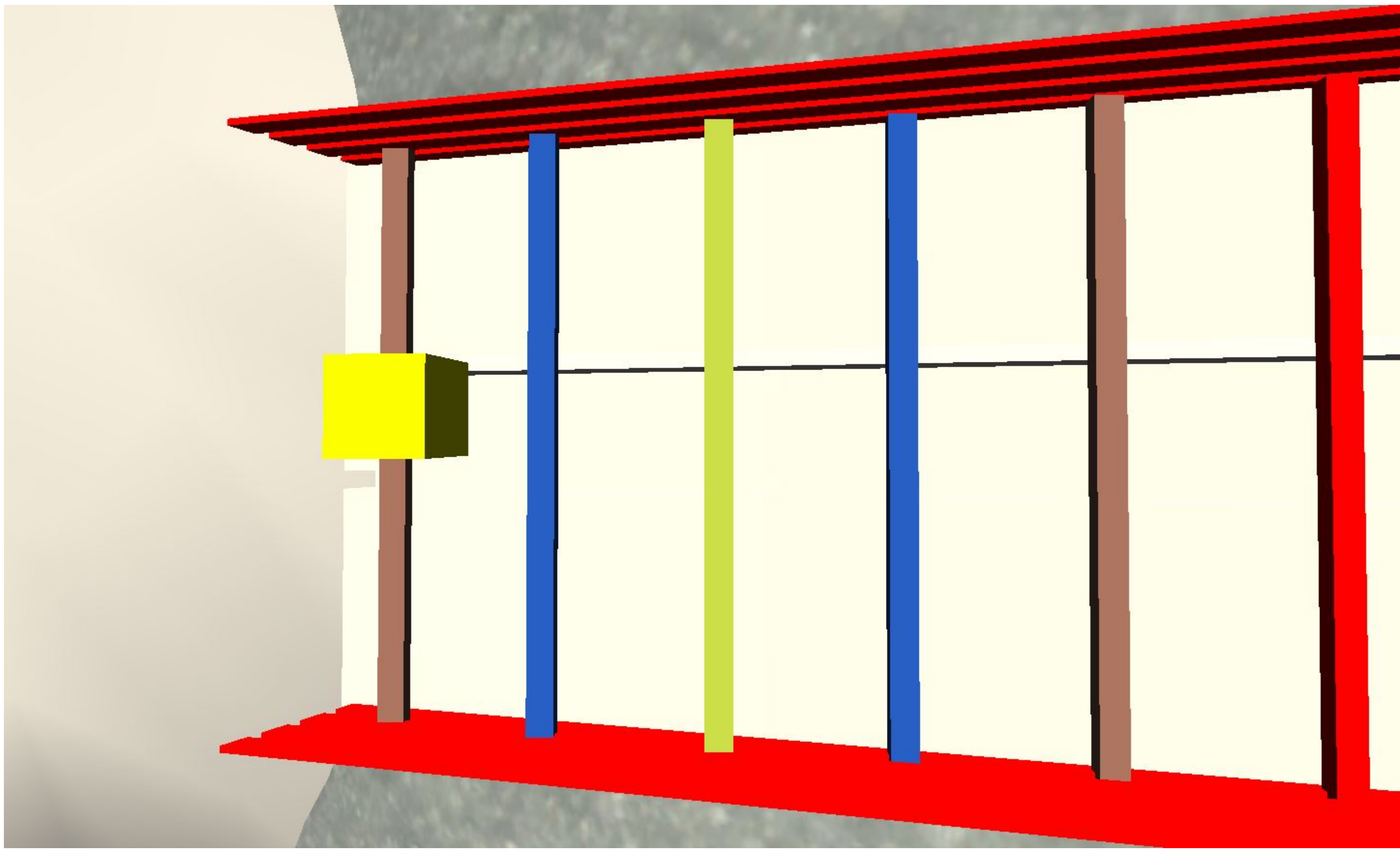


Figure 5.4: The evaluation scene.

jump the player performed. When Jump Manager calculates the jumping accuracy it saves the position of the player in PlayerPrefs, which is a dictionary where values can be stored between game sessions. The yellow cube then has a script attached that reads the position, and places the cube accordingly. The JumpEvaluation scene is shown in figure 5.4

5.3 Measuring length

Next I needed to a way to measure the length of the jump. This proved to be a non trivial task, as Unity has no built in functions for measuring distance. The length of a ski jump is measured along the ground, and not the distance the skier moves in the air. My solution to this was to manually place 1 meter long cubes along the hill. It is important that the cubes are rotated so they follow the ground, because else the measure the distance incorrectly. The initial plan was to

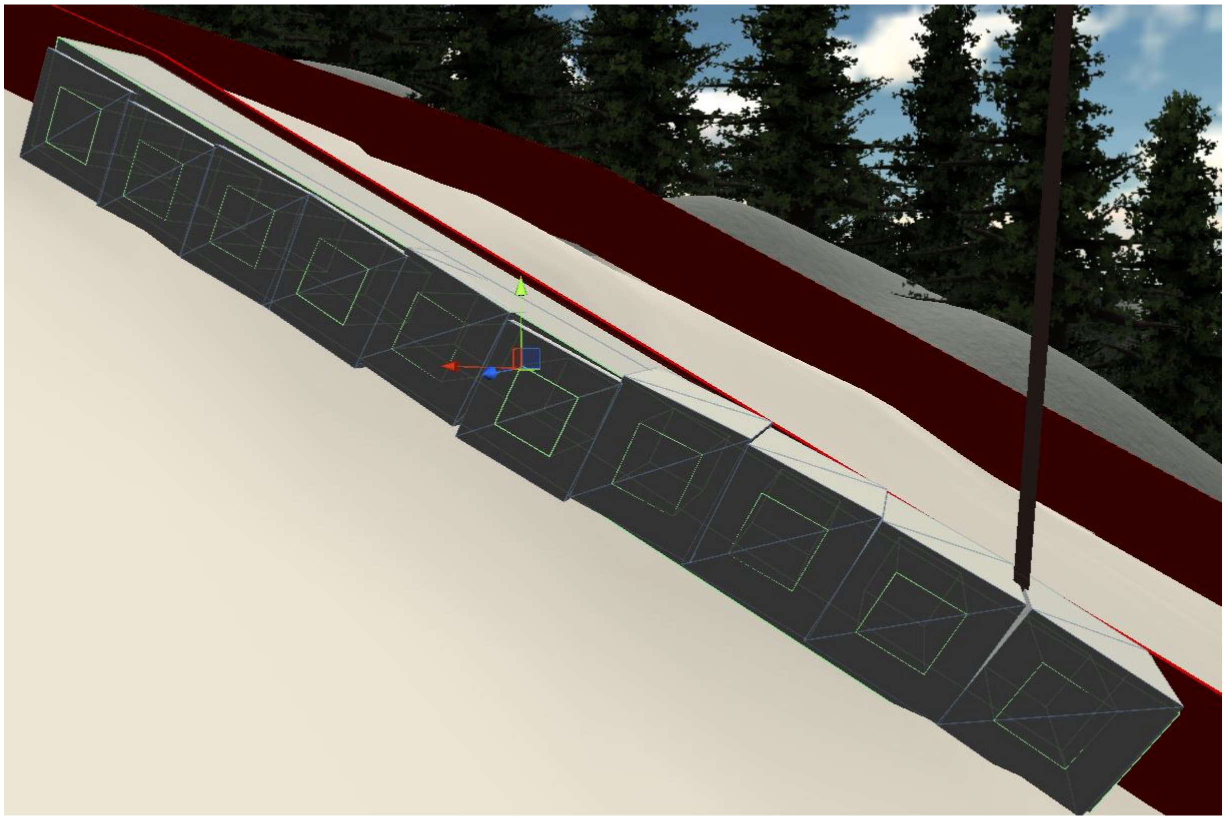


Figure 5.5: A group of 10 distance calculators

let the cubes have a similar script as the jumping cubes measuring for measuring the distance, and iterating through all of them to find the closest. This would work,but would be somewhat computational expensive as the operation would need to be 150 times. So I implemented a method inspired by binary search. I organized the meter cubes into groups of 10. Each group had a 10 meter long parent cube as shown in figure 5.5. All the cubes are child of the out-run game object, which has a script called CalculateJumpDistance. When the player collides with the trigger mesh collider of the in-run, the position of the player gets broadcasted to this script, and CalculateJumpDistance gets called, which is shown in algorithm10. The function iterates through all the 10-meter long cubes to find the closest cube. Next the closest 10 meter cube is responsible for finding the closest meter cube. It does this by iterating over them in a similar fashion as in algorithm 10. When the distance is calculated this is broadcasted in the player object. Figure 5.6 shows how the different scripts interacts with each other.

After the distance is broadcasted it is received in a script called HighscoreManager. HighScoreManager is responsible for managing the high score list and notifying the GUI about the

Algorithm 10 Calculate Jump Distance

```
1: procedure CALCULATEJUMPDISTANCE(PLAYERPOSITION)
2:     $minDistance \leftarrow 99999$
3:     for cube in children do                                  ▷ Find closest 10-meter cube
4:         $temp \leftarrow cube.CalculateDistance(landPos)$
5:         if $minDistance > temp$ then
6:             $minDistance \leftarrow temp$
7:             $minCube \leftarrow cube$
8:     $distance \leftarrow minCube.FindClosestMeterCube()$
9:     $BroadCast("JumpDistance", distance)$
```

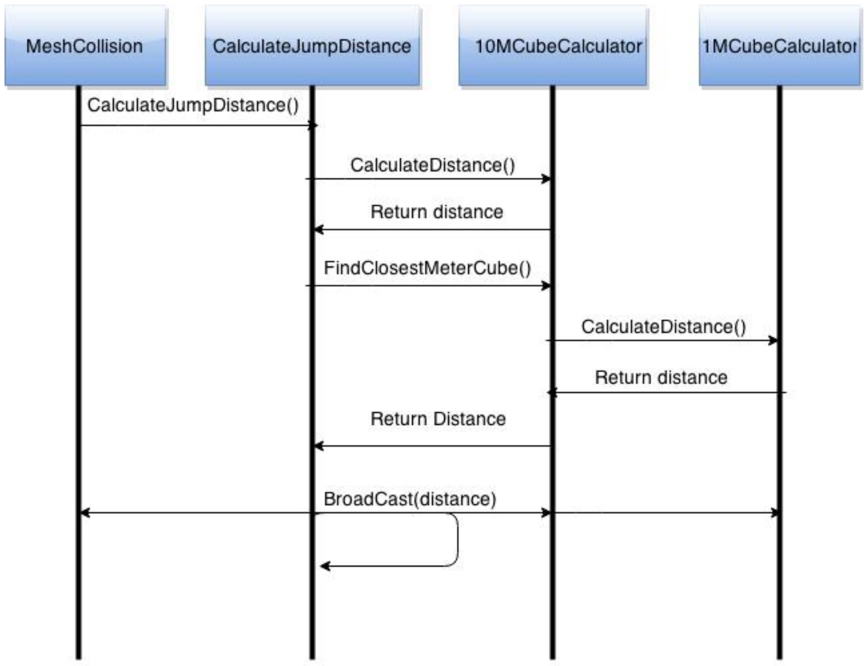


Figure 5.6: Diagram of script interaction for calculating distance of the jump

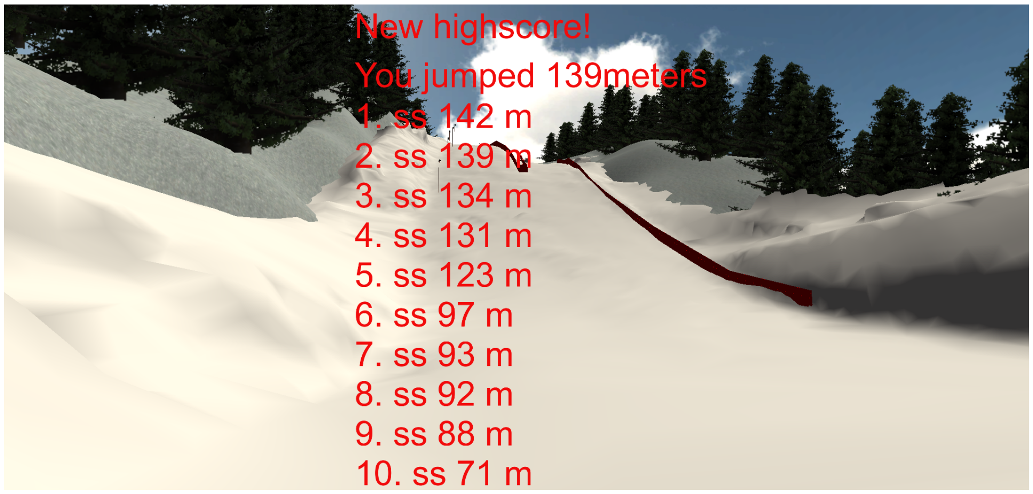


Figure 5.7: The high score list.

jump length. The high score is being saved in the PlayerPrefs dictionary, so its persistent between game sessions. The main function in the script is called AddScore, and takes the distance as a parameter. It first checks if the player has fallen. If he fell then the score won't be added to high score list. Next the algorithm updates the high score list with the new score. The Highscore-Manager broadcasts the updated high score list to the GUITextManager which is responsible for updating the GUI.

The GUIManager is attached to a Empty game object that is parent to the GUI objects which is a Unity Text mesh. I wanted the application to be compatible with both the Oculus Rift and regular 2D monitors. For this reason the player object has two camera rigs attached to it the standard 2D-camera, and the Oculus Rift compatible OVR-rig. Only one of the cameras should be enabled when running. The GUI objects should be attached to the cameras so that the text remains in the same position even if the camera rotates. Hence both of the cameras got their own GUI components with the same scripts attached to them, and since they are child of the cameras they will be disabled when their parent are disabled. Figure 5.7 shows how the high score looks like.

5.4 Falling

The player also has a dedicated script for handling when the player has fallen. The implementation of this is not based on reality, but is intended to be a game element, forcing the player to land early enough. The landing algorithm of the player is shown in algorithm 7 and it rotates the body of the skier upwards. The fall scripts gets called when the player collides with the trigger collider of the out-run. It checks the angle of the body of the skier, and if its less than 40 degrees on the x-axis, the player has fallen. This is then broadcasted to the HighScoreManager which makes sure that the score is not added to the high score list. Furthermore the player's body is rotated so it is flat on the ground. This rotation is done in the same way as in the slerp rotation to air function explained in Algorithm 6 The initial plan was to have the body bounce up and down a few times, but this felt really uncomfortable when wearing the Oculus Rift, so I decided that it was enough to let the player just slide horizontally on the ground. The fact that the player has fallen is also broadcasted to the skis, which just stop following the player if he has fallen.

5.5 Ski

The skis only has one script attached to them, called follow player. This script was initially intended to handle the decoupling of the skis and the player object as proposed for solving the camera rotation in section 5.1.1. But it ended up containing all the code handling the ski's movement. The update function is the most important function in the script and is dependent on the state that the player is in. The algorithm is shown in Algorithm 11. The auxiliary functions are updating the position and rotation of the skis according to the players state. They are very similar to the algorithms for slerping the player rotation. There was a problem with the ski going through the in-run and out-run mesh as shown in figure 5.8. I tried to solve this by adding a collider to the ski's but this was not solving the problem. So then I decided to create own slerping functions for both the in-run and the out-run. These functions are triggered by cube colliders similar to the deceleration cube. Furthermore in the SkiToVStylePosition function I wanted the ski's to be moved according to the ski jumpers rotation on the x-axis. I.e. that the ski's was closer to the skier if he was lying flat in the air, and further away if he was vertical. This was done by an auxiliary function that scaled the skis distance from the skiers body from 0.2m to 0.9m dependent on his rotation on said axis.

Algorithm 11 Update function in follow player

```
1: procedure UPDATE()
2:     if $PlayerIsGrounded$ then
3:         if $NotplayerHasFallen$ then
4:             $DoStraightSkiPosition()$
5:         if $SlerpHillCurve$ then
6:             $DoSlerpHillCurve()$
7:         else if $SlerpInrun$ then
8:             $DoSlerpInrun()$
9:     else                                        ▷ Player is in the air
10:        if $DoLanding$ then
11:            $SlerpToLand()$
12:        else
13:            $SkiToVStylePosition()$
```

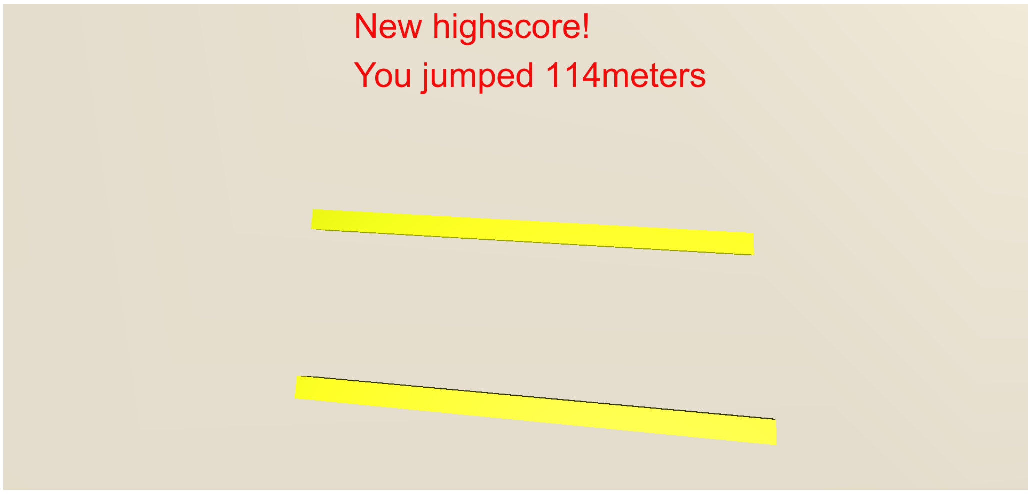
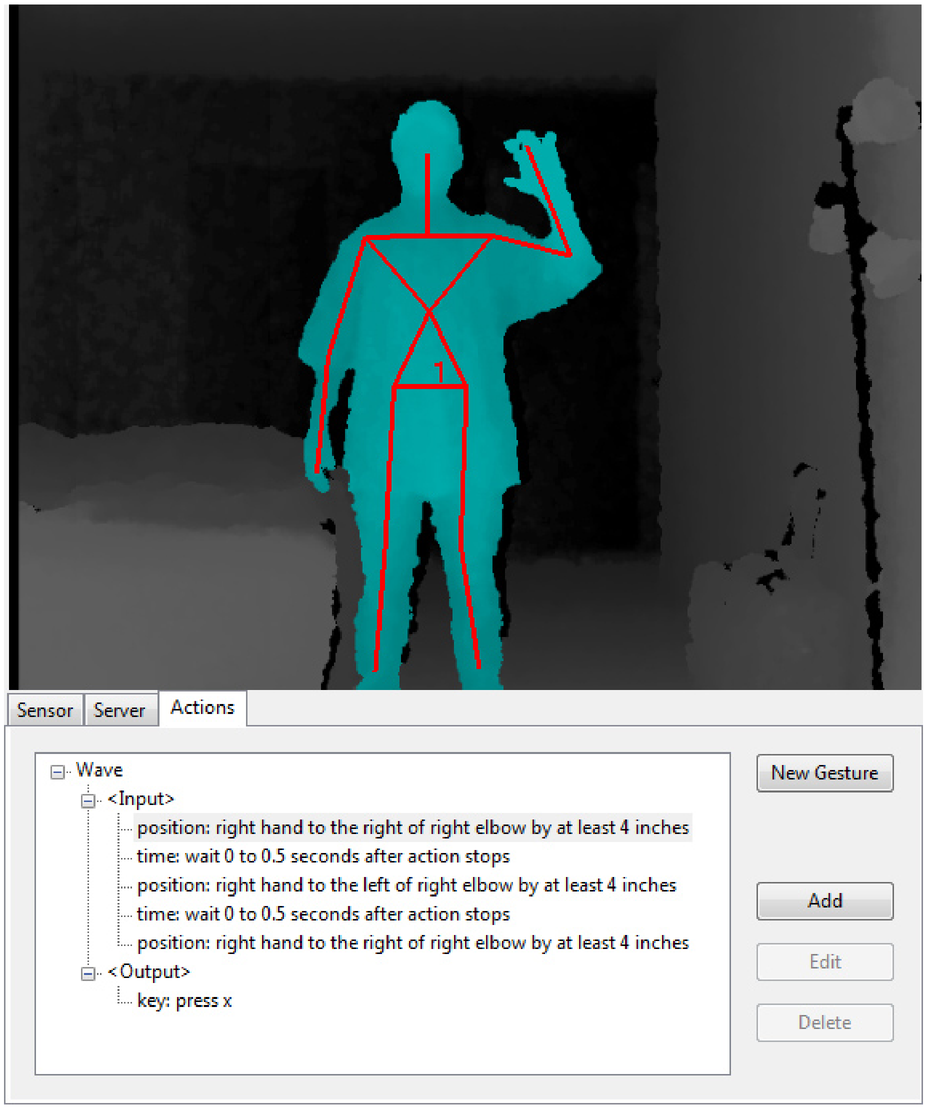


Figure 5.8: The skis are going through the ground.

5.6 Kinect

The next step was to integrate Kinect with the application. Kinect is a motion sensing device created by Microsoft. It can be integrated with Unity using a software called FAAST(Flexible Axtion and Articulated Skeleton Toolkit). FAAST is a middleware used in integration of full-body control games. It contains a customisable VRPN (Virtual Reality Peripheral Network)-server. VRPN is a device independent framework for accessing virtual reality peripherals in VR applications. FAAST tracks the user and creates a skeleton made up of 24 joint transformations. The plan was to use this data to measure the angle of the upper torso and the horizontal axis as the angle of attack. The skeleton data is streamed over the VRPN server. The VRPN-data is then passed through UIVA(Unity Indie VRPN Adapter) which is another middleware adapting VRPN-data to Unity. UIVA consists of a server side and a client side, where the client resides in the Unity game engine. The server side is a VRPN client talking to the VRPN server of FAAST. Unfortunately there was a problem with the UIVA server, as I was not able to get it to run. I contacted the creator of UIVA, but did not receive any answers from him.

An other way to integrate Kinect with Unity is to use Zigfu. Zigfu is a third party software which integrates Unity and Kinect. Zigfu has a large and well documented API, and some sample scenes which makes it fast to get started with development. Zigfu also provides a skeleton with 24 joint transformations. I did some testing with the skeleton in a provided scene called BlockMan3rdPerson. In the skeleton update function I extracted the vector between the torso- and the head-joint, and calculated the vectors angle on the x-axis. This seemed to work fine as long as the player was standing upright, but when the player was leaning forward the skeleton got deformed, and due to this the angle was of course wrong. This test was performed with the Player facing the Kinect, I also tried having the player standing so that the Kinect was tracking the player from the side. However this did not work, as it had trouble tracking the skeleton from the side. I suspect this is because the Zigfu skeletal tracker is using Microsoft's tracker which is model based, i.e it is looking for certain shapes and then extrapolates the estimated skeleton pose from that. So when the player are leaning forward the tracker does not find the shapes it is looking for and the skeleton ends up being deformed. A possible solution to the problem could be to create a new tracker that finds the contour of the player and fits a medial axis through the



```
Wave
  <Input>
    position: right hand to the right of right elbow by at least 4 inches
    time: wait 0 to 0.5 seconds after action stops
    position: right hand to the left of right elbow by at least 4 inches
    time: wait 0 to 0.5 seconds after action stops
    position: right hand to the right of right elbow by at least 4 inches
  <Output>
    key: press x
```

Figure 5.9: This figure shows the reconstructed skeleton in FAAST.

contour. That would make it possible to find the angle between the medial axis and the ground plane.

5.7 Wii Remote

As the Kinect did not work, I had to look for other possibilities for measuring the angle of attack. The solution was the Wii remote, also known as the Wiimote. The Wiimote is the primary controller for the Nintendo Wii gaming console. It has both an accelerometer and an infrared sensor. There is a Unity plugin called UniWii which lets you integrate the Wiimote with Unity.

UniWii supports use of the accelerometer, the IR sensor and all of the buttons on the Wiimote. It also allows you to connect up to 16 Wiimotes to you application. The plan is to use the accelerometer to get the pitch(y-axis rotation), and use it as angle of attack. The Wiimote is then attached to the players torso using a belt. This was done in a script called WiiRotator. The script is shown in algorithm 12. It first checks if the application is using the Wiimote. This is done so that the system can work with different controllers. The angle of attack can be changed from the keyboard, a playstation controller and the Wiimote. The WiRotator are setting two different angles in the character motor. The BodyAngle is the angle of attack the skier has while in flight, while the InrunBodyAngle is the angle of the torso while the player is in the in-run. The InrunBodyAngle is broadcasted to the character motor. Basically it can be thought of as an acceleration multiplier for when the skier is in the in-run. If the player is standing straight while in the in-run the acceleration is only 75 % of the maximum acceleration. And if the angle of the torso is less than 10 degrees the player accelerates 100 %. The acceleration multiplier is not based on real physics, it can be thought of as an game element added to force the player to emulate the movements of a ski jumper. There are of course other important factors in the ski jumpers technique in the in-run such as the angle of the knees, and head placement. And in reality the torso should be horizontal, but it can be difficult for regular people to assume a proper in-run position. So I decided that less than 10 degrees should give max acceleration.

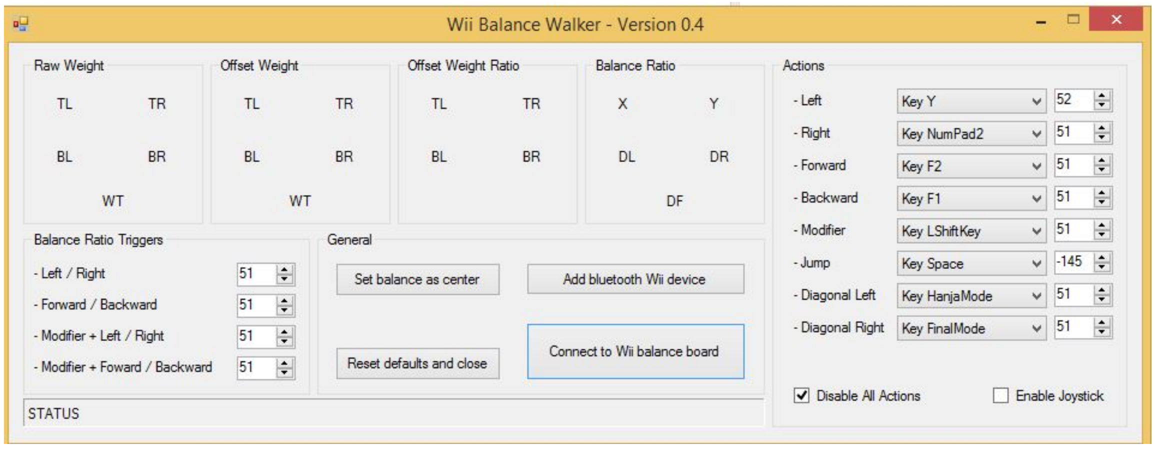
The MeasureAngleTimer is also a simplification. As the player is supposed to jump with his own body. I wanted to give him some time to land and assume flying position before the Wiimote starts measuring the angle of his torso. I also tried using the accelerometer for jump detection. This was done by looking for high acceleration in the z-axis, if the acceleration was over a given threshold a jump event would fire. However the approach suffered from inaccuracy with both firing phantom jumps, and real jumps was not being detected.

5.8 Wii Balance Board

As my approach with the Wiimote did not work I decided to try to use the Wii Balance Board for jump detection. The Wii Balance Board is a balance board accessory for the Wii gaming console. The balance board is connected to the computer via Bluetooth, and I used a software

Algorithm 12 The WiiRotator functoin

```
1: procedure UPDATE()
2:     if $useWii$ then
3:         $pitch \leftarrow wiimote_getPitch()$
4:         if $playerHasJumped$ then
5:             if StartMeasureAngleTimer >0.6 then
6:                 $BroadCast("SetBodyAngle, pitch)$
7:             $startMeasureTimer = startMeasureTime + \Delta time$
8:         else
9:             $BroadCast(SetInrunBodyAngle), pitch$
```



Balance Ratio Triggers
- Left / Right 51
- Forward / Backward 51
- Modifier + Left / Right 51
- Modifier + Foward / Backward 51

Actions

- Left	Key Y	52
- Right	Key NumPad2	51
- Forward	Key F2	51
- Backward	Key F1	51
- Modifier	Key LShiftKey	51
- Jump	Key Space	-145
- Diagonal Left	Key HanjaMode	51
- Diagonal Right	Key FinalMode	51

[✓] Disable All Actions ☐ Enable Joystick

Figure 5.10: The Wii Balance Walker interface

called Wii Balance Board walker to communicate with Unity. Wii balance board walker allows you to use the Balance Board as a foot input device. It does this by sending key presses and mouse clicks to the application. These actions is triggered by certain customizable thresholds. For this application the only trigger used was the jump action. Which sent the spacebar keypress to Unity making the skier jump. This approach did not require any scripts in Unity. The events from Wii Balance Walker was handled as a regular key press in the FPSInputManager.

Chapter 6

Conclusion

6.1 Purpose of the tests

After the implementation it was time to evaluate the prototype. In user testing it normal to focus on both the weak and strong sides of the prototype, where the goal is to continuously improve the prototype. This was the second iteration of evaluating where the first iteration was conducted in november and is described in Staurset [2014]. For this prototype there are two well defined user groups: Ski jumpers and non-ski jumpers (the general public). The plan was to let representatives from both groups test the system, and give feedback on it. In the following chapter we will explain how the tests was conducted, and the results from the evaluation.

6.2 Expert evaluation

The evaluation with ski jumpers was conducted with athletes and trainers from the Norwegian national ski jumping team. The evaluation was in the form of a semi structured interview. The interview gave valuable insight in the strengths and weaknesses of the prototype. The visual impression they got was that the in-run was to short, mainly the straight part of the in-run should be 20 meters longer. They also thought that the radius seemed a little flat. However the out-run looked very similar to the out-run in Granåsen.

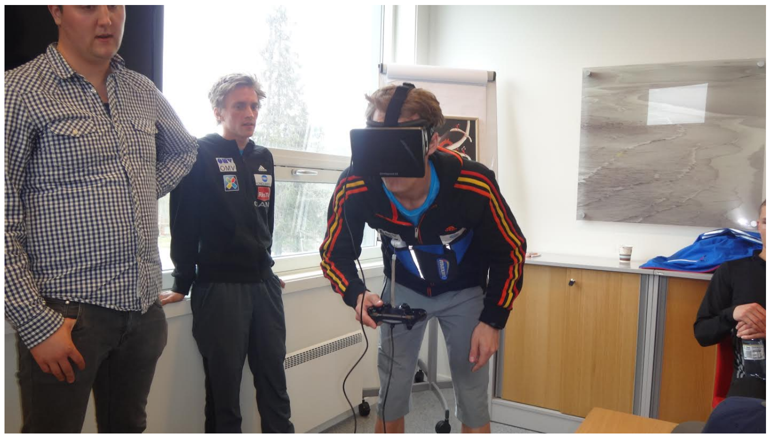


Figure 6.1: A picture from the expert evaluation

The test was conducted with the Oculus Rift Development Kit 1, with the Balance board for jumping, and the Wiimote for body angle measurement. The athletes really struggled with hitting the timing of the jump, always being to late on the take-off ramp. We concluded that this must be due to a delay with the Balance Board. This delay may not be more than 100 milliseconds, but that is greatly impacting the jumper on the take-off ramp. A normal jump takes about 0.3 seconds from the skier starts the jump until he leaves the ground. The skier is moving at ~ 26 m \s which means that the he moves 7.8 meters during the jump, and a delay of 100 milliseconds would result in the skier moving 2.4 meters extra, which have severe consequences for the length of the jump. Hence we had to improvise and find a method that could satisfy the athletes. We ended up discarding the balance board, and letting the athletes use the Playstation 4 Controller for jumping. Even though it was not necessary the testers still jumped physically, and pushed the button as they jumped. This was to connect the physical and visual experience of the ski jump.

The skiers found that there was a problem with the head rotation, as they was not able to see the take-off ramp while sitting in a normal in-run position. This is very important because the skier use a combination of visual and physical impressions when he jumps. Typically the skier starts the jumping movement as soon as the acceleration from the radii is released. Fortunately this was fairly easy too fix, as I could just change the head rotation in the HeadManager script. This change made the system feel much better according to the athletes.

As for the flying phase the skiers said that it was highly realistic, and feels very similar to how it is to jump in real life. "The feeling of "take-off" in a long jump feels very good, and reminds me much about how it is in real life" a jumper said. However one jumper said that it felt like profile of the jump felt a little off. By this he meant that you was too high above ground after take-off, and a little low above ground at the end of a jump. But this is individual for every ski jumper, and is dependent on many factors such as jump timing, how much force the jumpers generate, and flying technique of the jumper among others. However they pointed out that there was a problem with the physical model. The way it is implemented now the lift increases as the angle of attack decreases. I.e the lower the angle of attack the longer the jump. In real life the skiers body and the ski's acts like a wing and to minimize the drag and maximize the lift forces acting on the skier. Ideally the skier should have an angle of attack of about 11 degrees. An other aspect that the model does not catch is how important the rotation is in a ski jump. A ski jumper should have a small rotation forward during a jump. However if he adjust the rotation forward to fast he may get an over rotation, and if the rotation is to small the skier will be pushed back and thus generating more drag resulting in a shorter jump. They suggested that there should be implemented sort of a breaking point in the physical model where the lift is reduced if the angle is below 11 degrees. Besides of this they where pleased with the physical model.

All the jumpers agreed on that the in-run seemed to short, and especially the problem was that the straight part of the in-run should be at least 15 meters longer. They also said that the straight part felt a little to flat. After the evaluation I checked the steepness of the straight part of the in-run and the take-off ramp, and they are correct according to the hill certificate. I also checked the length of the in-run, and it really seem to be shorter then it is supposed to be. First I checked the manually created in-run that was imported into unity, and it was about 73 meters long, which is 20 meter less then the real in-run. My first theory was that there was a weakness in the surface reconstruction algorithm so it omitted the top part of the in-run. This theory was dismissed after I checked the raw data from the drone. I imported the drone data into Meshlab and converted it into a PLY file, so it could be opened in Blender. And from measuring there this was also about 73 meters long. So it appears that the LIDAR-system has failed to recreate the top part of the in-run. The consequences of the short in-run is not very severe, as it has successfully recreated the radius and the take-off ramp. Fixing the in-run requires only that you extrude the straight part of the in-run 20 meters in the local x-direction. The same has to be done for the fence, and the lamp posts as well. But when this is done, the in-run should be satisfactory according to the skiers.

One of the jumpers suggested that the in-run may feel flatter because they are standing on the flat ground. And they are used to feel the steepness of the in-run in their feet, this disconnect between what they are seeing and what they are feeling may lead to the skiers feeling the in-run is less steep. Another factor is that they do not feel the acceleration forces act on the body as it does in a real ski jump. This may contribute to the skiers feeling that the simulator is less extreme. It is impossible to recreate the acceleration forces that acts on a skier while he is jumping, but it is possible to build an apparatus that the skier stands on, which rotates the ground according to the movement of the skier. However this would both be quite complex and expensive.

The jump is now implemented so that the player jumps immediately when the jump button is pushed. As mentioned earlier the average jump takes 0.3 seconds, and for the skiers it would be much more natural to have a 0.3 second delay on the jump button so they can push it when they would start the jump movement. The trainers also gave valuable input on the jump multipliers shown in figure 5.2. In reality the skier want to jump as close to the end of the take-off ramp as possible, and a difference of 3 meters on the take-off ramp could result in a 40 meter difference on a ski jump. So the jump multipliers should be changed, scaled accordingly.

Other possible improvements was also discussed. One suggestion was to use infrared lights attached to the shoulder, hip, knee and ankle as shown in figure 6.2. These IR- lights could be read by the Wiimote which looks at the person from the side. The Wiimote has an IR-camera which is supported by the UniWii plugin for Unity. So the IR-lights could be used to reconstruct a 2D- skeleton of the skier. This skeleton could possibly be used for jump detection, by checking when angle between the knee, hips and ankle start to change. Alternatively the jump could be triggered when the light at the ankle starts to move in the y-direction.This would also allow to create a replay system where you could watch the skiers 2D skeleton as they jump. Furthermore you could also use the angle between the horizontal axis and the torso to measure the angle of attack, replacing the Wiimote attached to the jumpers body.

It was also suggested to use force scale which could be used to detect the jump. With a force scale the application can use the force generated by the skier as input for the jump. And you

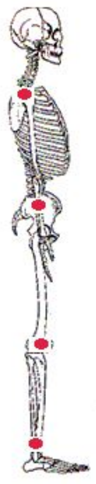


Figure 6.2: Suggested IR-LED attachments are shown as red dots.

may even be able to look at the distribution of the force of the jump. Ideally the jump should act vertically, but if the skier is leaning slightly forward some of the vertical force is lost to the jumper. With these improvements the system could also be used to evaluate the skiers jumping technique.

The skiers seemed to be immersed into the virtual reality, and one of the trainers noted that the skiers was adjusting their body's in the in-run as they would do in a real jump. In terms of what the prototype can be used for the skiers stated that if the in-run is extended and the jump button gets a 0.3 second delay, the prototype can be used as a tool to practice the timing of a jump. They also said that it could be used as a tool for visualisation and gives a feeling in how it is to jump in the modeled hill . One of the trainers suggested that if you had modeled all the hills the skiers competes in the world cup, the prototype could be used to prepare the skiers before competitions. As for the flying phase the technique is to simplified so does not offer any training value. However the feeling of flying is very similar to how it feels in real life, and can give amateurs an authentic experience of performing a real ski jump. They think that the application could be used to trigger the interest for ski jumping, and also help amateurs in practising the timing of the jump.

6.3 General public

The prototype was also tested by the general public. The test was conducted at Vitensenteret and at an event called Open Day at NTNU. Open day is an event where high school students visit the university, and Vitensenteret is a scientific "hands-on" experience center in Trondheim. The plan was to have the participants answer a questionnaire afterwards, but the participants at Vitensenteret was mainly children less than 10 years old, so the questionnaire was not suitable. But we made a simplified questionnaire where the testers could give a rating to the system from 1 to 5, and answer if they wanted the prototype to be part of the exhibition at Vitensenteret. The system was tested by 62 children and 58 of them gave it a rating of 5 out of 5. The remaining 4 gave it a rating of 4 out of 5. Furthermore all of the testers wanted the system to be part of the exhibition at Vitensenteret. From this we can conclude that the children enjoyed the application. Initially the test was conducted with the Wii Balance Board for jump detection, and the Wiimote measuring angle of attack. However this setup proved to be difficult for the chlidren, and 3 out of 5 of the first testers fell on the ground after jumping off the Balance Board. So I decided to let the rest of the children test the system using the Playstation controller for jumping, and adjusting the angle of attack.

On the Open Day at NTNU the test was conducted with Oculus Rift, and using the Balance Board for jumping and Wiimote to measure the angle of attack. After testing the prototype they answered a questionnaire. The questionnaire was designed to focus on user experience, realism and presence. In total 32 people answered the questionnaire, and of these 28 was male and 4 female. Of these participants 24 had no experience with ski jumping, 7 had little experience, and 1 had much experience with ski jumping. Most of the participants was experienced with computer games.

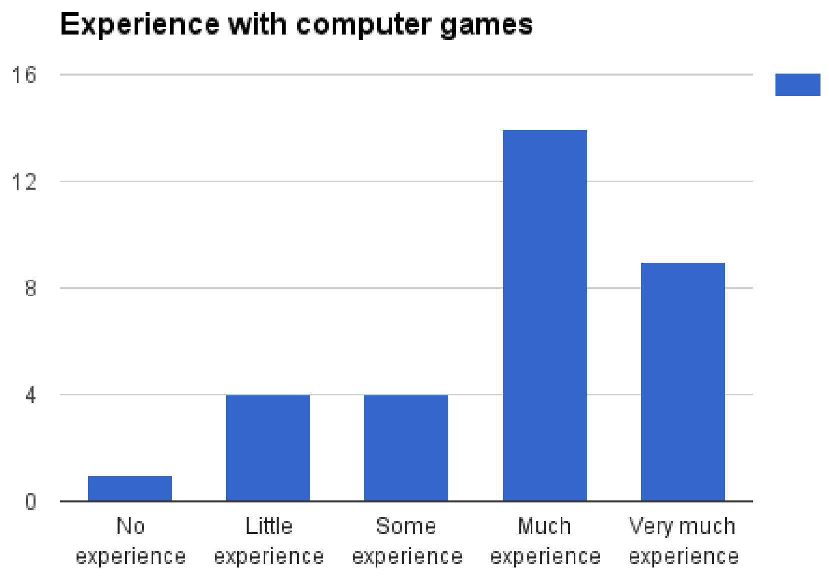


Figure 6.3: Computer game experience of the participants

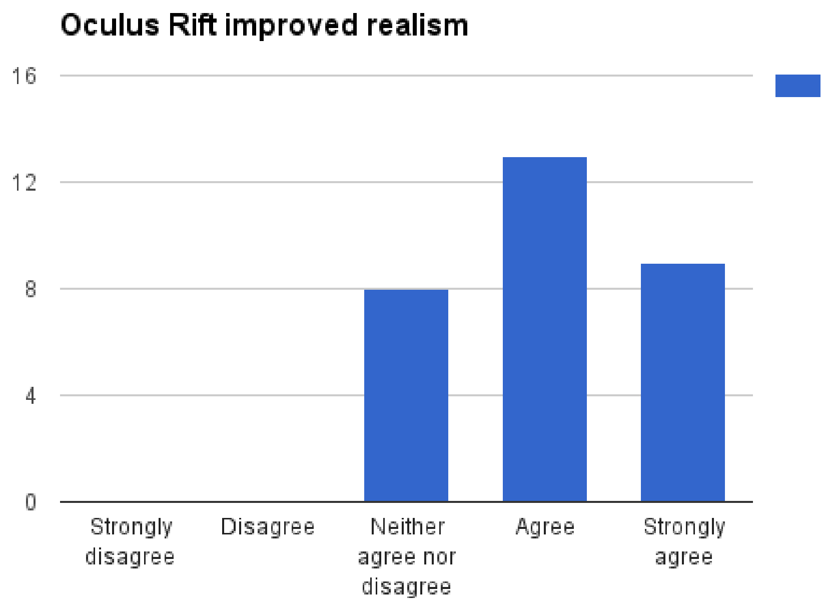


Figure 6.4: Did Oculus improve the realism?

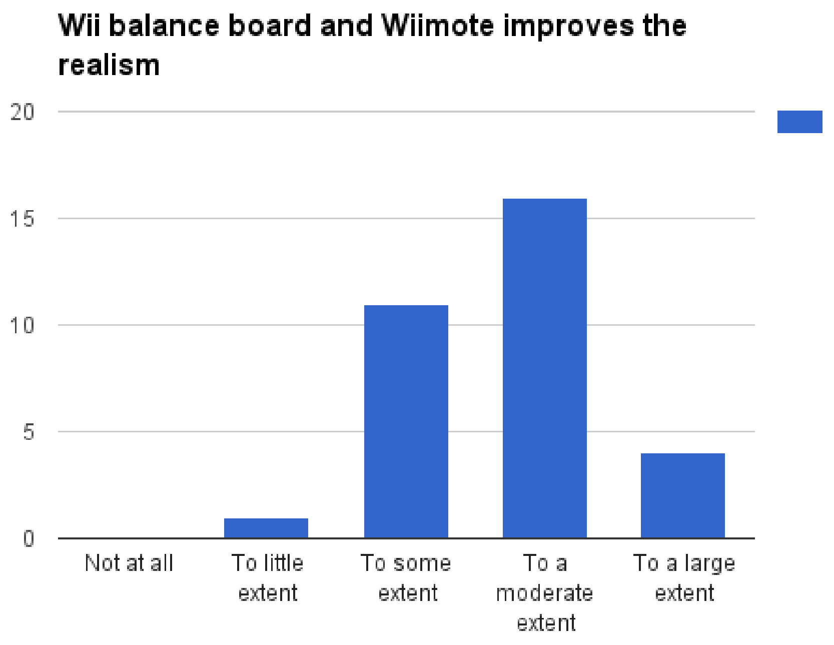


Figure 6.5: Would more body movement improve the system?

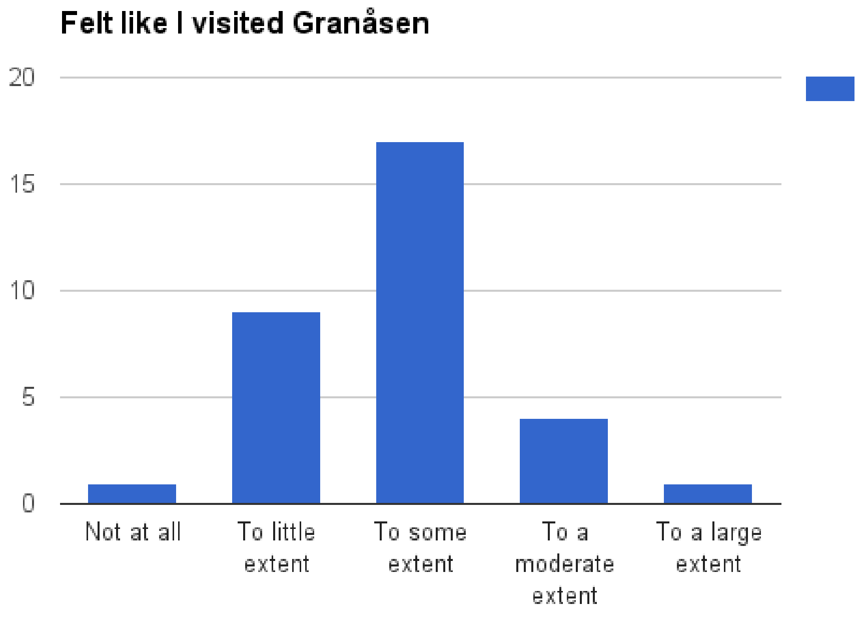


Figure 6.6: How the participants perceived the experience

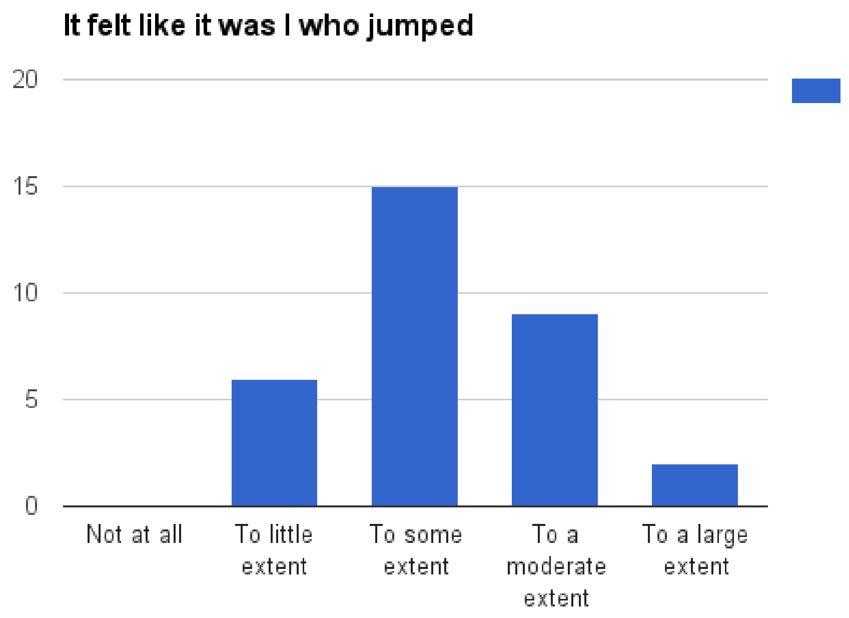


Figure 6.7: Did it feel like the participants jumped themself

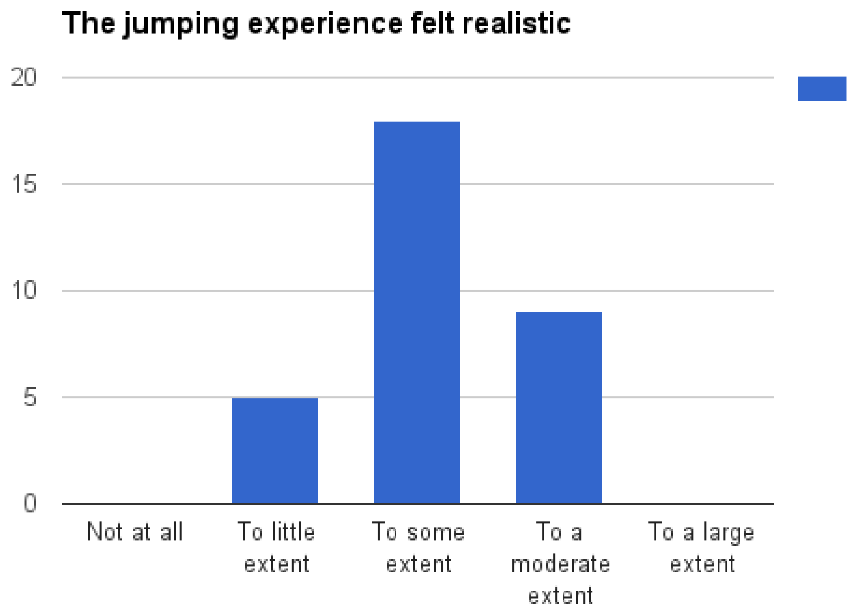


Figure 6.8: How realistic was the experience?

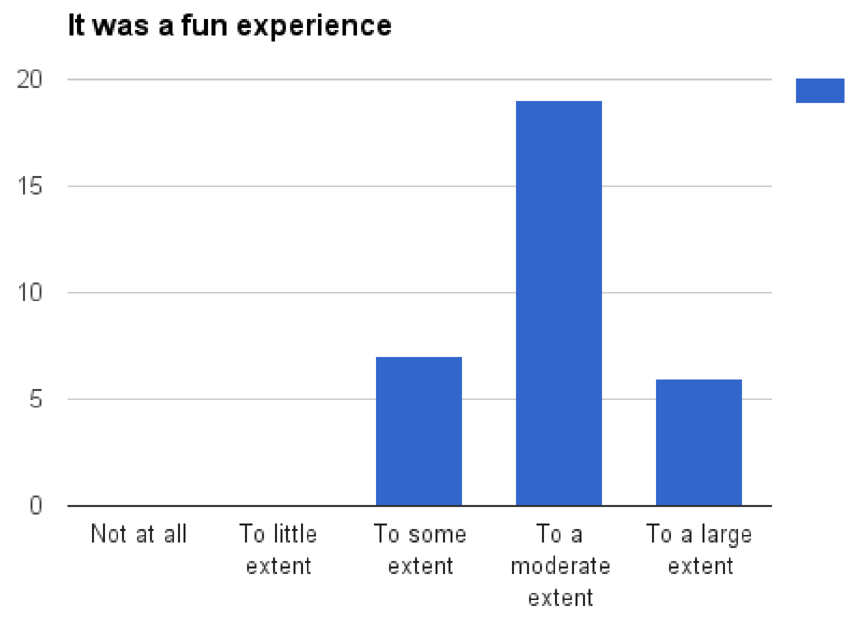


Figure 6.9: How fun was the simulator

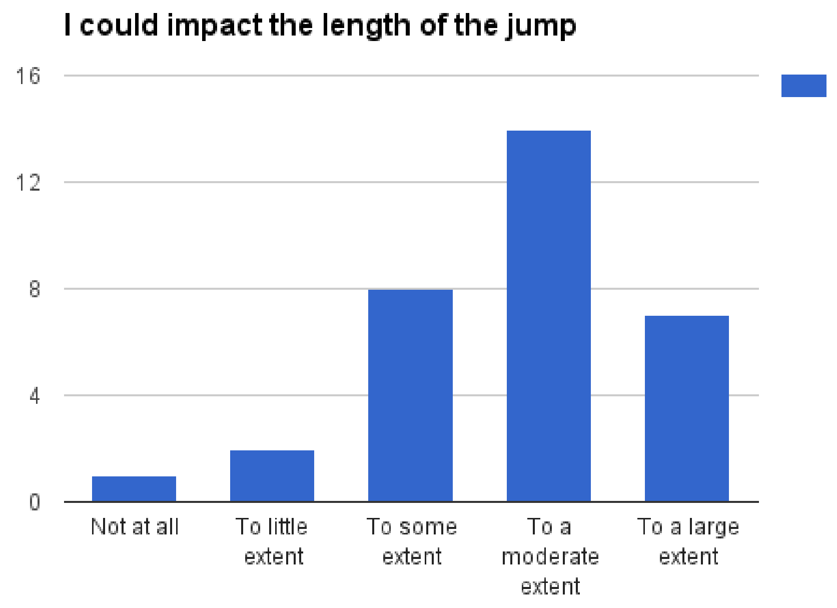


Figure 6.10: Did it feel like the user could influence the length of the jump?

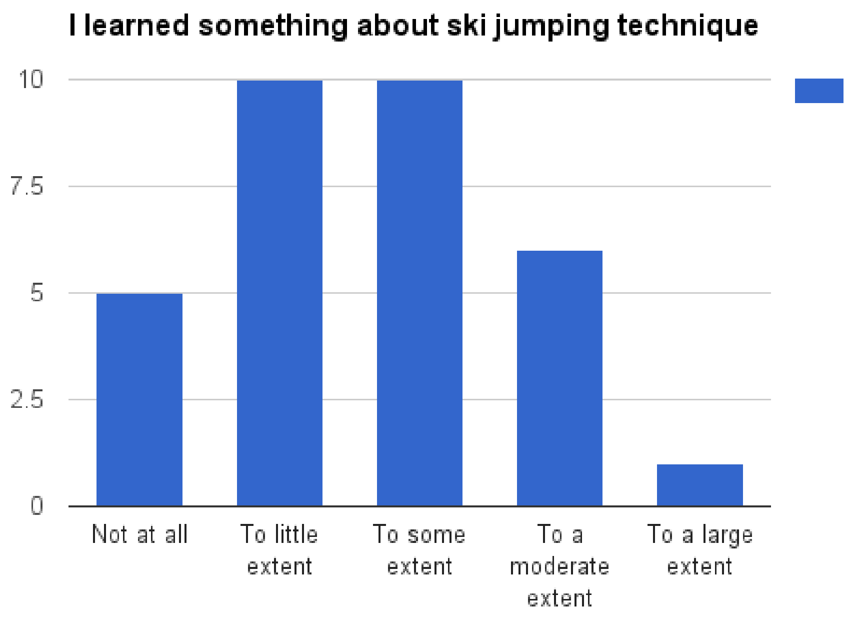


Figure 6.11: Did the participants learn something about ski jumping technique?

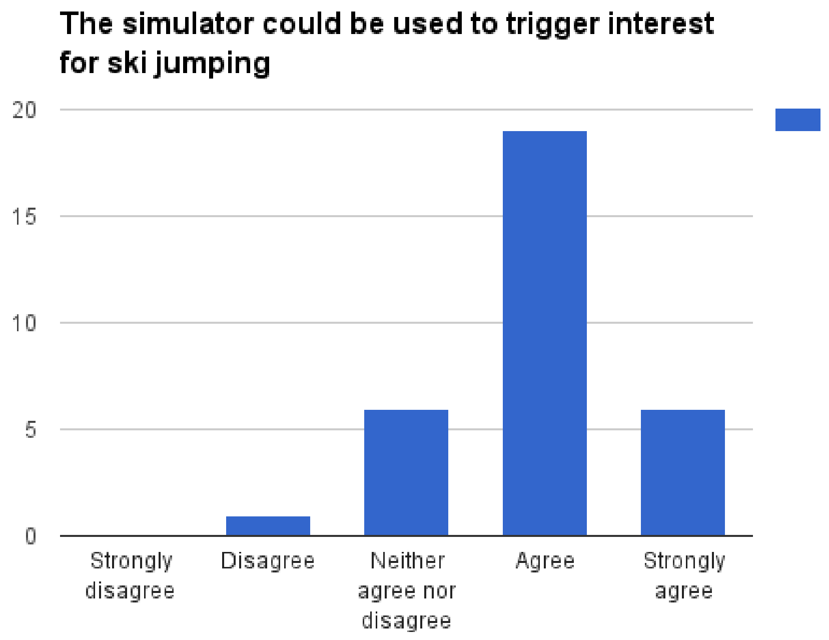


Figure 6.12: Did the participants learn something about ski jumping technique?

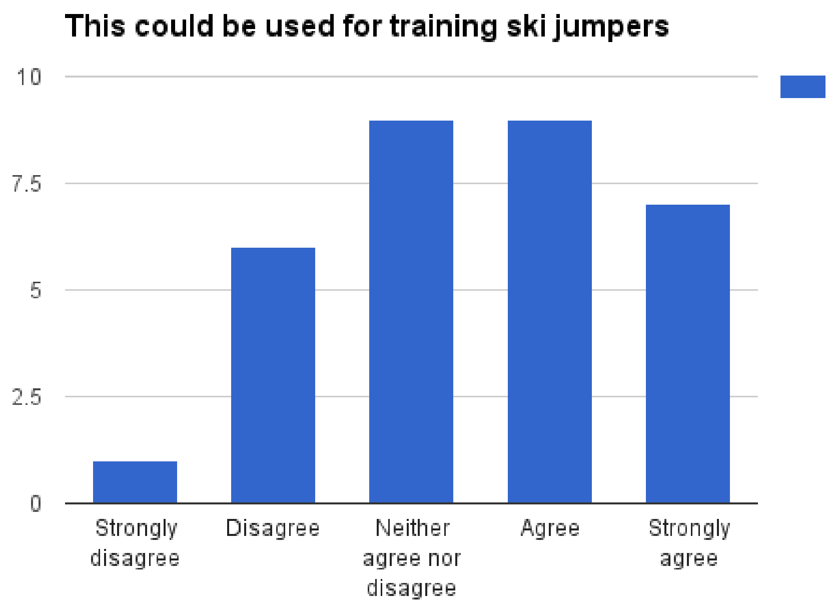


Figure 6.13: Could the system be used to teaching ski jumping?

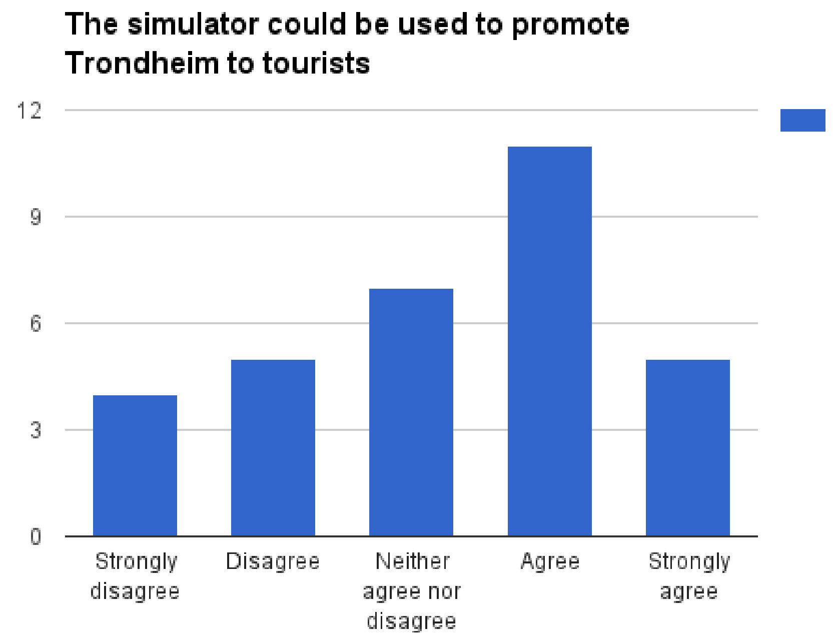


Figure 6.14: Could the system be used to teaching ski jumping?

Figure 6.4-6.8 are the questions focusing on presence and realism. From figure 6.4 and 6.5

we can see that the participants agrees that the Oculus Rift is improving the realism of the prototype, and the same goes for the Wii Balance Board and the Wiimote. The participants does not seem to feel like they really visited Granåsen as shown in figure 6.6. I believe that this is because they still feel like they are playing a game, and not physically visiting a place. I believe that adding audio to the application would improve the feeling of visiting the physical place. It would also be interesting to have a fan blow "wind" on the player adding to the perception of physically doing a ski jump. The test was conducted with an Oculus Rift Development Kit 1 where the resolution is 640 x 800 pixels per eye, and the refresh rate is 60. It would be interesting to test the prototype with the Development Kit 2 which has both higher resolution and refresh rate and see if that changes the level of immersion. Refresh rate and screen resolution are factors in immersion according to Bowman and McMahan [2007]. More of the participants seemed to feel like it was they who jumped as shown in figure 6.7. From figure 6.8 we can see that the participants does not seem completely convinced of the realism of the prototype. I find this interesting as even though I do not have quantitative data from the evaluation with the ski jumpers, they seemed to rate the realism higher than the general public did. It is hard to draw any definitive conclusions from figure 6.11, but there seem to be a tendency that the participants did not feel like they learned something about the ski jumping technique. Figure 6.12 shows that the participants seems to agree that the prototype could be used to trigger interest for ski jumping. Also the majority seems to agree that the prototype could be used as a training tool for ski jumpers, and also used to promote Trondheim to tourists.

6.3.1 limitations

In hindsight, the Open Day was probably not the best setting to evaluate the system in. As the participants did not have much time for testing the system. Thus we had to limit the number of questions in the questionnaire. Most of the participants only tried 2-5 jumps, which probably is a too small foundation to really judge the system. The tests was conducted using the Balance Board for jump detection, which was not accurate enough according to the experts. This could also have influenced the results of the questionnaire.

6.4 Discussion

In section 2.7 the requirements for the system was proposed. All of the requirements has been met to some extent:

The hill should visually look like Granåsen:

This was achieved by performing surface reconstruction on data collected by a LIDAR system. Several other visual elements was modeled using images as references, e.g. the fence, the lamp posts). Based on the expert evaluation the scene looks similar to the real hill. Unfortunately the LIDAR data was not able to capture the whole in-run, and this resulted in a too short in-run. This is not something the untrained eye will notice, but for athletes it is important that the in-run is accurate.

The prototype should be physical correct:

The physical model is a simplification of the real physics of the ski jump. The experts that tested the system found the physical model satisfactory, and the flying phase was realistically modeled. The only complaint of the physical model is that there should be a breaking point in the angle of attack, so that you get less lift if the angle of attack is less than 11 degrees. This could for instance be achieved by implementing a multiplier in the same way as the acceleration modifier when the skier is in the in-run. That would also add more skill to the game. To perform a long jump in the current physical model you have to have as low angle of attack as possible, but with the breaking point implemented the goal will be to find the "correct" angle of attack.

The system should provide a realistic ski jumping experience for amateurs:

The results from the question about realism is shown in figure 6.8, and from those results the participants found the experience to be realistic to some extent. The test was performed with the Wii Balance Board, which was proved too inaccurate in the expert evaluation due to the delay. This may have impacted the results from the questionnaire.

The system should be able to run in real-time on a mid-range computer:

The system has been extensively tested on a Samsung ATIV Book 4 Samsung [2015], which is a low- to mid-range lap top, and there has not been any performance issues with the application.

The system should have a natural user interface

There still are some work to do with the user interface. The angle of attack is being measured by the Wiimote, and this works fine. However the Wii Balance Board did not work well enough for jump detection. I would recommend to explore the IR-LED solution proposed in section 6.2. It may also be possible do more test with using the accelerometer for jump detection. There still are some functions that rely on traditional user interface (buttons/keys), such as landing, restarting the jump, and jump evaluation. These functions could possibly be activated with gesture recognition using the Kinect. However I did not have time to investigate this further.

As for development Unity proved to be a very well suited platform for development of virtual reality applications. The Oculus Rift SDK for Unity made it easy to integrate with Oculus Rift. Furthermore Unity has a well-documented API Unity [2015] and I found the software intuitive and easy to use. Furthermore Unity has plugins who supports input-devices such as the Wiimote and the Kinect. The use of LIDAR for reconstructing the hill also worked reasonably well. The only problem with it was that the system was not able to detect the whole in-run. Through surface reconstruction and post-processing we ended up with a scene where the experts could clearly recognize Granåsen.

Compared to the other ski jumping applications described in section 2.3 the application has some features that none of the other applications has. It is hard to compare with Alf Engen's Take Flight because there are not much information about it. But by using JDHGroup [2015] as a reference we are able to do some comparisons. Take Flight only has a regular TV-monitor for displaying the graphics. This should lead to a less immersive experience than by using the Oculus Rift. The application seems to be using some sort of a balance board for input, which seems to be the only way the player are interacting with the system. It does not require the player to mimic the technique of a real ski jump. It seems fair to claim that even without the Balance board for jump detection, my application has a user interface that mimics the ski jumping technique more accurate, and thus should be more useful for training ski jumpers.

There is also limited information on the "Planica 2015 Virtual ski flying" application, but the comparisons are based on Sporto [2015] and Triglav [2015]. This is the only other ski jump application I have found that also uses a head mounted display. It uses the Oculus Rift Development Kit 2, and it seems like it only uses the head tracker of the Oculus as input. It seems like the head tracker is only used to determine the timing of the jump. In terms of user interface I would still claim that my prototype has a more intuitive and realistic user interface, which makes it more suitable to use by athletes in a training situation.

As mentioned earlier Deluxe Ski Jump 4 (DSJ) is considered the best ski jump game in the market. I have tested the game extensively, and in my opinion the physics is the most impressive aspect of the game. It seems to have a more sophisticated physical model that is able to capture the rotation of the skiers body, and the ski's behaviour while they are in the air. However as I mentioned earlier it is primarily a game and not a virtual reality application. The game supports first person camera, but it is difficult to use as you cant assess how the skiers body is positioned. Both applications uses the timing of the jump, and the angle of attack in the air to determine the length of the jump. One of the trainers that tested my game is an experienced DSJ-player, and he said that the dream would be to have an application with DSJ's physics and my user interface.

6.5 Conclusion

In this report I have described how a virtual reality simulator for ski jumping can be developed. A LIDAR system was used to create a point cloud of the ski jumping hill in Trondheim, Granåsen. This point cloud was converted to a mesh by using the Poisson surface reconstruction algorithm. The application was implemented in Unity, and has a simplified physical model based on Marasovic [2003]. The application uses the Wiimote to measure the body angle when the player is in the in-run, and in the air. We tried using the Wii Balance Board for jump detection, but due to delay this did not work well enough.

Even though the prototype is not perfect, and has areas of improvement such as jump-detection, I would claim that this best known ski jumping application for ski jumpers in training. As mentioned in section 6.2 with some minor improvements (delay on jump, extension of in-run), the application can be used by professional ski jumpers to practice the timing of the jump. The flying phase is too simplified and does not offer any training value for the skiers. But the flying phase is extremely difficult to recreate in a way that could be transferable to the real technique. Furthermore the application can give a realistic experience of how it feels to perform a real ski jump. And it can be used as a tool to trigger interest for ski jumping, and inspire aspiring ski jumpers.

6.6 Future Work

For future works it would be interesting to continue the work on jump detection. The next step would be to find a way to accurately detect the moment of a jump. It is important that the method has low latency. In section 6.2 I proposed a possible solution using the Wiimote as an IR-camera, and attaching IR-lights to the jumpers body. This could be used to create a 2-dimensional skeleton of the jumpers body as shown in figure 6.2. A jump event could be fired when the IR-light attached to the ankle starts moving in the y-direction. Furthermore this method could enable the creation of a replay system, where you can see the jumper's skeleton during the jump. Still the application would be mostly effective for practicing timing, but the user interface would be more natural. To further improve this, one could use a force scale to detect the jump. Then the force the skier generates could be used as input for the jump. Also then you could look at the force distribution of the jump. Then the application would have potential to be used as a tool for practicing the technique of the jump as well.

FÉDÉRATION INTERNATIONALE DE SKI
INTERNATIONAL SKI FEDERATION
INTERNATIONALER SKI - VERBAND

No. 289 / NOR 39 2. Änderung

CERTIFICATE OF JUMPING HILL
CERTIFICAT DE CONFORMITE
SCHANZENPROFILBESTÄTIGUNG

Date of issue Établi le Ausgestellt am	03.09.2011	Valid till Valable jusq` au Gültig bis	31.12.2016
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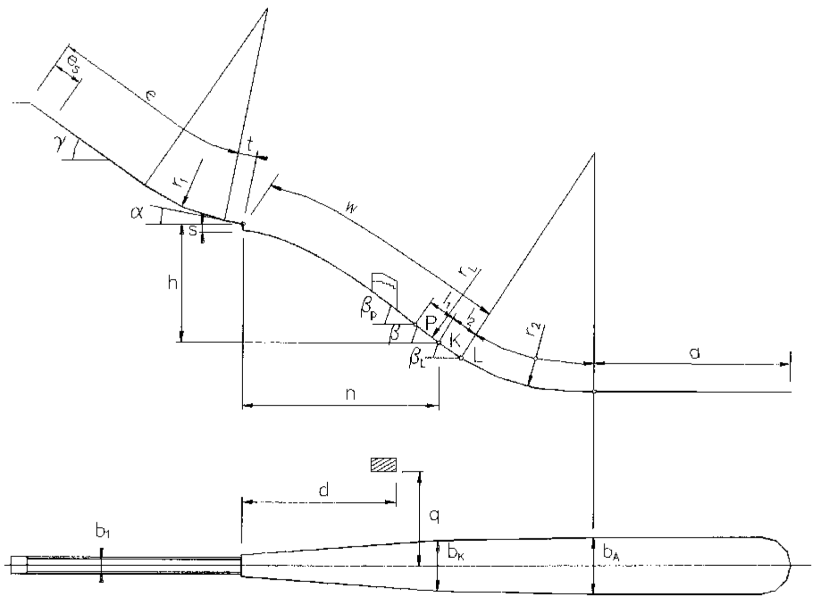

e =	93.13 m	l_1 =	15.9 m			P =	107.8 m
e_s =	16 m	l_2 =	17.1 m			K =	123.7 m
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γ =	34 °	β_p =	36.3 °			b_1 =	2.68 m
α =	11.0 °	β =	33.5 °			b_K =	24.6 m
r_1 =	105 m	β_L =	29.7 °			b_A =	26.9 m
h =	61.3 m	r_L =	286.6 m			d =	77.5 m
n =	107.1 m	r_2 =	107 m			q =	47 m
s =	3.0 m						

JUMPING HILL APPROVED BY THE FIS
TREMPLIN HOMOLOGUE PAR LA FIS
DURCH DIE FIS GENEHMIGTE SPRUNGSCHANZE

SUB-COMMITTEE FOR JUMPING HILLS

CHAIRMAN: [illegible]

APPENDIX B

Questionnaire

Sex?

☐ Male

☐ Female

Oculus Rift increases the realism?

☐ Strongly disagree

☐ Disagree

☐ Neither disagrees or agrees

☐ Agree

☐ Strongly agree

How much experience do you have with ski jumping?

☐ No experience

☐ Some experience

☐ Much experience

How much experience do you have with Computer games?

☐ No experience

☐ Little experience

☐ Some experience

☐ Much experience

☐ Very much experience

It was a fun experience?

☐ Not at all

☐ To little extent

☐ To some extent

☐ To a moderate extent

☐ To a large extent

It felt like I actually visited Granåsen?

☐ Not at all

☐ To little extent

☐ To some extent

☐ To a moderate extent

☐ To a large extent

It felt like it was I who jumped

☐ Not at all

☐ To little extent

☐ To some extent

☐ To a moderate extent

☐ To a large extent

The ski jump felt realistic?

☐ Not at all

☐ To little extent

☐ To some extent

☐ To a moderate extent

☐ To a large extent

I learned something about ski jumping technique?

☐ Not at all

☐ To little extent

☐ To some extent

☐ To a moderate extent

☐ To a large extent

It would have been a better experience if the hill looked more like the real Granåsen?

☐ Strongly disagree

☐ Disagree

☐ Neither disagrees or agrees

☐ Agree

☐ Strongly agree

The use of Wii Balance Board and Wiimote improves the realism

☐ Not at all

☐ To little extent

☐ To some extent

☐ To a moderate extent

☐ To a large extent

The simulator could be used to trigger the interest for ski jumping

☐ Strongly disagree

☐ Disagree

☐ Neither disagrees or agrees

☐ Agree

☐ Strongly agree

This simulator could be a useful tool to teach ski jumping?

☐ Strongly disagree

☐ Disagree

☐ Neither disagrees or agrees

☐ Agree

☐ Strongly agree

This simulator could be used to promote Trondheim to tourists

☐ Strongly disagree

☐ Disagree

☐ Neither disagrees or agrees

☐ Agree

☐ Strongly agree

Appendix C

The project is available here: `https://goo.gl/Mz4yzp`. The URL is a reference to a Dropbox folder. The folder contains a copy of the Unity project, Unity builds with different target platforms, and the audio file from the expert evaluation.

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