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Virtual Reality Spectating

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Preface

This master thesis was carried out at NTNU i Gjøvik in the spring semester of 2017 by Jan Greger Hemb. The theory behind the master was assembled after a few open discussions with Simon McCallum, related to Virtual Reality (VR). I have unintentionally specialized myself in VR over the course of this master with several key projects focusing on research and development of VR. Watching someone else play in VR have been a suboptimal experience for the spectators through these projects, and a proper system for spectating VR content was needed. This formed the basis for developing a proper spectating system for VR, and scientifically assessing it.

A general knowledge base related to computer science and VR is preferred for understanding this thesis, but is not strictly needed. Key parts of the thesis are explained in detail, including what VR is, and how it works.

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I would also like to thank my girlfriend Hanne Solberg Engebretsen for her loving support, and her ability to correct even the worst spelling mistakes I made.

The feedback and support provided by fellow students, friends and family also helped this project reach its current state.

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Abstract

The goal of this master was to assess and evaluate Virtual Reality (VR) spectating. VR spectating refers to spectating someone playing a game in VR. A series of spectating modes (mirroring, 3D and VR) was assessed in a series of experiments, and user testing sessions to determine the preferred mode for spectating VR content. A range of related topics were discussed as well, including spectator placement models, streamers core success values, and the projected success of VR as a platform.

The overall conclusions supported VR as the preferred mode to spectate VR content in all metrics. The participants selected the VR mode as the preferred mode compared to the mirroring and the 3D mode. The VR mode was also superior in regards to quality of the modes, enjoyment of the modes and immersion of the modes. No statistically significant difference was found between the mirroring and 3D mode. The results of streamer evaluation found competence to be a non-critical factor for success, and advertising to be an important, but not decisive revenue source. VR as a platform does still have a few key challenges before reaching mainstream adoption, but VR spectating could become a key component in the future of VR.

The prototype developed received high interest and remarks from testers and participants and forms a great starting point for further work.

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1 Introduction

1.1 The new world of Virtual Reality

The first generation of high-end Virtual Reality (VR) systems has finally been released. From high end room scale systems, as the HTC vive, to a more affordable and readily available Google Cardboard VR system. The initial interest created by Oculus Rift back in 2012, with their VR Kickstarter, has come to the mass market. 2016 was the year where we finally saw wide spread consumer level virtual reality systems. We are also in the beginning of a new era for e-sports and spectating gaming experiences. A new marked have emerged where many gamers spend more time spectating other people playing games than playing themselves[1]. Both areas does still got a lot of unanswered questions. There is currently no answers on how to spectate and watch another person/player playing in virtual reality.

1.2 Description of Virtual reality

Figure 1: A girl playing in the HTC vive Virtual reality system [2]

Virtual reality (VR), in the context of this paper, refers to computer generated worlds that would replicate the real world, and simulate the user inside the world. The user interacts with this world by using a head mounted display (HMD) that consists of a screen where each eye sees one half of a virtual environment, deceiving the brain into thinking it is seeing something in 3D, also known as stereoscopy. The HMD has a wide range of sensors including gyroscope, accelerometer and some even got a tracking system on their headset position in relation to a stationary object, like a base station. These sensors allow the user to move and turn their head in real life and have it replicated in the virtual world, increasing presence and immersion in the virtual world. Some systems take this even further by tracking the user in a small room, allowing them to walk around and have it be mapped to movement in the virtual world. Additional devices can increase the interactive ability with the simulation, like tracked hand held controllers that serve as virtual hands. An example of VR can be seen in Figure 1

1.2.1 Virtual Reality spectating

Watching someone else playing in virtual reality can be boring unless you can see what they see. Most, if not all, games made for VR has the ability to display what the player sees on a secondary screen, also known as screen mirroring. However, this is far from optimal. Spectators of the VR gaming session can easily get motion sickness from all the camera movement. People watching the movie Cloverfield[3] reported the same type of problem as the movie featured a hand held, and really shaky camera. This gets even more complicated when the people are not in the same location as the player and they are watching a stream, or a video of it. There are currently not any optimal solutions to spectate VR gameplay, using VR for the spectator as well. This is not only a problem for gamers and game developers, but also in the world of collaborative VR where the technology is used to work together on a project, like designing a new car. Solving this by just putting the spectator into VR in not a good solution either. They can easily miss out on what is happening and need some structure to the experience. A proper system is needed.

1.3 The challenges of Virtual Reality spectating

Spectating is already a main force behind game sales for non VR games[4]. Missing out on this will hurt VR system and game sales. Watching a stream of a new game you are considering buying could be the deciding factor in your choice to actually buy the game. VR is not well suited for the standard way of spectating, where the same image shown to the player is also shown to the spectators. All the head movement makes sense to the player, but can give the spectators motion sickness/VR sickness. Every party involved will benefit from better spectating experiences as more people will use and engage with VR content.

Part of the same problem is also how a person in VR system can spectate another player in a VR game. Just showing the screen will not work well as it will cause motion sickness and give no extra benefit of spectating using VR. Solving these problems can bring a new golden era for VR, spectating in general, and e-sports. A system for spectating VR experiences can bring us VR e-sport. Many of the same concepts can even be extended into VR movies, where we will blur the line between spectating and interacting. This is just some of the application of VR spectating. Losing the ability to control the camera in relation to VR spectating and VR movies leads to the danger of users missing the action. Having a proper placement model for where the spectating can be done can help to mitigate this challenge and bring some control back into the hands of the game designers and movie producers.

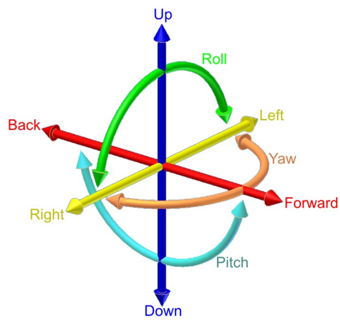

Figure 2: Six degrees of freedom [5]

A key concept in this paper is the 6 degrees of freedom(6DoF) which refers to the three rotational and three positional axes, as seen in figure 2. This is used to describe the available axis for a given VR headset. A VR headset with 6DoF can handle rotation and translation, along any of the axis seen in figure 2. As I will discuss later, having less than 6DoF reduces immersion for users. Another related concept is the room scale vs. sitting/standing experience. Room scale is a system where the VR user can walk around a room with the VR headset (and sometimes hand held controllers in each hand) while their position in 3D space is tracked and mapped to the VR simulation. A standing/sitting experience is where only limited room tracking is available. and the VR user can not physically move around. 6DoF refers to the capabilities of the headset, and room scale independently refers to where the VR user can move around in the room while in VR. A room scale system requires a 6DoF headset.

1.4 Research questions

The following research questions (RQ) are divided into groups of primary questions, and some sub questions within that primary question.

1 How does spectating someone in VR differ depending on the spectators setup/mode; mirror, non VR 3D, or full 6DoF room scale? What are the preferred mode of spectating a VR player?

  1.1 How could the spectating system be used for real life sport events? How a real world event could be spectated using the prototype developed, or by extending it.

  1.2 How do other non VR spectating sports earn money, an how does these mechanisms for revenue translate for VR spectating? Are there any new possibilities for VR spectating?

1.3 What are the potential core elements of a streamers success? Is skill a critical factor for a streamers success?
1.4 How could a VR spectating system be scaled up to more than a few spectators? What are the performance and cost trade-offs? How can the prototype support a wider range of different camera angles outputting simultaneously?
1.5 What are the current projections for VRs success as a platform? What are the potential critical success factors for the success of VR? A VR spectating system is dependent on VR as a platform. This is a auxiliary discussion of the primary research questions for this project (RQ1).
1.6 What is the state of the art for spectating?

2 Does restricting spectator movement to a certain defined game chokepoints increase spectator enjoyment and duration of spectating in VR? Chokepoints in this context are defined as narrow passageways that concentrate the actions at that point, as it is easier to defend a smaller front-line.
3 How often does the spectator see relevant game sequences depending on the spectator placement model? What is the effect of spectator placement models on understanding the context of an observed game action? A placement model in this context reefers to how the spectator are placed into the game for an optimal experience and game understanding.
4 What are the technical challenges of implementing VR spectating?
5 Do 3D spectators prefer an active or passive approach to spectating?
6 Does the demographic of the participant have any effect the results?

1.4.1 Hypotheses

The first, and most important RQ (1) relates to how each spectating mode differ, depending on interaction and levels of VR degrees of freedom. Expanding upon this we can form three hypothesis, as there are three different spectating modes tested: Mirror, 3D and VR. Mirror is just watching normally as someone playing VR, as their HMD screen content is usually mirrored to some other screen. The second, 3D, is a non VR based spectating on a separate computer with some control, and the last is full 6DoF room scale spectating. The hypothesis aim to explore if there is a preferred setup.

Hypotheses

1 VR > mirror. This hypothesis is that VR spectating is the preferred choice for participants in the experiments over the mirroring mode.
2 3D > mirror. This hypothesis is that 3D spectating is the preferred choice for

participants in the experiments over the mirroring mode.

3 VR > 3D. This hypothesis is that VR spectating is the preferred choice for participants in the experiments over the 3D mode.
4 VR vs 3D depend on user preference for consuming passive media.

Hypothesis 1 to 3 can be summarized as follows: VR > 3D > Mirror. This aims to prove VR is the superior way to spectate VR, with 3D still being a better choice than the default way of mirroring. One last hypothesis is added (H4), as there might be a preference between 3D and VR for some, or most of the players. The benefits of VR spectating might be too small to overcome the challenges. Both H3 and H4 can not be true, and will need further analysis and testing.

Null hypothesis

1 VR <= mirror. Either the mirroring mode being preferred in the experiments, or both mode are statistically similar compared to the VR mode.
2 3D <= mirror. Either the mirroring mode being preferred in the experiments, or both mode are statistically similar compared to the 3D mode.
3 VR <= 3D. Either the 3D mode being preferred in the experiments, or both mode are statistically similar compared to the VR mode.
4 VR vs 3D has no dependency on user preference for consuming passive media.
5 Sample 1 = Sample 2. This null hypothesis theories that there are no differences between two sets of measurements. To be evaluated between each of the modes.
6 Group 1 != Group 2. This null hypothesis theories that there are a difference based on group order.

1.5 Project goal

The goal is to determine the differences between spectating setups, and this will require a series of prototypes that explore the different ways of making VR spectating systems. This system needs to provide a benefit over the current standard solution of screen mirroring. Spectating someone in VR, while not using a VR of your own, will need to help the spectator to understand what the player is doing, and bring some level of entertainment value to the spectator. The spectating system need to help the player make the most of the setup, and utilize the new level of immersion added by the VR device. Full VR spectator with room scale 6DoF will have more of an ability to navigate by themself, but will potentially still need some level of restriction to help them focus on the game they are spectating. The planned contributions will focus on using what technology is already available, and not a high-end over complicated system like HTC mixed reality, where the player needs to be in a green screen room.

Determining the best placement model for the spectator will require exploring and evaluating a series of different placement strategies. The planned contribution is to determine if free movement, or restricting them to one or more predefined locations, will be best for the player. One example of such predefined locations are game chokepoints, where the actions tends to concentrate due to game and level design. Each of the types of spectator setups will need some level of separate solutions. The chosen placement model needs to help the player to be well informed on the action/sequence they are spectating, while at the same time not overwhelm them, helping the spectator to get a good overview of what is happening. Spectators, especially in VR, have the challenge of missing the action due to them looking in the wrong place, and a tested spectator placement model is needed to help solve this problem.

2 Related work

There is a clear lack of relevant research. This is mainly due to how new and cutting edge this field of research is. The field is experiencing rapid growth with the release of the first generation consumer targeted VR systems. The Oculus Rift and HTC Vive have finally been released in 2016. Only a few short research papers found are using the newly released devices, due to how recent they where released. The research area of VR spectating will need to be broken down and examined individually to overcome the challenge of little relevant academic literature. There is no relevant research on VR spectating, but there is some on VR, and spectating separately.

The ACM CHI 2015 and 2016 conference papers have helped to form some of the foundation for this paper[6]. This a annual conference dedicated to Human-Computer Interaction with the highest concentration of relevant papers related to VR. There is also some relevant research related to e-sport spectating and race car spectating. Some relevant research is exploring what devices work best for immersion and how to create immersive and engaging scenes in VR. One example of the later is VR storytelling, and how it is in the process of being applied to VR movies. Some research even focus on how VR can enchant telepresence by allowing as user in VR to control a remove robot. Other relevant research look at VR collaboration and VR data visualization.

2.1 Spectating

The first aspect to examine is spectating in sport events[7], e-sports[1] and live streaming [8] [9]. Streamers and streams in this context is players that are streaming live their gameplay for others to watch online at the same time as they are playing. Designing for the spectating experience is not as trivial as just adding in a camera they can move around. Spectating and playing the game is two different types of activities any spectating system need to take this in to account. A good example of this is how less information is usually better for the spectator, they don't need to know as much as the player playing[7][1]. The player might be concerned with different metrics like when they need to reload their weapon as they are interacting with the game and needs to plan accordingly. The spectator usually only want to know what is happening in general, and the information related to who is winning or not. This works well with a VR spectating environment where too much available information is never a good thing, and most VR games do not have a high concentration of information. Large scale e-sport spectating in tournaments work in many of the same ways as more traditional and physical sport like football. In both cases, there is usually commentators to help with the role of entertainment and play analysis, as well as who is winning.

There is a growing trend among casual players to spectate others playing rather than playing themselves. This is even more relevant regarding VR spectating as the high barrier of entry reduces the potential players even more. However, it can pose some challenges as the casual players do not have sufficient knowledge about how the game works, or VR in general. This is where the part of relevant information is paramount. Spectators need to be able to understand what is happening, especially those that have not played the game themselves.

Game performance is not necessarily an indicator of the success of a streamer. The two are loosely correlated, but game skill and understanding is not a deciding factor in the success of the stream. This can help to diversify the games that can be spectated in VR and help new games with no pro players to flourish. Many VR games currently on the market are short and do not offer too much in regards to content. Waiting for large e-sport focused games is not a good solution for VR spectating. However, there is a big challenge related to streamers in general that needs a solution. Female streamers face a lot more challenges that male streamers[9]. Female body focus and objectification is a major problem in the streaming community. a high degree of female streamers make a living based on income from the streams, and objectification. This gives them an economical incentive to not fight this objectification. The people watching the stream can easily just switch to another streamer. It is challenging to assess properly without a study, but there is a chance VR spectating can help here. The researchers behind the study found less objectification in smaller and more personal streams. VR removes a layer of abstraction between the participants and the game. If both the player and streamer are in the same VR space that might humanize each other more as a layers of abstraction are removed between them. However, this could be disproven by another study as they did not find any change in social presence when in VR [10]. Any VR streaming platform needs to address this problem properly.

2.2 Virtual Reality Storytelling

VR spectating and VR storytelling have a lot in common. They both work as a more passive form of entertainment compared to VR gaming. More traditional, non-VR moves are made with full control over the camera where the audience can only see what was intended. This is a challenge in VR where you cannot restrict the user's view in the same fashion. A team of researchers in 2016 looked at a way of solving this problem. They attached a motor to an office char, allowing the motor

Figure 3: SwiVRChair with the VR world on the left and the real world chair on the right

to rotate the chair around. They called it SwiVRChair[11], which can be seen in figure 3. The motor worked in conjunction with a series of VR movie people were watching. The chair then rotated as instructed to specific locations at specific times to direct the focus of the participants. The user could resist this movement and look where ever they wanted, but most chose not to. This is one way we can enhancing VR spectating. Give them a SwiVRChair setup and have it rotate to focus on the action. Users having to rotate by themselves can be exhausting and a challenge for VR spectating and VR movies. Most of the action needs to be centered in a place/direction that the user can easily identify, or else they can start to miss out on what is happening. This is something the Norwegian filmskolen[12] (school of move making) is also working on. Making VR moves have a lot in common with VR spectating as both is a non-interactive experience where some story unfolds around the audience. A new type of movies will be needed, and VR spectating can either help to inspire this, or draw inspiration of it own from VR movies. Even the company behind the Oculus rift VR system is looking at VR movies with theirs Oculus stories company[13].

2.3 Virtual Reality Devices

There is some relevant research going into how to create immersive VR devices. The majority of the research are outdated with the release of the current generation of consumer level VR devises, but the data can still be partially used to assess, and improve current generation VR devices. This applies to VR spectating as well as VR devices as you cannot have VR spectating without VR devices. The experience can easily be ruined if the spectator cannot see what is going on in the game due to bad VR devices. The screen door effect is still prevalent today as it were in the last generation. This is the effect where you can see the lines separating the individual pixels. The PlayStation VR does not appear to have this problem[14] to the same magnitude, but the individual pixels can still be seen. The screen door effect helps to remain players and spectator that they are still looking at a screen.

It is immersion breaking and needs to be fixed. However, just increasing the resolution to 4K is not an optimal solution either. The current VR devices like the vive and rift already require high end computers to run properly. This is due to the high frame rate required of around 90 FPS. For comparison we can look at console games where 30 to 60 FPS is the norm [15]. Increasing the resolution will diminish the potential market even more and might kill off VR completely. One solution is to wait for modern hardware to catch up to 4K 90 FPS gaming requirement. Current generation VR devices is also limited to only 110 field of view(FoV) [16] which is approximately the overlap of both eyes. However, the optimal FoV for VR is 140 degrees[17]. Loosing that extra 30 degrees reduces immersion. Having a higher FoV will unfortunately require even higher resolution displays to combat the screen door effect. The current generation devices are a compromise between all the limitations, but future devices need to improve on most, if not all specifications. VR spectating need to offer a clear benefit over non-VR spectating and sub optimal devices can easily destroy any chance VR spectating have.

2.4 Virtual Reality Immersion and Presence

Feeling immersed and experience presence is key in any VR gaming, or VR spectating scenario. VR games' success depend on whether the player will feel more presence playing in VR than outside of VR. This is just as relevant for VR spectating where the spectating experience needs to be enhanced by using a VR device. The presence felt by the player should also be visible to the spectating party, especially if they are spectating without a VR system of their own. Some research has gone into presence in VR, but it is a rather limited research area. A paper from 2012 looked at the question on if it is possible to feel more presence in VR and they concluded that it is indeed possible [18]. This helps to prove that VR spectating can have a benefit related to presence compared to non-VR spectating. Finding ways to enrich the experience by utilizing the benefit provided by VR is important. However, there is some big problems with this paper, and potentially many others. They used an outdated and old VR device for their study which provide a sub optimal experience for the participants. Immersion is tied to the quality of the VR device, and presence without immersion is a difficult challenge. It a challenge to use any research on old and outdated devices on the effects of newer consumer level devices. Modern VR devices are several generations in front of the once used by the researchers. However, any reported level of immersion and presence is most likely to increase as devices get better and virtual worlds more detailed.

Another, and older paper looked at field of view and its effect on immersion, presence and VR sickness[17]. They found a positive correlation between pretense and simulation sickness. This potentially indicates a challenge with VR where more engaged users will get more VR sickness. They also found a negative correlation between VR sickness and enjoyment meaning users that got sick playing did not enjoy it as much, to no surprise. This can potentially show how higher levels of presence can lead to VR sickness that lead to a less enjoyable experiences. VR sickness is reduced with each iteration of VR devices, but the effect might never disappear completely. The study is from 2002 reducing its value on current generation VR devices. It has the same problems as the last study with outdated VR systems. This is still something that needs to be investigated. Spectators getting punished for feeling more presence can easily diminish the potential use and value of VR spectating. The next generation of consumer level VR devices might improve to the point where VR sickness is a thing of the past, but the problem is still prevalent in this generation.

A key part of VR systems is the stereoscopic effect by seeing a different image on each eye. A paper from 2012 looked at the effect of this effect on spatial presence, anxiety and cyber/VR sickness. The results did show an interesting finding where spatial presence was significantly improved in VR using stereoscopy. This is the sense of being in the virtual world instead of the real world. This finding should not be a surprise as modern VR systems are built upon the idea of VR being able to make the user believe they are in the virtual world. This is good news for VR spectating as it can help the spectator to feel as they are in the same world as the player, not separated away by a computer screen.

2.5 Virtual Reality Telepresence

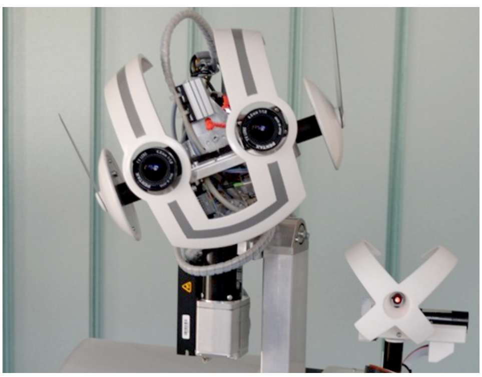

Figure 4: The robot being controlled

Being able to move a remote robot around could be a way of handling real world VR spectating. This is partially what a team of researchers did when they compared controlling a robot using VR and just observing the same room using standard cameras [10]. The robot used can be seen in figure 4. This could work just as well as a way of telepresence as a way of spectating in the real world. However, they did not find any strong evidence for a benefit from this setup. There was no change in social presence, and only a slight benefit to spatial presence, but that might just be due to VR stereoscopy. Social presence can be defines as being together with others, as a subset of telepresence. The benefit here to spatial presence can translate into a benefit of spectating using VR when spectating VR. Being able to determine the distance to an object is harder on a standard 3D screen, and the 3D stereoscopy added by VR can help the spectator to determine distance in the game scene. The study has some weaknesses including an old and low quality VR device that limits immersion. There is a potential for further work where the same experiment is redone using the latest consumer level VR devices to see if the effects are more noticeable with the improved technology. The paper can also help to serve as a further work for this master project where real world VR spectating is looked at.

2.6 Long term Virtual Reality usage

There is a recent paper published that addresses many of the ethical issues related to VR development, usage and research[19]. Most of these are not relevant for this project, but can influence VR spectating past the scope of this planned project. One key aspect is the long-term impact of virtual reality, especially on children. The effects of using VR for several hours each day for years has not been extensively researched. There is, as with any new technology a chance that high usage can lead to adverse and permanent effects. It could for example cause eye development issues in children, which is already a problem as myopia is already prevalent in some countries. The long-term success of VR spectating is dependent on solving these issues. If current generation devices cause problems, we will need to know about it. VR spectating can bring in a large new user base for VR and they will not take well to potential long term damage.

Another related ethical issue is the effect VR can have on the player, but also on the spectating. VR removes and layer of abstraction between the player/spectator and the virtual world. Horrific and scary scenes can potentially have more of an impact compared to non-VR. This also applies to other types of genres like action games. Seeing someone shot in VR makes it more immersive, and potentially damaging to the person viewing it. Streamers already have age limits on sensitive content, and it will be even more important when it comes to VR spectating. Being in the same VR space as the actual player have the potential of affecting the spectator just as much as the player.

2.7 Related products and companies

Academic research related to VR spectating is scarce. However, there is some companies developing VR spectating solution. The three are Silver TV, Vreal and HTC mixed reality. Each of them serve a different purpose, but no one is offering an ultimate and complete solution to VR spectating.

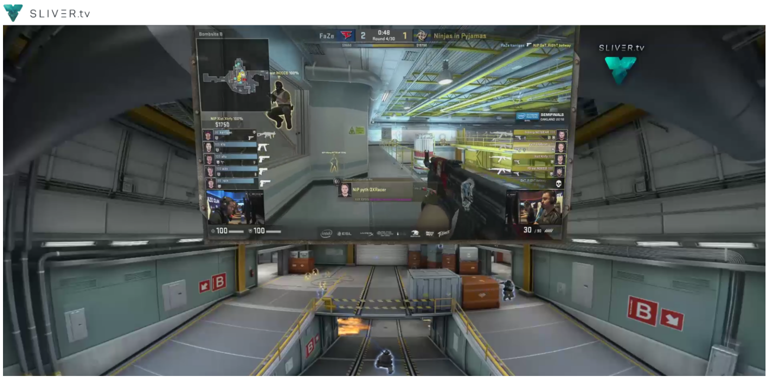

Figure 5: Silver TV spectating [20]

The first one, Silver TV is a esport VR spectating platform. They provide the ability to merge 360 video with game information overlays to provide a rich spectating experience for the users. They are currently relying on phone based VR with 360 video where the spectator can see either a camera on the esport stage, or on relevant places inside game. They also provide the ability to have 2D screens appear in these 360 videos to show for example the tournament commentators, or the scoreboard. They limit themselves to esport tournaments, and no not serve as a choice for more average streamers looking to enchant their VR streaming. Despite this they provide a potential solution for VR spectating as they show how beneficial it can be to place the spectators in strategic locations, known as choke points. These points are places where the action in the game tends to concentrate, especially in competitive games. The 2D info screens can be re-applied as well. Certain information will always be needed by the user and can potentially be used to preview other choke position before moving there. Several screens can be utilized to provide a view of several ongoing engagements at the same time. They can also be used for viewing the perspective of the player playing, as seen in figure 5.

Vreal is a company dedicated to developing Full VR to full VR spectating, using what they call shared reality. They are focusing on spectating full 6DoF content using full 6DoF spectating. This partially overlaps with the goal of this master project and are the most relevant company to draw inspiration from. Data on their plan is not well defined, but their end goal is something like a VR world you move around in, and can see potential VR streams as hovering platforms. Opening one of them will then allow you to see the player/streamer in VR move around and play the game. This is more of a social platform than any of the alternatives. It is hard to draw inspiration form such a vague source, but utilizing their social aspects can benefit this master project as well. Being able to have some interaction between streamer and spectator can help to build a bound between them. Streaming sites feature this already in some ways where the stream have a text chat, and the streamer can speak to the spectators using a microphone. Text chat is not as useful in VR currently due to the low resolution, but voice can be used as a replacement.

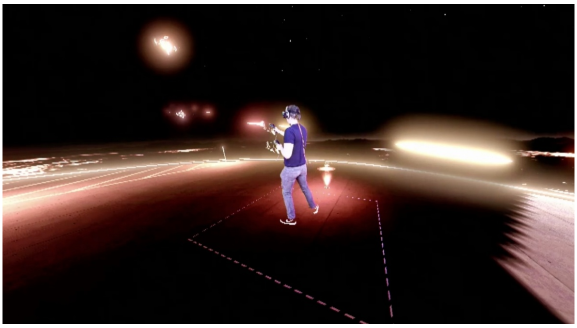

Figure 6: HTC mixed reality spectating [21]

HTC mixed reality is a way if mixing the in game virtual world with the real-world person playing. It requires the person playing to be put into a green screen room while paying and an either static or dynamic camera record them going around in the room. The two video feeds are combined by replacing the green screen with the in-game visuals. The resulting video makes it look like the player is in the actual VR world and can benefit these dedicated to the requirements. This combined video can be seen in figure 6. However, most streamers and gamers do not have a green screen room available. It also requires a cameraman for optimal camera positions. This will push the requirements so high it will need a dedicated team only available to professionals. Another challenge is how the setup requires two in game camera positions to be rendered, one for the player and one for the camera. This doubles the requirements for the already expensive VR computer. Using this as a foundation for a VR spectating system for the masses is a bad idea. Ways around this, that will be explored it just to use the in-game headset and controller tracking to append a virtual avatar to it. The success of a VR spectating system will depend upon its complexity in relation to its reward. Most gamers looking to stream their VR experience do not have the resources for expensive high end solutions. Proper VR spectating needs to work with the resources currently available.

2.8 Virtual Reality development

The success of any VR spectating is related to the difficulty of development, and what kind of developers are working on VR titles. The key challenge in 2016 is the lack of potential customers. Looking at one the VR systems, the HTC vive we can determine rough sales numbers based on one of the included games that require steam activation; Job Simulator[22]. This is a VR only game and thus needs a VR system to be played. As a result we can use sale numbers from the game to determine roughly the amount of vive systems sold [23]. The sale number is approximately 110 000 units. This means any sales for VR games is capped for the vive platform at this number. The problem in relation to VR spectating is that the market is small, and the developers are not earning as much as they could in other markets like the console market. Smaller teams with smaller development budgets do not have the ability to custom make a VR spectating system for their games. A general and easy to use system is needed. The few teams that manage to make finished VR games will need ways to show off their games to their full potential. Just screen mirroring is limiting this preview of gameplay. There is also the problem of exclusive deals in the marked. Game developers need these deals in order to survive, but they usually limit the game to one VR system[24]. This is causing problems in the community and helps to point out how important it is to have a VR spectating system that works with any device, not just limited to a select few.

2.9 Cave automatic virtual environment

Cave automatic virtual environment (CAVE) and CAVE2 is an immersive virtual reality environment not relying on a HMD as modern devices like the Rift and Vive are. Version one uses squared walls with projectors and version 2 used an array of TV screens to form a coherent image for the user. It works in some ways as a giant HMD where the user stands inside it. The system is large and expensive, as stated in the original paper [25]. It does not require the user to put on a HMD and it allows the user to bring in more people into the CAVE system without extra system. however, only one person can be head tracked at a time as the system only can output one correct perspective. This challenge is highlighted in the recent movie mission impossible: Ghost Protocol's hallway scene [26] where a mobile screen is mounted in a hallway to project an empty hallway between it in order to hide some agents. The system needs to account for the position of the observer and render an appropriate image for that perspective. However, the system fails a more guards arrive and the system can project all the new perspectives onto a single screen[27]. This is a challenge with CAVE. A large and expensive setup that can only fully be used by one user at a time. Other challenges include a fragile setup with is not suitable for any museum like environment, and it is hard to document by taking picture or video of it as it would require a 360 capture to get all the screens. The system is best suited for research and development in universities and large companies.

Version 2 of the CAVE systems uses an array of 72 LCD panels and offer improved resolution, tracking and usability of the previous system[28]. Both VR using HMD and the CAVE VR system are starting to focus more on VR collaboration. A recent paper evaluated to benefits and challenges of each system and performed experiments to determine which system is best suited for VR collaboration. The experiment results conclude that the modern HMD systems like the Rift offers and clear advantage over the CAVE system in certain areas and similar in others. Given the cost difference this could potentially lead to HMD VR systems replacing the CAVE system in areas like VR collaboration.

Either the CAVE 1 or 2 is suitable for virtual reality spectating, but the target audience for VR spectating is consumer level VR which the CAVE system is not. Any spectating system develop would only benefit a small number of CAVE system is use and they are dedicated to Research and development rather than spectating and entertainment.

2.10 Virtual Reality and Drift

In general, there are two ways of handling the position and rotation of a 6DoF HMD. Either using an internal accelerometer and gyroscope, or relying on external tracking using fixed location trackers. High end systems like the HTC vive rely on both systems. Combining both gives the best result, but is more expensive. External sensors are the most expensive and requires a setup rather than being able to use the device anywhere alone. Mobile VR systems like google daydream relies only on internal sensors, but this setup suffers from VR drift. This is the problem where small errors in the accelerometer and gyroscope accumulate over time and cause the origin to be offset from its initial position. This causes problems for the user as forward in the game moves around, reducing immersion. Solving this problem completely has the potential of removing the need for external sensors as the internal sensors can handle all rotation and position tracking. External sensors do not experience drift due to their fixed position. The Oculus rift developers have look at this problem to reduce the error rate [29]. Theirs proposed solutions reduces drift significantly, but does not remove it. Having a HMD that offers the same tracking as current base station bases setup will significantly reduce the barrier of entry as the setup can be used everywhere. VR spectating is strongly dependent on the availability and ease of use of VR HMD systems. Reducing drift to a tolerable level would potentially boost the availability of VR spectating as it can easily be used anywhere and not to a fixed base station setup.

2.11 Real world Virtual Reality reconstruction, and spectating

The focus for the experiment was to make a Virtual reality spectating system for spectating VR games and events. A key difference from mirroring based spectating is the fact that a new perspective is needed were the acting player is not. This is what the VR spectator needs to have all the game data available as they should and could move almost anywhere and that new perspective needs to be rendered. This is not a major challenge for computer games/simulations as this information in available within the running game. However, this is not the case for real world events. We don't have access to the position and velocity of all the objects in a real-world sports game like football. A solution to this is to make a digital reconstruction of the real world in VR, as described in [30]. The paper discusses applications for virtual cameras and 3D TV content, but it can be taken a step further with more data, better algorithms and more cameras and be turned into a station wide 3D scanner. The cameras could be placed around the stadium to capture all angles of the play happening and transform this data into a virtual world live. Games like football would be easier to transform as the players are already running around on a giant green screen with could be used to asses' wheat are players, and how far they are from the camera.

2.11.1 Eye tracking

Eye tracking in VR is the addition of a sensor inside the HMD what track the user's gaze and relays this information to the game/application. This is not currently supported in any of the three major VR systems (PSVR, vive and rift), but is being added by third party developers. Future VR generation have a high chance of including eye tracking due to the benefits. Eye tracking enables developers to use the user gaze to interact with the world, or other users. User interfaces could be made that rely only on where the user is looking. This makes for more natural user interface that require less effort to use. Other application is Gaze Prioritized Graphics with enables foveated rendering [31]. This is a technique for reducing computational resources for VR by only rendering what they user looks at in high resolution. The human eye only has a small center of vision where we can prove detail. The rest of the eye's field of view cannot perceive as much detail, and this need not to be rendered the same level of detail/resolution as the center. This could reduce rendering time and resource significantly, but is only possible to do with eye tracking. Eye contact is a fundamental form of human communication that is lacking in current generation VR systems. Eye tracking opens this new way of communication which removes a barrier for immersion currently in place. This is critical for any social aspect of VR and VR spectating. Being able to make eye contact with other players and/or spectators is required for deeper and more personal interactions.

2.12 Changing the rules of games to the benefit of the spectator

Some sports games like football and volleyball are relatively easy to follow along with the acting. There is one ball, and scoring is, for the most part, easy to understand when it happens. However, this is not true for all sports like for example table tennis[32]. The high speed of play and a wide range of spin maneuvers make it hard to follow for novice spectators. This problem is even more prevalent in some video games like for example Overwatch where it is hard for even experienced players to follow the action. This is due to the chaotic action happening in parallel among all the 12 players. Each of the players have a goal they are working toward achieving and winning is just an end goal, not the immediate reason for the chosen strategies. The design choices that lead to this chaotic gameplay is made for the players, and not the spectators. Each player is more engaged as they play as everyone have something to do at any time, but all this chaos is hard for spectators to understand. Being able to see how a play from one player influenced or amplified another is hard, even for pro players to understand. This reduces the spectating potential of the game as spectators do not always understand what is happening, and why one team won, and another lost. This leads to a discussion on whether any spectator heavy game should be changed to appeal to spectators, making the action easier to follow for inexperienced players and spectators. A portion of the spectator crown will never play the game, and they do not get the game scene and understanding players get from playing the game.

2.13 Spectating and revenue

Professional sport players and video game streamers need to make money. Hobby streamers that only dedicate a small portion of their available time to streaming could survive with zero income from the activity, but any full-time streamers, and sport players need to make money in the long term from the activity. Playing games, either video games or sport games does not create intrinsic revenue for the players, but they rely on revenue from the spectators, directly or indirectly. For real world sports this could include ticket prices, sponsor deals, and advertising. The revenue stream for video game streamers are a bit different, but they still rely on sponsor deals and advertising. Additional sources include subscriptions and donations, especially for Twitch streamers. Advertising, either directly or indirectly is by far the biggest source of revenue for real world sport events [33]. Breaking down the data for streamers are harder, but looking at a Twitch example we could see how advertising is a significantly smaller portion of the income as more direct revenue from the spectators are more common due to the prevalence of ad blockers in the internet [34]. Income inequality is significant in the industry as the biggest star in for example football earth almost 50 million dollars, while the drop is significant further down the list [35]. Numbers are harder to extract for twitch streamers, but several could be making several hundred thousands of dollars each year, or more [34]. Both sports players and video game streamers are treated like celebrities with dedicated fans that follow their every move. This is a key revenue source for both, but streamers are more dependent on this aspect. This is becoming a norm in online streaming and video content creation due to the low revenue from advertising alone, due to the prevalence of ad blockers. Several services like Patreon[36] have emerged in the last few years with the goal of solving this dependency on advertising. The service allows subscribers, spectators and fans of giving money/revenue directly to the creator giving them a stable revenue source.

Increasing the revenue in real world sports is a constant battle. Several changes to sports events and gamers have been implemented with the intent of make more money. One example is the technical timeout in volleyball stipulated by the Fédération Internationale de Volleyball which are a forced stop on the game while advertisement is shown. Another recent example is how Norwegian TV channels now are allowed to show advertising simultaneously with a broadcast as a split screen [37]. This is done to not break up the broadcast of the event with advertising slots, while still being able to expose the spectators to more advertising. This is a needed change for advertising in spectating and showing any sport on TV, or streaming a game in progress on Twitch has a major problem where the content cannot be broken up except for pauses in the gameplay. A football game cannot be cut off mid game for some advertising as an important play could happen at the same time. This is also true for streamers as interrupting a live stream with a advertising could prevent the spectators from seeing a critical moment in the stream. Another solution than picture in picture could be to have the live stream lag behind by a few minutes and insert an advertisement when there is some downtime is the gameplay.

Twitch have recently added another source of revenue for streamers where the spectators could purchase them game being played directly on the streaming website with 5% of the sale going to the streamer [38]. This is not a significant revenue source, but could help to make the work a bit more profitable for the spectator. Some of the more popular streamers on Twitch like Destiny[39] already reportedly spend more than 60 hours on steaming in any given week. It has become more than a full-time job. This is due to several factors including the steep curve to success as revenue start out bad and almost go up exponentially or the streamers. A lot of hard work with close to no reward are needed in the beginning to make a profit in the future. Gaming no longer will be than same as they need to play as a job, not just for fun.

2.14 Streamers and personality

There are a few core reasons spectators watch streamers on sites like Twitch, and YouTube. There is content that exclusively focus on skill like esport players and speed runners (A speed runner is someone that try to finish a game in the shortest possible time). However, not everyone streaming have a skill level that allows them to play at esport level. Streaming have also become a new form of entertainment for the spectator audience. A new culture is emerging with the focus on the streamers personality, or a character they portray while streaming [40]. These streamers might not have the highest skill, but the make up for it by portraying a charismatic and lovable character for the spectator/audience to watch and participate with. A good example of this type of streamer is PewDiePie[41] which has the most popular channel on YouTube currently [42]. He played games while providing jokes and funny commentary for the audience. The actual game disappears into the background as people come to the channel/stream for his personality, not for the games or his gaming skill. This focus on personality rather than gameplay allows the streamer to diversify what games they stream as spectators don't come for that one game. They are open to seeing a wide range of games which is a good opportunity to expose players to new games. The streamers are sometimes offered lucrative sponsorship deals where they are required to play a certain game and show it to their spectators.

3 Taxonomies

3.1 Taxonomies overview

This chapter aims to classify, group and clarify important terms and elements within VR, spectating and e-sports. There is a distinct lack of relevant pre-existing taxonomies for VR spectating. Properly categorizing these terms are an important part of this thesis.

3.2 Levels of Virtual Reality

All the currently available VR system can be put on a spectrum related to the level of control/interaction by the user. The focus here will be on VR systems utilizing HMD display. Other systems like the CAVE [28] exist, but will not include in this spectrum as the target systems are consumer levels, which the CAVE is not. The lowest end can be defined as non-VR systems like normal computers without any HMD and the currently highest end system is 6DoF room scale systems. Room scale and 6DoF are two different, partially independent variables in the following list. Room scale refers to if the player can move their body around in the room, and not just move their head. A 6DoF headset can work without room scale, but room scale cannot work without a 6DoF headset. An illustration of room scale can be seen in Figure 7.

From the top, down we have these important steps:

1 Full room scale 6DoF
2 Limited room scale 6DoF (standing/sitting, but stationary)
3 6DoF (HMD only)
4 3DoF (Can only rotate head, not move around in 3D space)
5 Non-VR 3D experience

Only the HMD is categorized and any potential controllers come separately, but generally does need to have 6DoF if they can be directly used in the virtual world/space. Two examples here are the 6DoF controllers for the HTC vive room scale system with function as virtual hands and on the other hand we have the Xbox one controller for Oculus rift that do not appear in any shape or form in the curtail world and just work as a normal console controller.

Anything less than 6DoF (Like 3DoF with Rotation, but not translation) will seriously reduce the immersion in the virtual world as any natural head movement to any side will not be translated into the virtual position. One example of this is

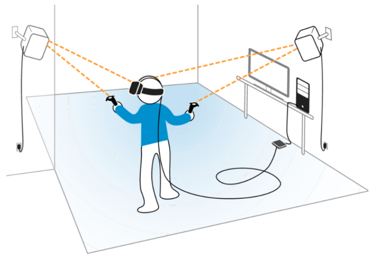

Figure 7: Illustration of room scale [43]

the first development kit by Oculus rift with caused many players to experience severe motion sickness as there was a large disconnect between what they did in the real world and what happened in VR.

Room scale systems like the first (1) offers the greatest immersion as they player can move around in the VR world by moving in the real world. However, one key challenge is that this setup requires a large space dedicated to VR. HTC vive room scale needs approximately 4x4 meters of space with is a lot for people living in small apartments. One solution to this challenge is using the second setup (2) which limits the movable area to only the space they are standing/sitting on. This still allows for mapping body movement to VR, but at fair less space. The downside is reduced immersion as they cannot move around.

The last element (5) is not technically a VR system, but any computer that can render a 3D world allows for interaction with a virtual world, even if just using a 2D screen.

3.3 Reality–virtuality continuum

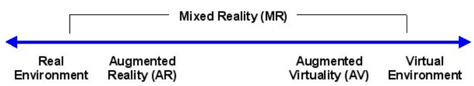

Figure 8: Illustration of the Virtuality Continuum [44]

The reality–virtuality continuum is a preexisting scale between the completely real and completely virtual [45]. It helps to properly define a few terms on a continuous scale, making them easier to define in relation to each other. The scale can be seen in Figure 8. The scale starts on the left at the real world with no virtual, and/or computer generated components. The next step is augmented reality (AR) which is mainly real-life with some virtual elements added. An example of this is Pokémon Go where the real-world camera feed of the phone is combined with virtual Pokémon's on screen. The next step is a less known element, which is Augmented Virtuality (AV). This is the opposite of AR as it is mainly virtual world, but with some real-life elements added. An example of this is a VR world where a camera feed from the real world is added. There is no clear border between AR and AV, more of a continuous scale. Both two are under the mixed reality (MR) group which is any combination of both the real, and virtual world. The last element on the right is virtual reality (VR) which is complete virtual and with no element of the real world. This scale helps to visualize and categorize the continuum, even if no clear borders exist between some of the elements.

3.4 Levels of VR spectating

3.4.1 Levels of real world spectating

Broadcasting, and watching a football game on a standard TV is not a challenge anymore. The broadcasters have a series of 2D cameras they switch between and stitch together a consistent livestream of the even for spectator to watch at home on for example a TV. This can be enhanced by adding different view directions/cameras on different channels/streams. However, moving into the three distinct levels OF VR adds a new level of problems. Spectating a sport event using the lowest, 3DoF is technically possible with 360 cameras. The broadcasters can add these cameras at strategic locations and allow the spectators to switch between them at will. This is possible to do with currently available technology.

Moving up to 6DoF (adding translation) is where the challenge is. Broadcasters cannot just add some more 360 cameras and hope it will work. Moving your head in 6DoF will require a camera for any potential head position which is impossible as tracking is down to sub millimeter position. "true" 6DoF spectating of real world events would require a 360 camera for each millimeter, which among other things would block each other. This is even more challenging with room scale where the spectator can move around as well. There are several solutions to this problem.

One is to add 360 and/or 2D camera feeds into a virtual space, like walking around in a room full of TV. This would not be true VR spectating as they are only seeing 2D streams inside a 3D world. This is also known as augmented virtuality, adding the real world into a VR world.

One partial solution is to have movable 360 cameras for each spectator, like for example drones. These drones would then move per the HMD position and try to track properly. The problem here is that the flying drones would never be able to react fast enough compared to the head movement of the spectator. Another challenge is scaling as each new spectator would require a separate drone. Not a great solution for large events.

Another solution is to take all the camera feeds and generate a virtual world based on the camera feeds. This would require cameras with depth sensors to get anything more than a 2D world. This would cause a loss of detail and sub optimal translations into the VR world. However, this spectating mode would allow any spectator to walk anywhere on the virtual football field. This might be more feasible in the future with more high resolution cameras and better algorithms for translating the real world into a VR world.

3.4.2 Levels of spectating services

Some games like Dota2 [46] and LoL [47] have their own VR based spectating modes, but these are hand crafted for each game and does not work on other games. There is generally two ways of handling spectating; either make a in game spectating mode where the spectator joins the game in process, or the players streams their game out to a third-party service, like twitch or YouTube. The following sub section describes and evaluates some well-known streaming services, and some newer, more VR focused streaming services

Twitch

Probably the most well-known video game streaming service is Twitch.tv with over 100 million views a month [48]. The service has a heavy focus on live streamed video game content, but also offers some level of playback on demand. The service works by screen mirroring spectating which makes any setup easy, but control limited. The service does not offer any extra service or benefit for VR streaming. The focus in on non-VR content.

YouTube gaming

YouTube is a primarily video sharing and viewing service with no special focus on video game streaming until they recently launched YouTube gaming[49]. The service is launched as a competitor to Twitch, but with a different revenue model. The service is like YouTube and mostly only different in design. It does technically support live streaming of 3DoF 360 VR video content, bit requires a lot of integration to work. The focus is on non-VR content, but support for up to 3DoF.

Silver.tv

Silver.tv is a esport focused live streaming service built for limited VR [50]. It supports mainly 3DoF using mobile devices and desktops. The setup works by having strategically placed 360 cameras both in the game and on the stage where the esport tournament is happening. The crew then switches between these cameras for the best viewing angle as well as having a large 2D screen inside the 3DoF VR world which shows relevant content like player's screen in a mirrored way. The service is currently new and have a small user base. It is not targeted toward average video game streamers and only works on dedicated setups at esport tournaments.

The focus is on 3DoF VR streaming.

VREAL

VREAL is the first and only real 6DoF spectating service [51]. It is still under development, but aims to cover all the needs of full room scale 6DoF spectating and streaming. The spectators are in a VR space where they can go in and out of games being streamed and watch in collaborative way. It will also have support for 3DoF and non-VR spectating. The service has many simulates with the prototype developed, but a comparison is hard as they have no released any prototype. The focus is on full 6DoF room scale spectating, but with support for the lesser levels of VR.

3.5 Passive, active and interactive spectator

A key concept regarding video game spectating is the distinction between a passive, active and interactive spectator. A passive spectator does not interact with the stream in any significant way. They watch it without any meaningful control over the content being streamed. This is the same as watching a football game on TV; you cannot change the camera in any way and only being able to either watch what is currently being streamed, or turn it off completely. Active spectator takes this further by allowing the spectator to have control over what they watch. A good example is joining a game in progress as a spectator and being able to change the current view at will. Another form of active spectating is watching a stream while discussing it with another spectator, on for example twitch. The key difference between active and interactive spectating is that interactive spectating allows for the spectator to affect the game/experience being spectated. This is still on step away from playing the actual game, but the border between them are blurry with active spectating vs playing themselves. An example of interactive spectating is any game where the players can see they spectators spectating the game. The spectators may not be able to do all that the players can, but their presence can affect they player's actions in the game.

4 Methods

4.1 Overview and choice of VR devices

4.1.1 HTC Vive

The virtual reality headset HTC Vive has taken the world by storm. It is made in collaboration between HTC and Valve, as both companies have a joint interest in VR. The main head-mounted display (HMD) for the HTC vive features a 2160x1200 resolution display with a 90 Hz refresh rate as well as a 110 degree field of view [52]. Each eye will inn effect see a 1080 by 1200 display, making it slightly pixelated. The HMD only weighs around half a kilo making it relatively lightweight. Inside the device there is over 70 sensors, including gyroscope, accelerometer and laser position system sensors. The vive is not only a headset, but also part of the room scale system, developed by Valve. It consists of two lighthouses at either side of the play area, usually between 1.5^2m and 4.5^2m. The lighthouses emit pulses of structured infrared laser light inside the play area that the sensors in the device picks up on. All the sensors helps to pinpoint the users position to a sub millimeter precision [53].

Figure 9: HTC vive setup

4.1.2 Oculus Rift

Oculus was the original company to revive the interest for virtual reality back in 2012. It all started with a Kickstarter campaign for a prototype VR headset[54]. The first initial prototypes (DK 1 and earlier) was the first attempt to bring VR headset to average consumers, but were lacking in features. A later updated version, DK 2, brought along increased specifications, like refresh rate and resolution, as well as head-tracking by using an IR camera[55]. The latest, and first consumer version to be released was in 2016 and have many of the same specifications as the vive, like the resolution and refresh rate, just without the hand controllers and room scale [52]. A hand controller system, Oculus Touch, is recently released as an alternative to VIVE's room scale system [56]. This will unfortunately lead to some problems as it is not bundled with the VR system, and developers need to support both versions. This is like how the Kinect from Xbox never reached its full potential.

Figure 10: Oculus Rift consumer version

4.1.3 Google cardboard/daydream

Mobile VR revolves around three different systems. The first is Google cardboard, which is a low cost, low barrier of entry VR platform developed by google. It usually consists of making or buying a cardboard head mounted case for putting a smart phone into. Many of the sensors in larger devices, like the vive, also exist in most smartphones. The system has some limitations compared to other, bigger VR devices, as it is running on a mobile device. It has seen great success despite the limitations, and a follow up system, google daydream, has just been released. Daydream is a more premium experience with a cloth and plastic versing of the google cardboard, with a hand-held controller. It also has strict requirements for the phone and requires android 7 to run. The device is superior in all specifications compared to the cardboard and should be used as long as a compatible phone is available [57]. The last system, Samsung VR works in many of the same ways as daydream, but is limited to top end Samsung phones, which excludes it from this project.

4.1.4 Target device

Several devices were considered for the project/prototype. The HTC vive was selected as the target device for several reasons. The first, and most important was availability. Simon McCallum established a VR lab at NTNU in Gjøvik where a total of 4 HTC vive systems with matching computers where installed. This allowed for several projects to be co-developed at the same time, and greatly helped with the development as it required at least two VR systems to work, one for the VR player and one for the VR spectator. However, the availability was not the sole deciding factor. The HTC vive was the only system with a robust room scale system available at the start of the project. The only relevant competitor, Oculus rift, did not have a proper system in place by the start of the project. Room scale, the ability to move around in a 5 x 5-meter space mapped directly to the VR simulation was an important part of the prototype.

Other, less capable devices, like Google Daydream and cardboard was also considered, but dropped due to the inferior immersive experience, and specifications. Only the HTC vive had all the required components, including room scale, 6DoF, and hand held tracked 6DoF controllers.

Another reason for selecting the HTC vive was due to previous experience with the system. The last project I made in VR was also developed with the HTC vive.

4.2 Choice of methods

All the questions used in the three experiments can be found in the appendix. All of the questioners where made in google forms.

4.3 TP experiment design

A short and simple study was needed before the main experiment could start, to determine if the spectator should be able to freely teleport or not. The experiment was mainly conducted as a quantitative study, but important qualitative data was also collected. The setup was two identical versions of the spectating system where the only difference was the ability to teleport anywhere as the spectator. Each participant then played both versions in sequence for a few minutes, while being aware of the goal of the experiment.

Each participant answered a google forms questioners in two parts, one pretest, and one post-test. The questioners were short and precise with a focus on preferred mode, enjoyment and immersion. The goal of the experiment was to assess user's preference for moving around as the VR spectator. The experiment was a hybrid testing session, as well as a development related feedback gathered by participants and testers.

4.4 Main experiment design

The main experiment for this master was designed to assess several key factors, including preferred system for spectating. The developed prototype served as the basis for the experiment, as it allowed for all the three spectating modes to be tested (mirroring, 3D, and VR). The experiment ran in three stages where the participant watched the game using one of the three different methods for spectating. Two

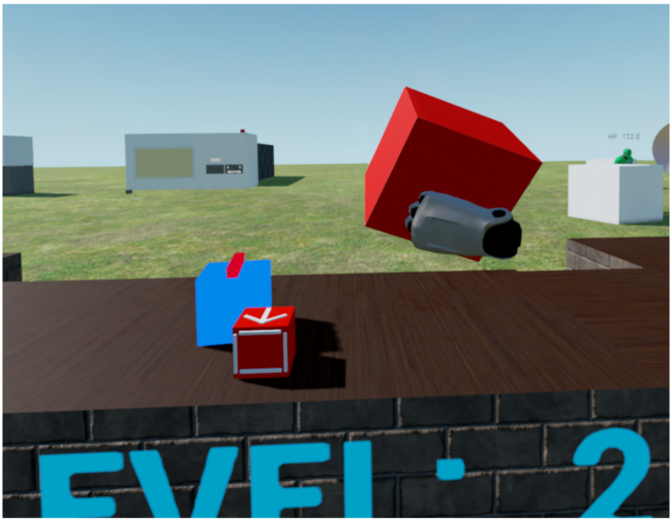

Figure 11: Activated bomb

independent people was used as the "player" in the experiment. A google forms questionnaire with 5 different parts (pre-test, mirror, 3D, VR and post-test) was administered.

The experiment was designed for two participants simultaneously as they got divided into two groups, random on arrival. Most, if not all, participants have previously watched someone else playing in VR using the standard mirror spectating mode (as is default on all VR games). This was the reason that all the participants first watched mirroring. The next part of the experiment had the participants in group A first watch the 3D mode, and then finally the VR mode, while group B did it the opposite way. This helped to parallelize the process, and have two participants at the same time. These two groups were selected to prevent order of spectating (due to especially the novelty factor) influencing the results.

The pretest was designed to evaluate the participant's preference for playing video games, watching gaming events (sport, or esport), how social they were while spectating, and how active they were when spectating. The next part was administered right after the mirrored spectating was over. This part focused on enjoyment, quality, immersion and preference for the given mode.

The next part divided participants based on their assigned group. The 3D spectating mode restricted the spectator to one of four camera configurations, focusing on automatic spectating with minimal effort required. The post questioner's questions for this mode was like the one for mirroring, but with the addition of questions for level of control and how active they spectated. The VR spectating mode

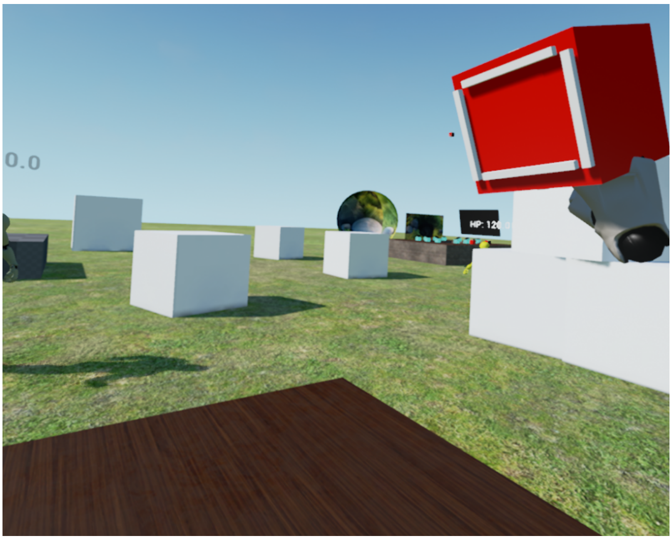

Figure 12: Adjusting VR spectator camera

placed the participant in the VR spectating room with camera cubes that could be used to watch and move to. The mode also included some features designed to enhance the experience, like the giant mode. The questions for VR was like mirroring, but with the addition of some questions for level of movement freedom, and rating of the camera placements.

The post survey focused on rating the three different modes from the best to the worst. It also looked at level of enjoyment, assessing if the participants understood the game and if they noticed the choke points. Each of the modes, and post-test, included optional comments fields where participants could type additional feedback. Each mode had the participants watch for around 4 minutes, including teaching them the controls.

4.4.1 Main experiment analyses

The entire experiment where conducted as a repeated measurement experiment where each participant in turn where exposed to one of three different VR systems, and then asked to evaluate them. This allows for individual subject change calculations, effectively showing how many users had a positive, or negative change from one system to the next independent of what they reported at the end as they favorite VR system. These values where then aggregated by summarizing the total change across all participants and doing the same for all negative and all positive values. That data was also counted by dividing them into three groups; one counter of all who had a positive change, all that had no change (neutral) and one for all

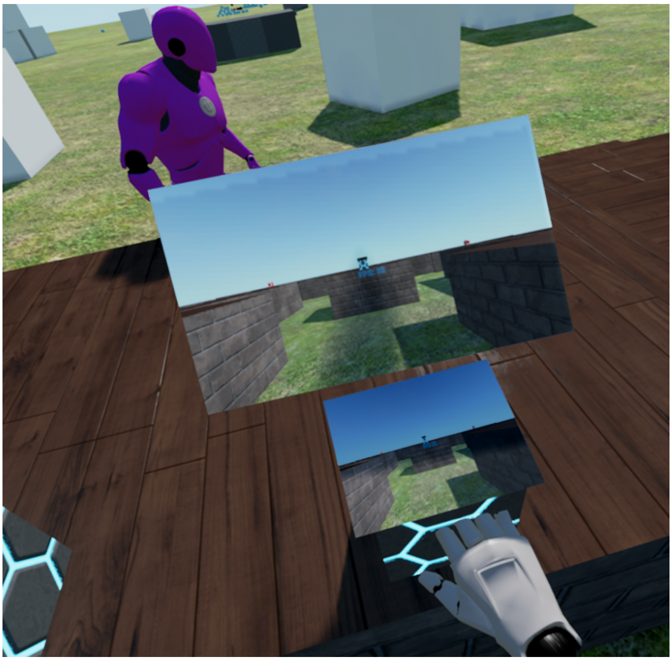

Figure 13: VR spectator camera preview

the negative. This was also done for each of the two groups independently.

The two groups were also evaluated independently to determine of ordering have any effect on the results. Both groups saw the mirrored mode first, at the same time. This would help to give a baseline before the other two modes that where in opposite order to each other.

Analyzing the results did no focus on just calculating the average values for each group. This approach is incorrect due to several factors including that the scale was not linear with an equal distance between each element on the scale. Going from 6 to 7 on a 7-point scale is a larger increase than from 3 to 4. The scale was non-parametric. A good well known example of this distance problem is found inside the grading systems in most schools. The distance between B and A are larger than between D and C, both in terms of time and skill required. A student who wants to advance from C to B needs to put in less time than a student who wants to go from B to A. The Median, and quartile 25 and 75 was the only relevant group wide values reported.

The student's t-test might suffice for the analysis, but it becomes a challenge to justify using it as the data is technically non-parametric. The scale might be on a numeric 1 to 7 scale, but the distance between number/values are different, thus causing the scale to be non-parametric and disqualifying the student t test as an option. A better option, the Wilcoxon signed-rank test was used instead at it can work with non-parametric values.

4.5 Second main experiment

The main experiment had a 3D passive spectating mode. 78 percent of participants reported that they wanted more freedom of movement in that spectating mode. This was also repeated in the open comments where many of the participants reported wanting to have a more active mode with 5DoF movement using wasd + mouse. 5DoF refers to all the positional axis and all the rotational except roll. This was the main reason for creating a second, slightly different experiment. The goal was to determine of the changes to the 3D spectating mode had any impact on the hypothesis related to VR being superior in this setup to 3D. Mirrored mode, and related questions where dropped due to time constraints and being outside the focus for the experiment. All other aspects of the experiment remain the same, except for having a new acting player (different from the first man experiment). The same tools and techniques for analyzing the data, as in the first main experiment, was used.

The roll axis was dropped as the norm within first person video games is to limit this axis as rotating in the roll rotational axis does not map easily to any controls like the mouse, as well as the axis being the least important for first person games. It is critical for the immersion of VR, but not needed in this prototype/experiment. Some games give a limited control over roll to allow players to peek around corners, but this feature is not needed in the current prototype. Allowing the 3D spectator to rotate in the roll axis could also easily cause them to loose track of where they are.

4.6 State of the art of spectating and VR spectating

Evaluating the larger field of spectating is an important aspect of assessing both the current state of spectating, and how it could influence VR spectating. The goal was to collect a range of relevant literature, both in the form of scientific papers, and less scientific publications like new articles and blogs. Collecting outside the scientific literature was done as there is a lack of relevant research on spectating related to video games. Reading and incorporating blogs and news articles will allow for a broader picture as well as the depth provided by the scientific literature. Adding nonscientific literature will reduce the validity and accuracy of the results, some, but is still a critical part due to low volume of relevant scientific literature on the subject. Several conferences occluding the acm chi conference were included due to their relevance, and partial focus on VR.

4.7 Evaluating the current projections for VR's success as a platform

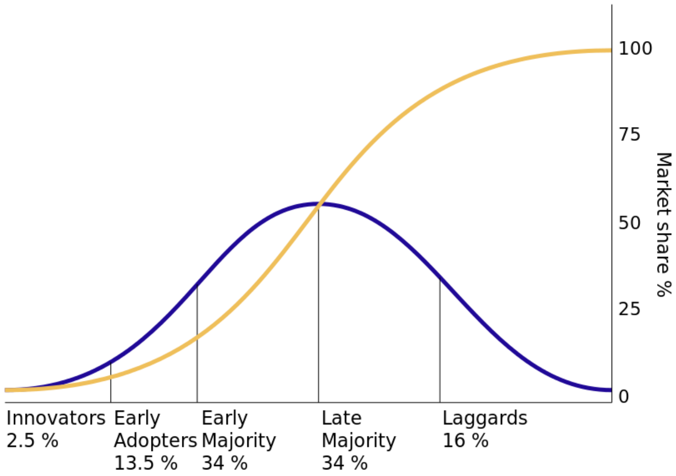

Figure 14: Diffusion of innovations[58]

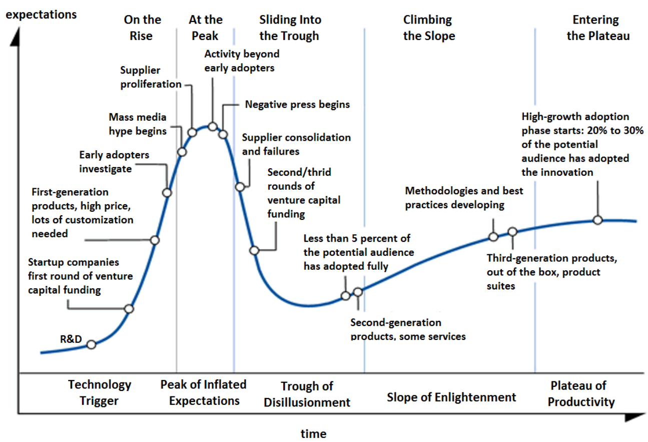

Figure 15: Hype cycle[59]

The success of VR as a platform is a critical part of VR spectating success. It is impossible to have VR spectating without VR as it both needs a VR player to spectate, and a VR system to spectate with. Evaluating this is difficult, but a few key concepts will be used to evaluate this. The goal is not to find conclusive evidence for the success of VR. More to provide a relevant discussion, and data on the subject.

Estimate the projected success of VR as a platform. While discussing what it needs to succeed, and what challenges potentially threaten it as a platform.

The core methodologies for evaluating are; Critical mass, the user-developer loop, diffusion of innovations (see Figure 14), the hype cycle (see Figure 15). The first, critical mass is a term in sociodynamics that refers to the point where adoption of a product or service becomes self-sustaining based on the number of users. The products adoption/growth becomes self-sustaining when passing the critical mass. The second term is the user-developer loop which is a positive, and negative feedback loop based on a systems adoption. The theory for the negative version of the loop is that a system with few user will attract less developers which in turn will attract few new users. The opposite is for a successful system where a large influx of users lead to a influx of new developers which in turn bring in more users. This is closely related to critical mass as the positive loops starts approximately at the same point as the critical mass threshold.

The third term is the diffusion of innovations which is a theory that attempts to explain the adoption rate of new technologies. The Figure 14 visualizes this as five different distinct categories which have their own distinct user base. VR are currently in the first parts of the graph, and it can help to illustrate, and explain what the next steps for adoption of VR could be. The last term is the hype cycle which help to illustrate and address the adoption of new technologies using the public's interest of that given technology. It is related to the diffusion of innovations as each divide the adoption of a new technology into distinct phases and user groups. The hype cycle is not entirely valid as it is created by a no scientific computations named Gartner. It is an opinion on the current state, and the future of VR which could be evaluated differently.

4.7.1 Comparison to similar gaming systems

Each VR headset/system is its own partially independent gaming system as games and applications need to either be directly made for each system, or requires alterations if ported between systems. This is in addition to each having partially, or fully independent stores for purchasing games. This allows for a comparison between a VR system and a similar gaming system, like modern consoles, like the PlayStation, Xbox, and Wii U. Evaluating critical mass and the projected success for VR can be supplemented and compared with the sales of a few modern gaming consoles, like the once described earlier. Sales numbers are available from primary sources including the systems creators for some systems, and by using secondary sources for others. Such secondary sources are less reliable, and several are needed to gather an approximate sales number.

4.8 VR development

Developing a simple two-dimensional game without any external libraries or engines is possible for a single developer within this project's time span of half a year. However, developing an immersive VR based game is not. The minimum requirements for developing a simple VR prototype with room scale working is a major challenge that can take half a year on its own. Therefore, an engine with build in support for VR is needed. A video game engine that allows the developer to focus on the game/prototype rather than on boilerplate code for running that prototype, and VR. There are in general two relevant choices for developing VR games in a supported engine; Unreal Engine 4, and Unity 3D version 5. These engines also provide comprehensive editors for making the game and even custom programming languages for controlling the game experience. The two choices approach the video game development community in two completely different approaches. Unreal engine, the oldest was mainly used by large scale game developers with several hundreds of developers, and have just recently expanded down into smaller team sizes, like independent developers. Unity 3D started in the opposite direction with small scale developers and are now scaling up to include those large-scale developers.

4.8.1 Unreal Engine

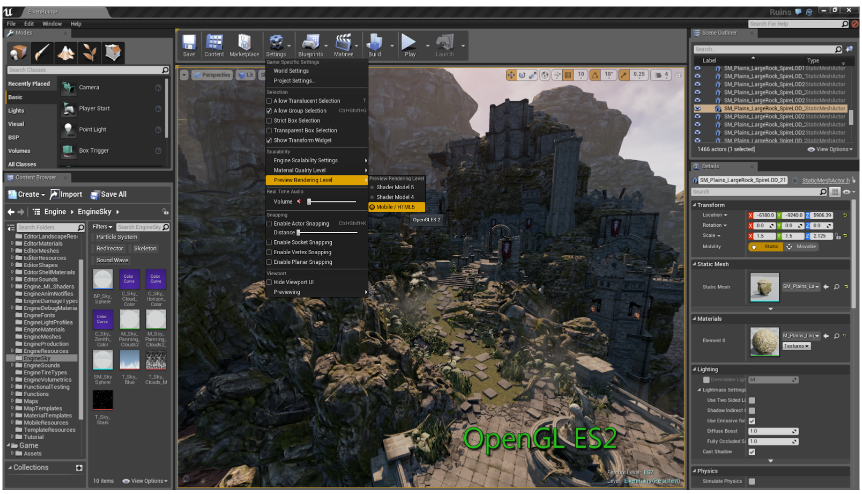

Figure 16: Unreal Engine Editor

Unreal engine is the oldest of the two. It was initially released in 1998[60] and used by its creator Epic games to power their first game, Unreal. The engine has since been further improved and the latest major version is Unreal Engine 4.

All major games platforms are supported including the HTC vice and Oculus rift. The engine is written in C++, and supports both C++ and blueprints for coding/scripting. Blueprints is a visual programing languages that focuses on speeding up development without compromising flexibility. One of its major drawbacks is the lack of good high quality documentation and it is mostly used by large scale developers that keep this information locked away in-house.

4.8.2 Unity 3D

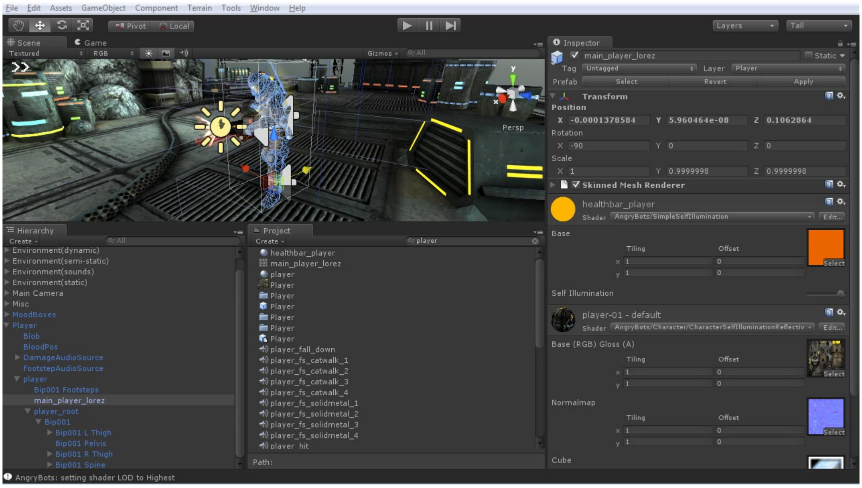

Figure 17: Unity 3D editor

Unity 3D version 5 is the main competitor to unity3D and had its debut back in 2005 by a group of Danish developers. It was originally designed just for OS X, but later added support for windows and Linux. The engine is a favorite among hobby and small scale projects due to its open nature with readily available documentation. It offers scripting in either C# or JavaScript.

4.8.3 Why Unreal

I have experience in both engines prior to starting this master. My bachelor project/game was developed in Unity 3D and my advanced project work horror game was developed in Unreal Engine. Both engines were thoroughly considered, but Unreal Engine was selected due to several key factors. One of the most important was that this master/prototype builds upon the work of another master done in Unreal engine. Continuing with the same engine saves a lot of porting work to the new engine. Having used Unreal more recently also helped to reduce initial startup time. Unreal has also a more open use policy with no restrictions until the developer starts earning money, with is not a problem for this master. The lack of documentation was a major challenge, but was manageable with the help of other master students using the same engine. The visual programing language, blueprints served as the best choice for a target language and helped to speed up development time in a unfamiliar environment/engine.

5 Implementation

5.1 The prototype

The development process was open ended with an exploratory process. Many key features for the resulting prototype where discoed during the development process and was not in any plans before they were discovered. The implementation of the prototype is important to the success of the experiment, and to any further development into virtual reality spectating.

The prototype was based the VR collaboration tool developed by another master student; Nicklas Løkkeberg Nilsen. He also helped especially in the early part of development with both general feedback, and specific help related to his prototype/tool.

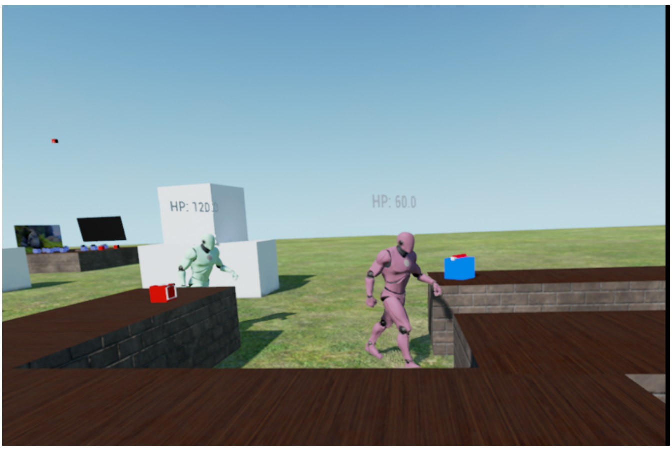

Figure 18: Enemies approaching the player and a tower

5.1.1 Blueprints

The majority of code written for the project was done in unreal engines visual language Blueprints. This visual scripting languages, as seen in Figure 19 provided all of the necessary control over the engine needed to develop the prototype. Blueprints allows for rapid development and prototyping which is critical in a time sensitive project like this master project. The scripting language functions by replacing written code with a node based interface where nodes are linked in

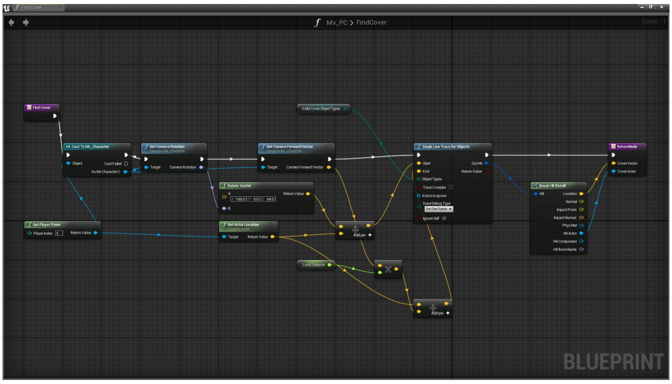

Figure 19: Unreal engine Blueprints Visual Scripting

the program's execution flow [61]. The language is Object orientated where all blueprint code is contained within one or more blueprint classes that can interface with each other, and the core engine. Each object is easily extended by a new blueprint class, and a C++ class can also be extended by a blueprint class. All the essential tools needed for computation are built into the language. The language is not optimal for math related calculations due to each operation requiring one or more linked nodes. However, the language is excellent at visualizing the execution flow of a program as each node links to the next on a continuous line with well described nodes.

5.1.2 The game

It is hard to evaluate different spectating modes without having a game to spectate. A simple first person VR tower defense survival game was made to serve as a basis for spectating. The game was designed to be easy to both understand, and play. It was inspired by another similar game Sanctum[62], of which it share many similar characteristics, even if the other game is not in VR.

The player starts the game inside a short maze with a few pre-placed turrets. The first round starts after a few seconds allowing the player to prepare some. Each wave consists of an increasing number of enemies approaching with a slowly increasing health pool. They can either be killed by the turrets, or by the player throwing spawn able bombs and mines. The bombs explode one second after being thrown, and the mines explode when some enemy steps too close. The turrets, mines and bombs have a fixed damage throughout the entire game, but the enemies get more numerous, and stronger with each wave. The game does not have any victory, or loss condition currently, but offers a suitable challenge and play time for evaluating the different spectating modes. Enemies relentlessly try to reach the player's position. This can actually frighten some players as they do not stop before they are right beside the player's face, as seen in Figure 20.

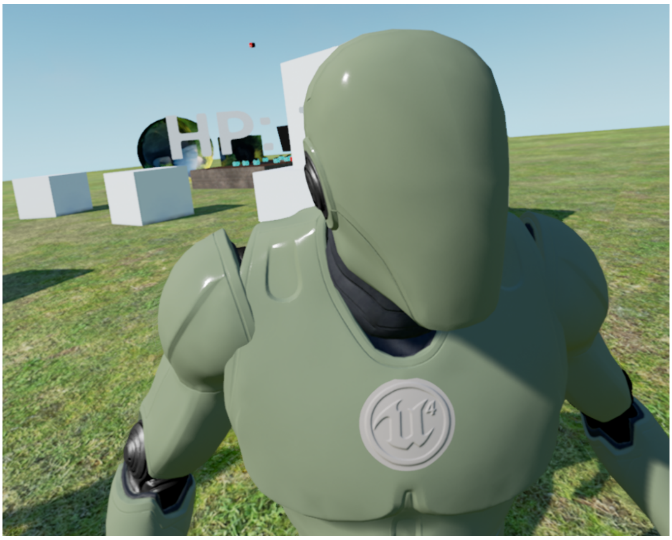

Figure 20: Enemy close up

The acting player can move around by either teleporting, or by walking using the room scale system. Bombs and mines can be spawned at will, but turrets are rewarded at certain key points in the game. These turrets can be placed wherever the player wants. The acting player can pick up the 3D spectator to lock the spectator to the acting player for the passive spectating modes. The 3D spectator can break free of this at any time. All the cameras can also be moved, and placed by the active player

5.1.3 3D spectating class

The 3D spectating mode consist of two core modes; the active and the passive spectating mode. The active allows the spectator to freely fly where ever they want to using the keyboard keys wasd + c and space for positions change and the mouse for rotation change. This is technical just 5DoF as the roll axis is not included. The mode allows the spectator to position themselves where ever they want to.

The second mode is the more passive/automatic spectating mode. This mode features four distinct modes with different functions. The first stops the camera where it is. The second mode gives a top down, almost 2.5D like experience from a bird's view perspective. They can zoom in and out in this mode for a better overview, or more detail. The next, and third mode is the third person mode. This mode tracks around a meter behind the acting player's head while having the same

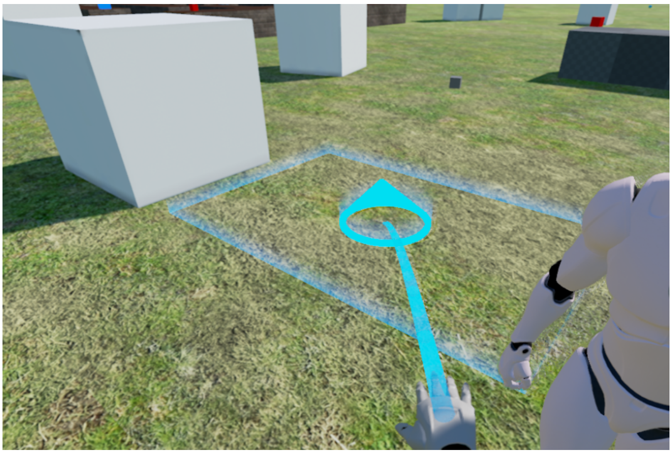

Figure 21: Moving my teleporting

view direction. This allows for seeing the same as the player. The mode has some level of smoothing/easing on the head movement. This is where some of the fast movement is eased out to prevent motion sickness for the spectator. This is needed as most VR player move their head a lot. The system works by lagging by around 200ms and easing any motion within that time frame. The last mode is the drone mode where the spectator is transformed into and automatic drone that tracks, follows and focuses on the acting player. The drone automatically adjusts height, distance to the player, and the view direction for and optimal viewing experience. The 3P spectating mode can be seen in Figure 22.

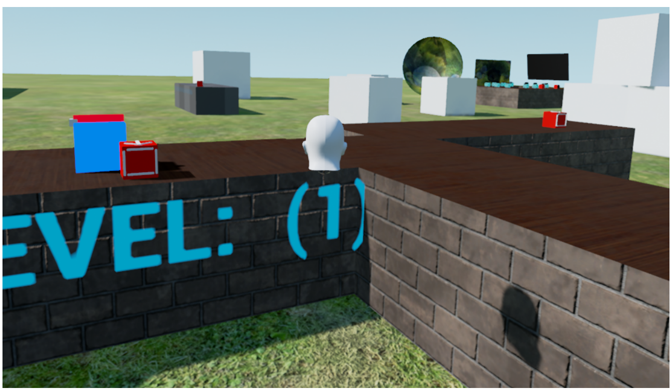

Figure 22: 3D 3P spectating mode

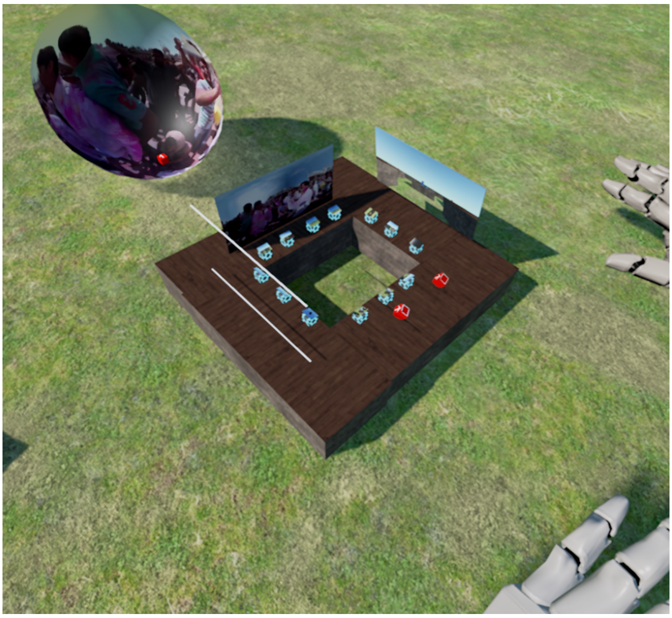

Figure 23: VR spectating room

5.1.4 VR spectating class

The VR spectating system tries to utilize the full potential of VR. The VR spectator is placed into virtual control room, as seen in figure 23. Here they have a series of cubes with a screen attached. Each of these cubes are linked to a camera somewhere in the play space/VR world. The spectator can view the camera feed from these location by holding their hand inside one of these cubes, as seen in figure 24. A feed from the camera is then displayed on a screen on their left hand. They can then pick up the cube to be teleported to the camera's location, with the same view direction. The VR spectator can return to the control room at any time by pressing a designated button. There are two camera cubes linked directly to the acting player. The first shows a first person view in real time, and the second shows a third person view. All the camera feeds can also be locked to a large TV screen inside the VR spectators control room, as seen in Figure 25.

The VR spectator control room have several other features. It has full support for video playback, both in 2D and 360. This allows for relevant video clips to be played while spectating. One use for this is provide a tutorial for the game, or showing off earlier game play sessions. This video playback solution features directional audio that changes volume based on the spectator look direction. Looking away mutes the sound. Watching a standard 2D video does not utilize the full potential of VR.

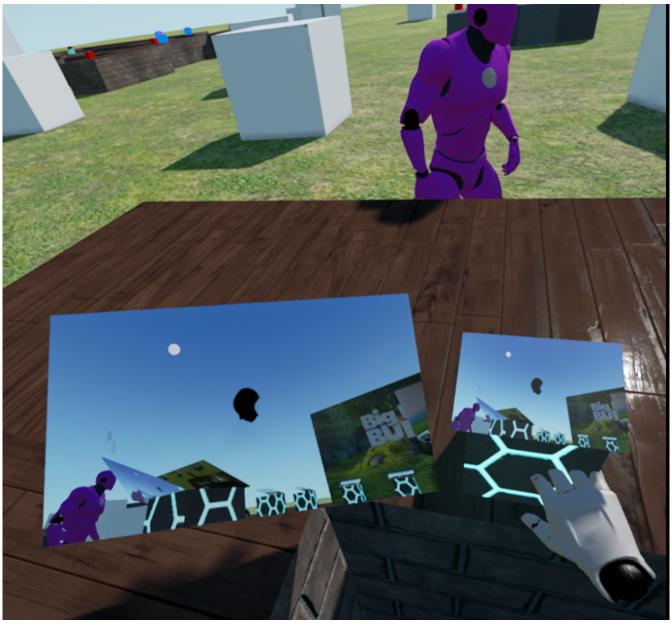

Figure 24: Camera preview on hand

Therefore 360 videos are supported as well where the player can stand inside a sphere with the video projected on the inside. Another feature is a YouTube web video player that can play any YouTube video directly in VR on any screen. This allows the spectator to watch relevant content from YouTube at any time while spectating, as seen in Figure 26. The web view does not support live streaming currently, but could be added in the future.

The VR spectator mode have a giant mode. This mode changes the scale of the VR spectator by a factor of 20, in effect making them 20 times larger. This mode is intended to help spectators get an overview of the game world as they do not have a minimap, or any map they could use. The mode was initially added for fun, but quickly proved to be useful for getting an overview of the game in progress. However, the mode causes some level of VR sickness as the perspective is incorrect, and causes a disconnect between what they see and how they expect to see the world. The VR user are not used to suddenly becoming 20 times larger in real life. The mode is intended for short used for a quick overview, and using it in short bursts mitigates the majority of the VR sickness, as only prolonged use cause it. Tester report loving this mode both for the usefulness, and the fun factor. The spectator becomes 20 times larger for everyone else too with does not look that different for other 3D spectators, but is a huge difference for another VR spectator.

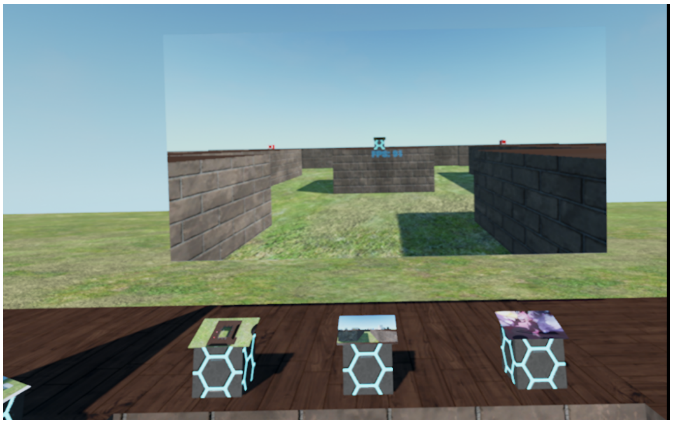

Figure 25: TV in VR spectating room

It looks like a giant entered the game.

5.1.5 Unreal engine

5.1.6 Challenges

Developing the prototype in Unreal Engine was not easy. The engine offers many advantages over its competitors including VR support, improved graphics and powerful scripting languages. However, it has a few key challenges including a lack of documentation and a development philosophy that down prioritizing fixing bugs. The editor was at times highly unstable with frequent crashes, especially, and unfortunately especially if there was a lot of unsaved changes. The auto recovery of unsaved changes from a crash did not work either. Debugging the prototype was a challenge as well as it did not have any easy way of debugging a multiplayer session. The engine did not either have the ability to show a different camera on the screen computer while using a HMD VR system. The screen and HMD screen needed to be mirrored. This made modifying the mirror mode impossible in Unreal Engine. A few core engine bugs where discovered during development which lead to some lost time.

5.1.7 Limitations and future work on prototype

The current working prototype have all the required features for the experiments, but lack in polish and balancing. The game was never the main priority and thus is lacking the most in features. Simple quality of life improvements like turrets visually firing pellet/bullets is a missed feature by testers. Other improvements to the game would be adding a win/loss condition as well as more balancing to damage values and enemy AI, health and spawn rate the game does not offer enough content or challenge over time. The game would also benefit from more turret, bombs and enemy variations.

Figure 26: VR spectating room youtube player

The 3D spectating mode have had some changes/improvements during the testing phase (before any of the experiments started), but still lack some work. Switching between active and passive spectating is technically possible right now, but can easily lead to camera rotation issues due to desynced values. Fixing this would be a high priority if the experiment is to be redone as it will allow users to utilize the full potential of the 3D spectating mode. Another missed feature is the lack of a first-person mode for the 3D spectator. This is partially in place already, but need some work as the player's head can easily block the spectators view.

The VR spectating mode have many of the same issues as the other modes where it lacks in polishing. Several key features need more work and development to achieve their full potential. Some of the comments left during the experiment pointed out several areas for improvements including larger hand held screens, more camera controls, and more refined controls. It is currently easy to lose track of which cubes link to which camera. One solution would be to bale each camera, or allow the user to group them/move they to where they want. The different camera feeds could be improved to output a video feed to file/stream. This would allow capture of several key camera during play. Several suggestions focused on further improving the camera system to support a key frame system where the cameras could be instructed to move to certain places at certain times, as well as a wide range of other options including field of view (FoV). A camera feed from the player's web camera could be included as well, making it possible to view the player moving around in the real world. This could further improve the player spectator relationship.

5.1.8 Discussion on the prototype development

Several key design choices were made during the development process. One of the decisions that caused the most discussion was the level of control the acting player should have over the spectator. The acting player can currently pick up and place the 3D spectator, but the spectator can break free of this at any time. The goal was to make the spectating modes independent in a way that the acting player could focus on playing, and the spectator could focus on spectating. This is especially important if the system is scaled up to more than a few spectators. The current prototype has no way for the acting player to control the VR spectator, except moving the red cameras.

A few of the participants reported missing the flying controls from 3D in the VR spectating mode. It was a key choice to not include this feature due to the restrictions of VR. Moving the VR player around without them moving in the real world is not a feasible option, except for teleporting. This is due to the VR/motion sickness it causes when the VR character moves while the real person stays still. Teleporting works as it is instant with no travel time. Having a movement setup like in non-VR games using wasd is technically possible, but would cause severe motion/VR sickness in several participants.

6 Results

6.1 The Gathering 2017

The first structured user testing sessions was conducted at The Gathering (TG) in Easter of 2017. The Gathering is Norway's biggest computer party where games and creators meet to play and collaborate on games. This was a perfect opportunity to conduct some qualitative testing and gather critical feedback for later development and testing.

Simon MC Callum on behalf of NTNU i Gjøvik rented a booth for showing of the virtual reality spectating system, as well as recruiting for the school. The setup was initially limited to only one HTC vive, but several other booths joined in later. A total of 4 systems where linked at one point. This helped to stress test the system and giving new feedback from user that have not tried the spectating systems earlier. One video game streamer from Komplett.no and one TV/film student from Lillehammer provided additional feedback. The testing process resembled a focus group. No questioners where handed out, but key points in the discussions was written down.

The feedback was great. Every participant reported having a good experience with the VR spectating prototype. The streamer and TV student provided additional feedback and potential practical applications for future use. The TV student lead the discussion on turning the prototype into a virtual production room, or a virtual theater/TV set. Each camera could output independently to either a stream or a file for instant or later use. Other suggestions included adding a key-frame system as well as more camera controls. This, as suggested, could work by allowing to program the cameras position during the scene as well as other parameters for it like the field of view (FoV). One challenge discussed was the computational resources required for capturing on all cameras all the time. This was suggested to be solved by either scaling up with a more powerful computer, or outwards with more computers.

Bother of the main testers (TV student and streamer) reported similar potentials and challenges, but the streamer saw a bigger potential within video game streaming. He had earlier attempted to stream himself playing a VR game, with little success. His earlier attempts at VR steaming was sub optimal and he quickly switched back to non-VR gaming. He reported waiting to use the spectating system developed for this thesis as he saw potential for it in his streaming career. The immersion and enjoyment factor was higher than with his last, unsuccessful attempt. He was later asked to further comment/elaborate over email, but never responded.

The entire testing session was a success with both positive and constructive feedback by participants. The ease of use was cited by several as their favorite key feature as many other similar projects do not take usability in to consideration and they making any attempt at testing the experience/project harder.

6.2 Mini teleporting experiment

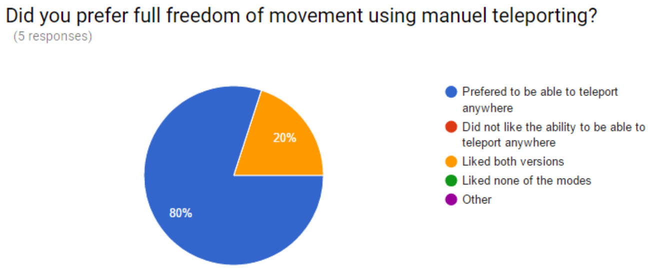

Figure 27: Main results for TP experiment

Only a small number of people participated (n = 5), but the results helped to pinpoint one mode to be superior to the other. This was backed up by qualitative data from the gathering and other testing sessions. The results showed a clear indications that participants preferred the ability to teleport anywhere, as seen in figure 27. This result was used to calibrate the main experiment and allow all VR based spectators to teleport anywhere.

The participants reported an average interest for VR of 6.4 out of 7. The average enjoyment for the experience was 8.8 out of 10, and the average level of presence in the virtual world was 5.6 out of 7.

One participant commented on how both systems for traversal complemented each other and helped to give the player more control over where they could go. Manuel teleporting was also reported to be helpful for participants in smaller VR room as they could not physically move to all the relevant cameras in the start room.

6.3 Main experiment comparing all three

The main experiment had 24 participants. Males accounted for 83 percent of participants. 66.7 percent of participants where in the age range 21-26, and with some above 30. The main hypothesizes (H1 and H3) where confirmed by this experiment. They supported that VR based spectating for this particular setup is superior

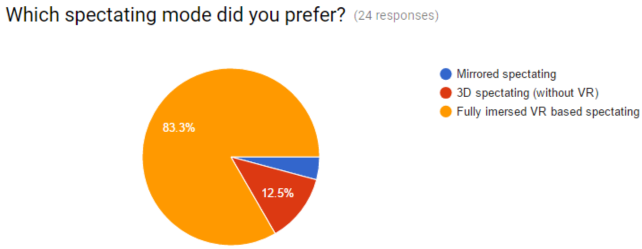

Figure 28: Preferred spectating mode

to both mirrored view and 3D based spectating, as seen in figure 28. H2 (3D > mirror) is not entirely confirmed by the study as only 58.3 percent reported mirror as the worst with 33 percent reporting 3D as the worst, as seen in figure 29. The mode and the mean for the experience rated on a scale from 1 to 10 had a value of 7 for both.

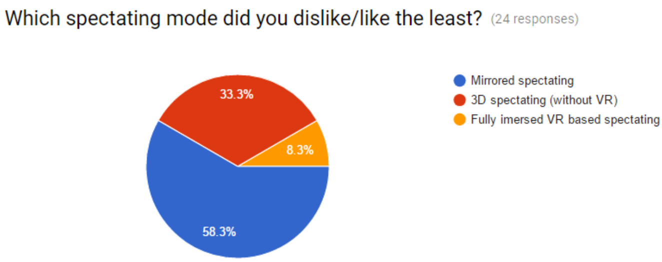

Figure 29: Worst spectating mode

Three key questions focused on the freedom of movement for spectators. The post 3D survey asked participants if they wanted more freedom of movement in the world, and the post VR survey asked if they felt a lack of control, and if they wanted freedom of movement in the world. The first question for post 3D can be seen in figure 30). The results for post VR lack of freedom of movement 31, and the results for level of control for VR in figure 32. One last related question focus on how much the participants liked the pre placement positions of the VR cameras, as seen in figure 33.

Each of the more general questions related to interest in VR, overall enjoyment of the experience and level of concentration of the action are listed below in tables. For each question, there is the calculated Median, and quartile 25 and 75 for the question.

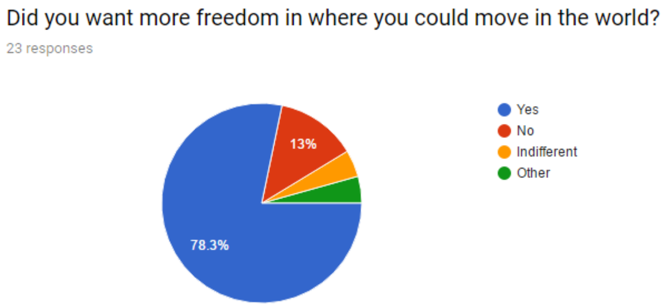

Figure 30: Lack of freedom of movement for 3D

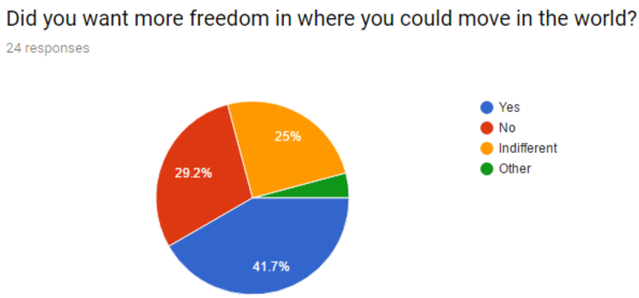

Figure 31: Lack of freedom of movement for VR

6.3.1 Within subjects evaluation

Each of the three modes was followed by three questions that also was presented after each of the other questions. They were related to enjoyment of the experience, quality of the spectating mode and immersion in the virtual world. Each data point is independently interesting, but the core evaluation can be extracted when compared up against each other for each participant. Looking at how much each participant changed their opinion when going from one mode to the next. The first table below compares answers related to the enjoyment of the activity for each mode. The ttest results, even if inaccurate are also included. The better choice,

	How interested are you in virtual reality (1-7)?
Median	6
Quartile 25	5
Quartile 75	6

Table 1: From pre questioneer

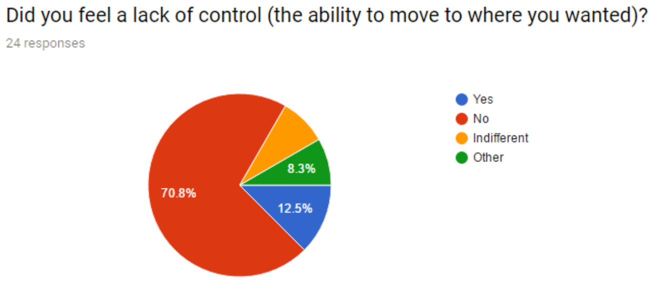

Figure 32: Lack of control VR

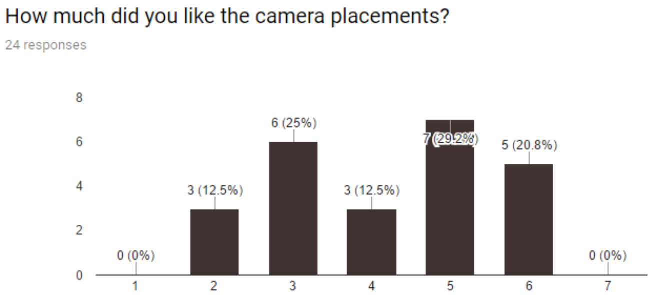

Figure 33: Camera placements preference

Wilcoxon signed-rank test are right after the ttest

The next table compares quality of the given spectating mode for all the three modes.

The third table below compares the presence reported by the participants for each mode.

6.3.2 Test order results

Participants were divided into two groups to determine if order have any effect. The tables/images below compares each of the two groups for enjoyment (figure 34), presence (figure 35), and quality (figure 36). Each of the two groups had the same questioner administered, but the last two modes where switched between

	How enjoyable was the overall experience (1-10)?
Median	7
Quartile 25	5.75
Quartile 75	8

	Did you experience that the action was concentrated in specific places (1-7)?
Median	4
Quartile 25	4
Quartile 75	5.25

	3D <- Mirror	VR <- Mirror	VR <- 3D
sum positive	7	28	35
sum negative	-16	-4	-2
count positive	6	17	21
count neutral	7	3	2
count negative	11	4	1
ttest	0.13	0.0006	0.000002
Wilcoxon	0.10 < P < 0.20	0.001 < P < 0.005	P < 0.001

	3D <- Mirror	VR <- Mirror	VR <- 3D
sum positive	9	30	30
sum negative	-10	-3	-2
count positive	7	18	17
count neutral	9	3	6
count negative	8	3	1
ttest	0.85	0.00008	0.00008
Wilcoxon	P > 0.2	P < 0.001	P < 0.001

	3D <- Mirror	VR <- Mirror	VR <- 3D
sum positive	16	89	83
sum negative	-10	0	0
count positive	11	23	24
count neutral	8	1	0
count negative	5	0	0
ttest	0.407	0	0
Wilcoxon	P > 0.2	P < 0.001	P < 0.0011

the groups (Group 1 had Mirror, 3D and then VR. Group 2 had mirror, VR and then 3D). The figures show the difference between results as a within subject's evaluation. The sums represent the total change reported for each group, and this is further broken down into sum positive and negative for each group. The last two rows summarize the absolute value for negative and positive change for a group.

	3D - Mirror How enjoyable?	VR - Mirror How enjoyable?	VR - 3D How enjoyable?
Sum group A	1	16	15
Sum group B	-10	8	18
(N/A = 0)			
sum positive group A	5	17	17
sum positive group B	2	11	10
sum negative group A	-4	-1	-2
sum negative group B	-12	-3	0
abs sum Group A	9	18	19
abs sum Group B	14	14	10

Figure 34: Order comparison for enjoyment

	3D - Mirror presence?	VR - Mirror presence?	VR - 3D presence?
Sum group A	11	49	38
Sum group B	-5	40	45
(N/A = 0)			
sum positive group A	13	49	38
sum positive group B	3	40	45
sum negative group A	-3	0	0
sum negative group B	-8	0	0
abs sum Group A	16	49	38
abs sum Group B	11	40	45

Figure 35: Order comparison for presence

	3D - Mirror quality ?	VR - Mirror quality ?	VR - 3D quality ?
Sum group A	3	19	16
Sum group B	-4	8	12
(N/A = 0)			
sum positive group A	6	20	16
sum positive group B	3	10	14
sum negative group A	-3	-1	0
sum negative group B	-7	-2	-2
abs sum Group A	9	21	16
abs sum Group B	10	12	16

Figure 36: Order comparison for quality

Using the ttest for comparing the groups is not entirely statistically valid, but is included below in table 2 for reference and comparison. The ttest is calculated

ttest for each group	Enjoiment	Quality	Presence
Mirror	0.0054	0.012	0.13
3D	0.65	0.61	0.55
VR	0.85	0.74	0.49

Table 2: TTest between groups

Wilcoxon for each group	Enjoyment	Quality	Presence
Mirror	$P < 0.001$	$0.02 < P < 0.05$	$0.10 < P < 0.20$
3D	$P > 0.2$	$P > 0.2$	$P > 0.2$
VR	$P > 0.2$	$P > 0.2$	$P > 0.29$

Table 3: Wilcoxon test between groups

between the two groups answers. Higher values indicate more similar groups, and thus reducing impact of order.

The following table 3 includes the Wilcoxon signed-rank test P values for each group as the last table.

6.3.3 Qualitative results

3D, VR and post survey had comment fields where participants could report anything not covered by the actual questions. The amount of comment where high with around 40-50 percent of participants commenting in one or more of the fields. The first comment/short answer was after the 3D mode where participants were asked "Any comments on the 3D spectating mode?" A total of 12 responses was recorder. The general consensus was how many of the spectators felt that the passive mode was too passive and wanted more control. Many suggested to add a wasd interface for full freedom of movement allowing the spectator in 3D to move where they wanted at any time, compared to the actual automatic mode they used in the experiment. Some of the rarer comments focused on lack of polish for the modes with sub optimal transitions and frames per second (FPS).

The post VR survey had a similar open ended comment/short answer with the title; "Any comments on the VR spectating mode?" 12 responses were noted here as well. The general consensus was on certain elements that reduced immersion, ideas for how to develop the mode further and on the camera placements. Some participants reported dizziness (VR sickness) in the 20x larger mode. Others reported on the screen door effect and a low resolution. Others reported on a lack of control and wanted the ability to move wherever they wanted. A few mentions that it was hard to follow gameplay when the acting player teleported around a lot.

The post experiment questionnaire had two comment/short answers with the first being; "Anything you felt was missing from the 3D or VR based spectating mode?". A total of 10 responses was registered and the focus for 3D improvements was once again on the lack of full freedom of movement using a wasd + mouse movement setup. The improvements suggested for VR focused on camera placement adjustments and on a lack of a tutorial. Several players reported struggling to remember the controls for VR. The next and final comment/short answer was titled "Any last comments?" with a total of 7 responses. The responses focused on general game polish and feedback, but it was in general positive.

6.4 Second experiment with free movement for 3D

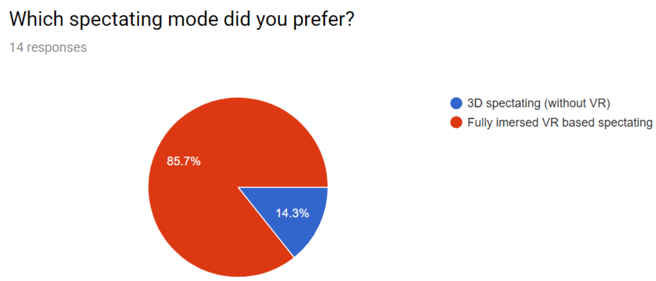

Figure 37: Preferred mode for second experiment

The second main experiment had two main differences from the first. The first was that the 3D move was changed from and passive/automatic mode into a fully active mode where they could move anywhere. The second part was that mirrored mode was dropped, as well as some irrelevant questions. A total of 14 participants participated in the experiment, with was approximately the desired target.

The overall results where similar to the first main experiment with VR based spectating still being selected as Superior by participants, as seen in Figure 37. The within subject evaluation still had the highest positive change going from 3D to VR, but less than in the previous experiment. The Wilcoxon signed rank test returned a statistically less significant result that last time for quality with $0.05 < P < 0.10$ (and ttest of 0.028). The rest of the within subject evaluation results can be found in Table 4. The three count negative of one was not from the same participant.

6.4.1 Level of freedom of movement

Figure 38, Figure 39, and Figure 40 displays the data from the main experiment two related to level of freedom of movement reported in the post questioner for the 3D and VR mode.

	Enjoyment	Quality	Immersion
sum	14	7	33
sum positive	15	8	36
sum negative	-1	-1	-3
count positive	10	7	12
count neutral	3	6	1
count negative	1	1	1
ttest	0.0018	0.028	0.001
Wilcoxon	$0.005 < P < 0.01$	$0.05 < P < 0.10$	$0.001 < P < 0.005$

Table 4: Within subject evaluation for main experiment 2

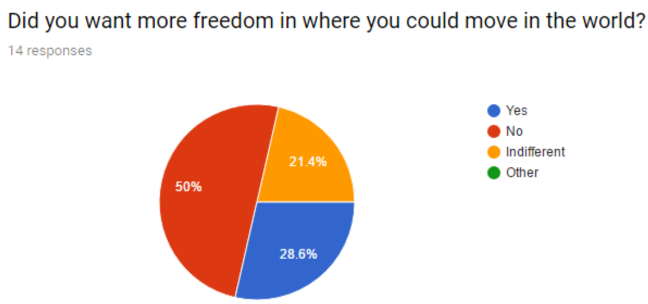

Figure 38: Response to the 3D mode for freedom of movement, for main experiment 2

6.4.2 Qualitative results

Each of the post spectating mode and overall post questioner had at least one comment/short answer for general feedback. The first one was titled "Any comments on the 3D spectating mode?" with a total of 7 responses. The feedback focused on imperfect controls as several reported feeling the controls was a bit "floaty" as the character did not come to a full stop immediately when the player stopped pressing a movement key. Other comments focus on the difficulty of following gameplay due to the player teleporting around. One participant reported wanting a spectating mode like the one in the first main experiment.

The post VR comments focused on general feedback for using VR. Some of the comments expressed a lack of interest for the camera placements as they only moved around using the manual teleport system. One comment reported how they felt the game was boring, but at the same time how the spectating system was great.

The last two short answers in the post survey had little feedback with only answers 4 for each. The few focused on the still lack of movement freedom for

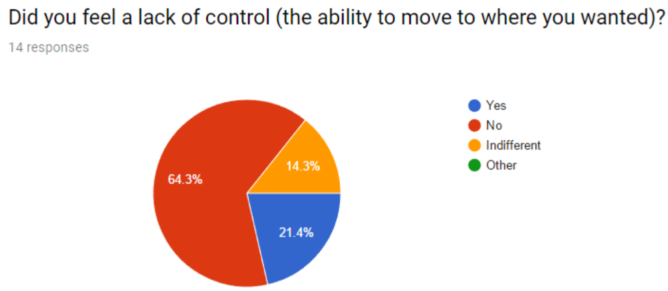

Figure 39: Response to the VR mode for freedom of movement, for main experiment 2

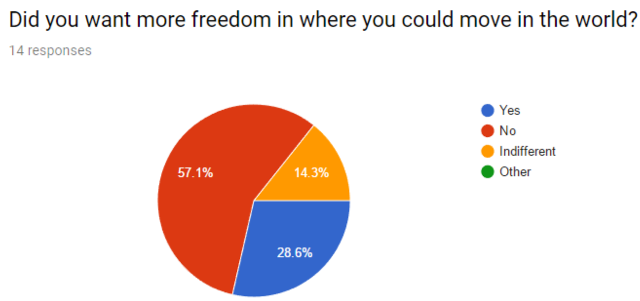

Figure 40: Response to need for more freedom of movement for VR mode, in secound main experiment

both 3D and VR as well as how some lost track of the acting player due to them teleporting around.

6.5 State of the art for spectating and VR spectating

The results of the survey can be found in related work under 2.11, 2.12, 2.13 and 2.14. The survey resulted in a few relevant papers, but the area of research is still limited. The papers where supplemented with relevant blogs and news articles covering the state of the art. Spectating is a new and rapidly growing field which reflect how important up to date information is.

6.6 VR sales and similar systems

Sales numbers are difficult to gather, but some good estimates have sales for PSVR on the top with around 900 000 units, vive with around 400 000 and rift last with around 250 000 [63] [64] [65].

6.6.1 Console sales numbers

The WiiU sold over 13 million units, but was still considered a failure due to the lack of games and less than expected sales [66]. The system was a failure due to several factors including a small games catalog at launch and outdated components in the console [67]. For comparison, its predecessor the Wii sold over 100 million units. The PlayStation 4 have sold around 50 to 58 million units [68], [69].

6.6.2 VR on the hype curve

Figure 41: Hype curve 2016

VR is currently in the early parts of the "Slope of enlightenment" according to the creators of the hype curve[70]. The figure 41 of the hype curve for 2016 shows the state for the curve in 2016.

6.6.3 Next generation of VR

Valve have stated in a interview that a new generation of the HTC vie VR system is under development [71]. The new system will include improvements to the display, lighthouses, tracking, and more.

7 Discussion

7.1 Experiments discussion

7.1.1 The Gathering 2017

The prototype user evaluation and qualitative study at the Gathering proved several key insights into VR spectating, and further development of the prototype. The open discussions regarding the prototype (from 6.1) helped to form the final weeks of the development process. The Gathering (TG) was a good place to collect feedback on the prototype, and future experiments. It is one of the worlds largest gatherings of gamers, spectators, and streamers. All the target users of VR spectating are present at this event. The participants who were testing and evaluating the prototype was from a wide background including streamers, content acquisitions, gamers, teachers and spectators. However, there was some challenges, as most participants only had a limited time to evaluate the prototype and provide feedback. The experiment was also conducted on the last day of the event causing some of the participants to be tired, and low on energy.

Implications on development

The feedback helped to shape the last weeks of development, even if the impact was not significant. Only minor changes were implemented, mostly quality of life improvements, like small changes to objects positions and controls. However, the feedback helped to motivate for the experiments as the main theory of VRs superiority was repeatedly expressed at TG. The clear majority of the participants preferred VR at the event. A few changes to the experiments was done due to feedback in the event, including adding a few more streaming and spectating related questions in the pretest.

The testing at TG also worked as a stress test of the system, as 5 HTC vive systems were linked at one time. The prototype had no difficulties performing under this train, and proved that the VR prototype was ready for large scale testing.

7.1.2 Mini teleporting experiment

The mini teleportation experiment was intended as a short study on the preference of players over manual teleporting or not. It was conducted as a quantitative/qualitative hybrid. The statistical power of the results is low due to the low participant number, but the general consensus among the participants in the post discussion was that having both systems were the best option, as they complement each other well. The two systems for moving, as the VR spectator, involves picking up preview cubes (and returning back), and manually teleporting around. The camera helps to give the player key areas to move this, while they can adjust by manually teleporting, or just positioning himself wherever they want. Spectating in VR needs to capitalize on the possibilities provided by the extra immersion. Reducing and restricting the spectators movement options is not a good option.

The experiment also helped to prepare for the two main experiment, as feedback from this experience was used to improve the prototype in the last few days before the main experiments started. The mini teleportation experiment did not have any time limit on the participants, as one of the goals was to test engagement over time. Several participants played around for more than twice of the expected time span of 5 minutes. This helps to show how engaging the prototype was for the participants, but it could also be due to the novelty factor of VR. Only 12 to 20 percent of participants reported using VR more than a few times earlier, which was similar across all the experiments. VR has a high level of novelty, which could help to influence results in a positive manner, as the excitement for VR affects their interest in the prototype. This not a good confounding variable, as it reduces both validity and reproducible while at the same time makes it harder to assess the long-term impact and usage of a certain VR product/prototype. Novelty fades over time, and the same might be true for this VR spectating system. The goal was never to study and evaluate the long-term impact and usage of VR spectating, but it is still relevant in further research.

7.1.3 Main experiment comparing all three modes

The goal for the main experiment was to determine the preference by participants between the three different spectating systems; mirroring, 3D and VR. The key question at the end of the experiment asked participants to select their favorite mode, and least favorite mode, thus creating a ranked order. This preference showed a clear indication that the VR spectating mode was the superior spectating system with 83.3%. This supported H1(VR > mirror) and H3(VR > 3D). On the other side of the spectrum there was not as clear of a consensus for the worst spectating mode. Mirroring had the majority, but only at 58.3% which makes it harder to definitively confirm H2 (3D > mirror). This is also because the follow up experiment excluded mirror. No correlations were found to support H4 (VR vs 3D depend on user preference for consuming passive media)

Participants reported a preference for 3D over mirror in the post questioner, but the between subject evaluation for quality immersion and enjoyment did not have a statistically significant answer. The P value between mirroring and 3D mode for the quality of spectating mode was as high as 0.86 for test, and $P > 0.2$ for the

Wilcoxon signed-rank test. Both immersion and enjoyment had P values above 0.1 for both tests and Wilcoxon. This makes it a challenge to declare 3D as superior to mirror for this experiment. A future follow up experiment should evaluate if the changes to 3D mode for experiment 2 had any significant impact on H2.

Novelty was an important factor in this experiment. Only 12.5 percent of participants reported having played VR more than a few times. This combined with the very high interest for VR with a median of 6 out of 7 creates an environment/experiment where the novelty of VR, and general high interest, positively affects the results in favor of the VR mode. The results would probably be less significant for VR if the same experiment was conducted after a few years, since so few have still to experience VR. A few participants even reported on this as they tried the VR spectating mode. They were astounded by how immersive VR was, even if they might not like the actual spectating system in the long term. It was not only VR that was affected by the novelty factor. The 3D mode, and mirrored mode was potentially affected as 20 percent of participants had never watched someone play in VR before. This is far less than the 87.5 for VR, but is still high enough to potentially affect the results. Controlling for VR novelty on just 24 participants were hard, and potential further studies could evaluate both the effect of novelty on VR, and redo the study when VR have reached higher adoption levels.

Game understanding and playing habbits

All participants understood what the game was about. A single question in the post questionnaire presented them with a range of plausible answers to the goal of the game, and all participants manage to answer this question correctly. This was added as a part of evaluating RQ 3 to evaluate what effect the spectating mode had on understanding. A flaw in the experiment design prevented the gathering of relevant insight on the problem. The question should have been duplicated and added in the post questionnaire for each mode to detect if some modes made it easier to understand. However, qualitative data during the experiment indicate that VR spectators might have more of a difficulty due to the novelty. Most participants needed a few minutes in VR before they could start spectating as they learned the controls and got over the initial immersive surprise. 3D and mirror might be faster initially as most participants already were familiar with these modes and adjusted quickly to both the mode and its controls. This initial disadvantage could easily change in the favor of VR after some time due to the extra level of immersion. Watching a VR game on a non-VR device removes a dimension, being there in the same world equalizes this equation. There are other reasons as well including the fact that VR have a higher field of view compared to non-VR which enables the spectator to take in more of the world visually at any given time. VR potentially allows the spectator to view more of the world at any given time. Compared to mirror, VR have the advantage of allowing the spectator move and position themselves where ever they want. Mirroring spectating are restricted to the player's viewpoint. However, this helps the spectators to see what the player are seeing, but they could lose track of the game happening around the player. For the high level of play in esports this is a significant challenge, especially for chaotic games. The player usually understands the game better than spectators as the freedom of VR enables them to explore the game at their own phase, while being able to focus on what they find important. The acting player might be preoccupied with shooting at a single enemy while a larger play is happening somewhere else. The 3D and VR spectator can watch this larger play, but the mirrored spectator cannot as they have no control. However, this is a two-sided problem as the active spectator (in VR) could miss out on key play sequences happening. This problem is reduced in the prototype as the VR spectator can watch a third, or first person camera of the acting player at any time. Further development could solve this problem by allowing the VR spectator to interact with time. This would only be possible in a recording.

Weaknesses of the experiment

The feedback from the 3D mode was generally agreeing on that the lack of active controls for spectating (using wasd + mouse) was a problem. This is understandable as spectator's preference may differ with some preferring a more automatic, and passive mode, while other preferring a more manually controlled, and active mode. This choice of only having passive 3D spectating for the experiment could have potentially polluted the results and decreased the potential for the 3D mode. It would be incorrect to conclude that VR was superior to 3D without testing for this much-requested mode change. This is the primary reason a smaller secondary study was conducted. The main goal was to switch the 3D move from passive to active and evaluate it against the VR mode (without changing the VR mode in any way, from the first experiment). The mirrored mode, and a few questions were removed due to time constraints. This was before the data was analyzed to the point that proof was found that there was no statistically significant difference between mirror and 3D. 3D might have been superior to mirror in the follow up study, but time constraints prevented the testing for this. However, the quality, immersion and enjoyment values could be compared between experiments due to their similar setup. This would no longer be a between subject evaluation, and a conclusion is harder to draw. A further discussion on this can be found in the second experiment discussion.

The experiment only had 16.7 percent women. This means the gender is severely under represented and any gender difference is hard to statistically detect and evaluate.

Assessing impact of order

The participants were divided into two groups with one key difference. Both started by watching mirrored mode, but then split into two different orders where the first group saw 3D, then VR and the second group first saw VR, then 3D. The results for 3D and VR (which was subjected to a different order) all had P values above 0.2 showing a statistically insignificant difference between the groups. The supported orders did not affect the results for 3D and VR. However, the problem is the P values for mirror. Presence had a statistically insignificant P value, but both quality and enjoyment had. Enjoyment had the biggest difference with a P value of less than 0.001 which makes it statistically significant assuming a significance level of 0.05. This is strange as the order was the same for both groups for mirror, the only difference was their assigned group leader, and the computer they answered on. This could potentially be caused by participants not entirely understanding the question and or questionnaire. Assessing quality and enjoyment is hard without any reference. Evaluating the differences between groups using between subject evaluation shows no clear trends.

7.1.4 Second experiment with free movement for 3D

The second experiment was conducted to evaluate how user's preference for the 3D spectating mode would change when it was changed from a passive to an active mode. This was done by enabling 5DoF (without the roll rotational axis) using a wasd + mouse control setup. The experiment was a success with the same conclusion as the last experiment. VR based spectating was still superior even with the changes to 3D spectating mode. However, the differences were less and within subject evaluation found a statistically less significant result when comparing quality ($0.05 < P < 0.10$). This makes it harder to conclusively declare VR as the preferred, but the P value is still less than 0.01 which still makes is unlikely that the modes are similar. The last question which asked participants to rate their preferred mode still had 85.7% reporting they preferred the VR spectating mode. This shows that the VR spectating mode are superior to mirror from the first experiment, and both 3D spectating modes tested. Spectating someone in VR seems to work best if the spectator also is in VR, at least for this setup/experiment.

The wasd + mouse 5DoF control setup was designed to increase control for the 3D spectator, but it made it harder for them to follow the action. More control did not necessarily result in a better experience. This was possible due to several factors with the most prominent being how much the acting player where teleporting around. This was repeated by several participants, both in the comments and in experiment feedback 6.4.2. It was easy to lose track of the player as they teleported, which was not a problem in the passive 3D mode as they would automatically move to the new location. This could be easily solved by adding an animation (that only the 3D spectator sees) which acts as a transition between the locations. This could also be accomplished by highlighting in any other way where they moved to in a way that the 3D spectator could easily follow. The control setup was not perfect as some participants reported the controls being a bit "floaty". This was due to the spectator not stopping immediately when the movement key was released, they went on flying a bit while they slowed down slowly. This design choice made it a bit hard to move around as the spectator did not have pinpoint accuracy over the 3D spectator. Positioning themselves exactly at a position was hard as they had to factor in the floating effect.

The same question regarding a lack of control was asked in the post 3D spectating mode as with the previous experiment. The results from this question in the previous experiment formed the basis for this experiment. However, this experiment also had some amount of responses indicating a lack of control in the new 3D active spectating mode (28.6%). This could indicate some participants wanted a wide range of movement options, like combining the active and passive mode. This could allow spectators to switch between the automatic and manual mode at any time depending on what worked best in any given situation. Some spectator focus game offer further controls for the spectator as well which could be what they wanted. One example is a location to key mapping feature where the spectator could capture their position, and return to that location and rotation with the press of button. This is beneficial for rapid games where the spectator doesn't have time to manually fly to all the locations as the game progresses. Other controls could include quick buttons for jumping to the player, which would be especially useful if there were more than one acting player. These extra controls would be essential for spectating any esport game session as those games tend to be fast pace, and a bit chaotic.

Weaknesses of the experiment

The experiment had a few limitations, of which most were similar the previous experiment. The first weakness was the complete lack of female participants (n = 0) which significantly reduces the ability to analyze for gender differences in the data. The second experiment was conducted at school in a male heavy department which is the main reason for the lack of women. Other problems include the less independent setup for testing where the experimenter also was the main player. This reduced the available help for participants and potentially created a more biased testing session, compared to the last experiment. The experiment had some (28%) which participated in the previous experiment, but the majority of participants had not tested the prototype, or participated in any previous experiment prior.

The demographic for this experiment were less diverse than the previous. All participants were students at NTNU i Gjøvik, and only from technology based studies. The results might be different with a different demographic. However, the previous experiment had a wider demographic with students from both NTNU i Gjøvik and Lillehammer without any significant difference to the results of this experiment. Any potential impact seems to be low, but further, larger studies with wider demographics are needed to properly evaluate this.

7.1.5 Experiment general discussion

All the three experiments provided relevant data and insight into both the prototype and users preferences for VR and spectating. The experiments were a success and conclusively found VR spectating to be the superior mode. However, no statistically significant difference was found between mirror and 3D which could be due to several factors including how similar the modes where in the experiment. Both modes were presented as a passive spectating mode where the only significant difference was more control over the camera angles in the 3D spectating mode. A future study should combine both tested 3D modes (the active, and the passive) and compare it against mirror and VR to see of it changes the content conclusion. However, there is no data that indicate any reason for 3D to surpass VR spectating of VR content even with the new 3D mode. The difference between VR and 3D is currently too high for any small change to influence significantly. However, as more conclusive conclusion could potentially be drawn regarding mirror vs 3D.

There are no clear correlations to support H4 (VR vs 3D depend on preference for consuming passive media) in either of the two main experiments. This does not mean there is no actual correlation, but that the experiment failed to prove any statistical correlation between user's preference and preferred mode. Analyzing this is hard as the clear majority reported VR as the superior mode which makes the group selecting any other mode too small for any statistical analysis. A future study could potentially repeat the same experiment, but with several times more participants to grow this sub group to a reasonable size of at least 15 participants. Given

$$x * 0.17 = 15$$

we could calculate the x (which is the total number of participants, and 17 being the number that did not select VR as preferred) to be approximately 88 participants. This mean a repeat experiment should aim for around 90, or more participants to properly evaluate the group that did not prefer the VR mode.

All the experiments had a portion of the participants requesting more control over movement. This is understandable as all modes do not provide all the same controls as some other, similar spectating mode have. A longer development time could have helped to create these alternative movement options, and refining the once already in place. Having responsive and natural controls are critical for movement based experiences and games as this is one of the key ways they spectator/user can interact with the world. Having an improper translation from their intention to what happens in the virtual world leads to user frustration. The experiments also revealed that many participants wanted better camera placements for the VR spectator. This could be to several factors including the fact that each user's preferences are different and one perfect setup is not possible. This could be solved over time by allowing spectators to place their cameras where they want future spectating sessions in the same game. This could work by for example the spectator spectating their favorite esport team playing a match in overwatch. They would after a few games begin to understand where the gameplay tends to concentrate in the choke points, and they could place the cameras at these locations. The cameras could also be pre-placed for new spectators in the most popular locations to give an easy start.

7.1.6 Demographics

One of the RQ (in 1.4) was to evaluate if the demographics of the participants had any significant impact on the results. However, this was hard to evaluate due to few women and the majority being in the age range 20 to 29. The core demographics for both main experiments were therefore males in their twenties. This is not an optimal sample of the population as both age and gender could have an impact on the results. Getting a high enough female participation rate was a major challenge as the experiments was conducted at a school department with few girls in each class. This is in addition to it being easier to recruit men to the experiment. This might be due to all the experimenters being male as well, in addition to the complete absence of females at times. Further studies should evaluate if there are any gender differences to VR spectating.

Approximately 65% of the participants was between 21 and 25 years old. This is due to the sample size being drawn from a university population where most students are in that age range. No significant differences were found between the age groups, but a more diverse range of ages are needed to properly assess this. There was no significant difference observed due to demographics in either of the experiments.

7.1.7 Passive vs active preference for spectating

One of the initial RQ and hypothesizes was to determine if there are any difference between preferred spectating mode based on the participant's preference for consuming active or passive media. Several key questions were included in the pre-test to evaluate each participant's preference for spectating and passive vs active media consumption. However no statistically significant difference was found based on the active vs passive media consumption. A range of different spectating preference were recorded, but so correlations to preferred mode was discovered. This is partially due to the high preference for VR, which led to the group not preferring VR being too small to evaluate statistically. Further studies with more participants are needed to properly evaluate, but the experiments did not discover any clear correlations. The experiments ran over just a few minutes for each mode which might favor the more active approach. The theory is that spectator might have a high interest for active spectating in the beginning when the novelty factor is high, but them change their preference more to a passive mode over time. Active spectating is more demanding, mentally and physically especially as they must stand, and move with a VR HMD on their head. The benefit of the 3D and mirroring modes, more passive approach is that it can be used in a more relaxing manner. They could even be set aside, on for example a secondary screen while the spectator does something else on the primary screen. This would allow for a more relaxing spectating experience which might be preferred for some people, especially when they are tired after a long day.

7.1.8 Validity

The experiments have some challenges related to validity. The systems were self-developed, as no similar solution for VR spectating were available at the start of the project. However, this does not necessarily reduce the validity significantly due to a range of key factors. The mirroring mode was not altered in any way, which makes it identical to the mirroring mode provided by other VR games and programs, as it is just an exact mirror/copy of what is being projected inside the HMD. This makes the validity for the mirror higher, and works as an anchor for the other modes. The 3D mode was developed using standard practices for 3D based spectating. The mode used in the last experiment was a 5DoF setup, which is found in all games that allow for free spectating of the game. The other "modes" for the 3D spectating system included, among other, a third person camera and an overview camera which is found in many other spectator games. The validity is not as high as for mirroring, due to the development bias, but is still within acceptable levels due to how common practices were followed during its development. The VR mode was developed in an exploratory process, as no similar VR spectating system existed at the start of the project. Development focused on first discovering new features, and then maximizing their potential with rigorous user testing and evaluation during the development process. No claims are made to signal that the VR mode are the only acceptable way for spectating using VR, but provides one example of how this could be accomplished. The results indicating VR to be the superior mode are only strictly valid within the confines of this project, and any generalization to VR in general needs to be done cautiously. The validity might be sufficient to prove VR spectating to be the superior mode for spectating VR content outside of this experiment, but no such conclusive conclusion is drawn on this thesis.

Comparing VR to the other modes with higher validity, and still being superior, helps to display the preference for VR spectating, while at the same time increasing its validity. The anchor effect provided by the mirroring mode helps to form a foundation for VR to be evaluated against mirroring, and provides some validity for the VR's superiority. The modes implementation is affected by developer, and testing bias, but each mode was given an evenly divide in focus, and development time. There was a bias towards VR during this project, but this effect was minimized during development and testing. Each mode was given a fair chance during testing with no mode being allocated more time, effort or interest by the experimenters, than any other mode. However, the experiments showed a high interest in VR from the participants, which makes them pre-biased towards VR, possible reducing the validity slightly. The order of VR and 3D was different for half of the participants to mitigate some of this bias and other similar aspects.

There is a good indication for the validity of the experiments results, especially for the main results. A few of the questions could have benefited from a more precise wording, but the impacts of this problem were minimal, as these questions were clarified upon request. The validity of the data was high regarding assessing which mode was ranked the best, as the participants were directly asked to select their preferred and disfavored mode. These data were also backed up by independent numerical values regarding quality enjoyment and immersion for each of the modes. These results were then statistically evaluated, both using Wilcoxon signed rank test and the repeated measurement experiment, to further improve the validity of the data. Furthermore, most of the key questions related to the ranking of the modes were taken from earlier research with proven methodologies. Although some of the questions outside the focus for the experiment (like the one related to spectating habits) had a reduced validity as they were not repeatedly asked, and had less well proved formulations.

7.2 Discussion on causes and consequences of the results

7.2.1 VR superiority

Both main experiments proved consistent results and support for the VR spectating mode in the prototype being superior to all the other modes, in all metrics tested. Having such a conclusive conclusion has little value without understanding the reasons behind the results. There are many plausible reasons for the VR modes superiority in the experiments. On of the core reasons are the similar level of immersion for both player and spectator. Both the active player and the preferred spectating mode are in VR, on the same level of immersion. Spectating using the 3D mode reduces the immersion experience by the spectator, which could be critical for the game immersion, and understanding. There are more concrete examples of this reduced level of immersion. One example is how the VR spectator could more easily asses distance than the 3D spectator, due to the stereoscopy of VR. Other examples include the increased field of view and more natural control interface. The VR spectating modes superiority are due to other factors as well, where novelty and VR pre-bias are two important factors. Participants reporting in general a high interest for VR, while at the same time having little experience with trying VR. This increases the positive impact of the VR system. However, a high interest for VR could have also reduced the enjoyment for VR if the participants were disappointed in the experience. This is the same problem as where people anticipate new technology to be great, but the actual product are below their anticipated level. This could be the reason for some of the participants reported favoring the 3D, or mirroring mode over the VR mode. The bias towards VR are a significant factor in the experiment as well. Participants testing the 3D mode tended to be just as interested in their current mode as watching the VR spectator. This was in addition to possibly a few, or more, of the participants initially becoming interested in joining the experiment due to the presence in VR. Other factors that is in favor of the VR mode included a more active spectating setup, where the spectator was more in control of the experience. VR are inherently more immersive than 3D, which is both proven by earlier research, and by the experiments. The higher field of view provided by the VR mode helped to give more information to the spectator, as they could see more of the VR world at any given time.

These factors affected the results for VR, but should not have had a significant impact on the results. This is due to several reasons, including how participants that participated in both experiments did not display a reduced interest for the VR mode going from the first to second main experiment. The group order also helped to prove the validity of the VR spectating modes superiority, as first showing the participants either VR or 3D (before the other) did not significantly impact the results in any way

7.2.2 3D and mirroring inferiority

There are several potential explanations for why the 3D mode are inferior to the VR mode. The initial 3D mode in the first main experiment was designed and developed as a passive experience, where the user just selected among four different automatic spectating modes/angles. This reduced the enjoyment and immersion for participants that wanted more control, as the majority reported (see 6.4.1). This was changed for the next experiment, but did not impact what mode was preferred in any significant way. However, the divide between 3D and VR was reduced with the change from passive to active. This proves the change had a positive impact on the mode, but was not enough to move it or change it to the most desired mode. The mode suffered as it tried to translate the VR experience for the player into a non-VR interface. This was evident in the reported reduced immersion and subsequently enjoyment for the mode. The mode also had one less degree of freedom (6DoF minus the roll rotational axis), but this should not impact the results in any significant way. This is due to how little this axis benefits the spectator as rotation in the roll axis do not inherently increase the experience significantly. The 3D spectating mode was modeled after a similar spectating mode, in which no one had controls for the roll axis. Limiting this axis was also done for practical reasons, as a standard computer mouses has no accurate way of tracking the roll axis. The mouse is only a two-dimensional interface, and roll needs to be handled by other controls.

Mirror may be inferior due to some of the same reasons as 3D, but to a higher degree. Mirroring removes all control over the experience from the spectator. This is good for some experiences as the spectator could be satisfied with seeing the same as the player, but this is not always the case in VR spectating. The mirroring mode reduces the field of view for the spectator significantly, as only the center view for the VR player is shown on the mirrored image. This is due to the higher field of view of the headset, and higher resolution. Omitting the extra field of view reduces the quality, immersion and enjoyment for the mirroring spectator.

Only one participant reported favoring the mirror mode in the first main experiment, where three on total favored the 3D mode. No significant difference between the modes were found, which makes it impossible to draw a conclusion to one mode as the clearly superior one. This could be due to how similar the modes were, at least for the first main experiments where both was tested. The 3D mode was like the mirroring mode in this experiment, as both were passive, and the 3D mode only had a bit more control for the participant to use. This ultimately lead to both modes looking similar, and behaving similar. The extra control in 3D was too little to set them apart.

7.2.3 Implications of the results

The results supported that VR spectating are the superior way of spectating VR content, at least within the confines of this experiment. Both other modes are valid options, but a clearly superior mode exists. Spectating someone playing in VR is best done using VR for the spectator as well. This may imply a relationship between the level of immersion for both participants. Further studies could evaluate this relationship by assessing spectating of 3D, non-VR, content using VR spectating.

Both passive and active 3D spectating mode were evaluated against the VR mode, with VR surpassing 3D in all the experiments, which indicates that neither a passive or active approach to the 3D mode has any significant effect on the results, compared to the VR. Providing both options improves the mode, but will still be inferior to the VR mode, within the confines of the prototype.

No significant difference was found between the mirroring and 3D spectating mode, for all metrics collected. This indicates that both modes provide the same level of enjoyment, immersion and quality. Neither of the modes was a failure, and they are valid options for spectating VR content if the VR mode is unavailable, or not preferred for some reason. This helps to validate VR as a spectatable activity as either mode works.

The VR mode had a range of positive feedback with a substantial amount of suggestions for further development. The prototype, and the associated research, could serve as the basis for several related research projects.

The positive feedback loops

VR being the superior way to spectate VR content could lead to a positive feedback loop in favor of VR as a platform. The experiment have found support for the fact that VR spectating is not just good in theory, but provide a clear benefit compared to more traditional mirroring and 3D based spectating. The possibility is that VR spectating could bring in new users as they want to experience the best/ultimate spectating experience, which in turn bring in more users to VR that play, and stream themselves. This then loops back again with more spectators purchasing a VR system. This loop would be reinforced by the fact that spectating is a new and important form of advertising, as previously established in 1.3. These new spectators who just purchased a VR system to spectate would be more willing to purchase some of the best games they spectate. VR games provide a higher immersion that non- VR games, which is something a significant portion of the spectators potentially want to experience for them self. This is further reinforced by the player to developer loop. This is the loop where more users/players lead to more developers, as the system has more potential customers, which in turn lead to more users and players as there are more games to play on the system. These positive loops combined could mean VR spectating is a cornerstone in the future of VR.

7.2.4 Spectator movement restrictions

One of the key research questions was to evaluate restricting the spectator's movement to key locations, known as choke points. This was evaluated across all three experiments with the first small experiment evaluated this relationship for VR, while experiment two and three evaluated it for VR. The results show a positive effect with less restrictions placed on the spectator. The first experiment related to the VR spectator proved a preference among the participants for more control over movement. The initial configuration only allowed the VR spectator to move to pre-defined locations at chokepoints. However, this proved sub optimal as testers repeatedly requested more freedom of movement, especially by manually teleporting to where ever they wanted to. Some participants still reported a lack of control even with the addition of full freedom of movement. Only 12.5% felt a lack of control in the first main experiment for VR, but 41.7% also reported wanting more "freedom in where you could move in the world" (From one of the questions, see Appendix) (data can be found in 6.4.1). This could be interpreted as the level of control was sufficient, but could still be improved on. That the level of freedom of movement was sufficient for the experience, but still had potential for improvement. Some participants reported struggling slightly with the controls, especially remembering them which could be one reason behind the relatively high number of participants reporting wanting more control.

The second main experiment was conducted to evaluate if less restrictions in the 3D spectating mode caused any significant difference to the preferred spectating mode. It helped also to evaluate if restricting the mode to pre-defined locations was a bad practice. The feedback from the first main experiment had 78.3% reporting they wanted more freedom in where you could move in the world. This was reduced to 28.6% percent for the second main experiment (data from 6.4.1). This displays a significant difference between the passive and active 3D spectating mode, proving that more freedom of movement if favorable for the spectator.

The experiment support that restricting the spectator's movement is a bad practice, and more freedom is generally preferred. Further research is needed to properly find the right level of freedom for both the 3D and VR mode.

7.3 Discussion on streaming revenue, culture and rule set

7.3.1 Changing rules of the games to the benefit of the spectator

Changing the game in favor of the spectators would potentially help more spectators understand the game and draw bigger crowds of spectators, but could ruin the core game experience the actual players play for. A game with more players that spectators should not design for the spectator experience as the lost revenue and players would be greater due to the lower spectator numbers. However, this does not mean a game with more spectators than players should be changed completely to satisfy the spectators. The game rules are there for a reason and changing just one could upset the balance between the teams. Esport focused games have a significant number of spectators, but the games are also carefully balanced to prevent dominant strategies. Esport players are at the top of their game and experts and finding these dominant strategies and exploiting them. Therefore, improving the spectator experience needs to be carefully executed to not upset the players experience. A dominant strategy is a strategy that's superior no matter what the opposite player(s) do. Many competitive esport focused games rely on no dominant strategy with no weapon, ability or similar beating all other and having a counter/block for each of them.

7.3.2 Spectating and revenue

VR spectating has a few key challenges related to revenue for the VR streamers. There are currently no good solutions for advertising in VR which is one of the key revenue sources for many spectator focused businesses. This problem is solvable, and could potentially lead to a new area of advertising as VR makes any advertising more immersive, which is something any advertisement company strive for. Having the VR spectator be inside the advertisement could make it exponentially more effective. Another challenge for VR spectating is the physical straining aspect of the activity. A streamer streaming for 60 hours while sitting in a chair is far less affected than a VR streamer standing for 60 hours a week streaming. This could be a limiting factor for streamers and could lead to them switching between VR streaming and non-VR based streaming as they need a break. Making any significant amount of money from VR spectating is currently not possible as no service like twitch exist for VR spectating yet, but there is a lot of potential. This is an untapped market with potential.

7.3.3 Streamers and personality

VR spectating, within the system from the prototype could help to reduce the barrier between streamer/players and spectators as they would exist in the same space where they could potentially see each other, and interact. Virtual meet-ups could be arranged by the streamers where thousands of VR spectators could meet with the streamer in a virtual space. A deeper connection between streamers and spectators are possible if they are spectating the action within the same level of immersion. This like what VREAL is attempting to achieve with their system. They are making a community and platform around the actual spectating where VR spectators could jump between streams at they want while interacting with other spectators and talking to the streamer. VR needs to be utilized to its full potential in order for it to succeed as they cost of using VR to spectate is higher than non VR based spectating. This is due to the cost factors as well as their extra effort required to put on the HMD and walk around with it. A great support community would help to significantly reduce the cost of using VR.

7.4 Real world Virtual Reality spectating

This generated 3D virtual world could enable spectators to join the match in process as VR spectators with the same (or more) controls and features as in the prototype. The VR spectator could immerse himself on a new level by positioning themselves wherever they want. Maybe run alongside the players when to are about to make a goal, or stand by the keeper as they deflect the incoming ball. The choice would be with the spectator This system is technically possible with today's technology, but would not be without some challenges. One of the more visual are the fact that such a 3D reconstruction of the real world could lose some key detail in the process. A football stadium is large and makes it hard for cameras at either side to capture the fine details of the players running around. It would be apparent when standing next to a player as their features could look a bit strange. Another challenge is the loss of information if all cameras are blocked at some point. An example of this could be a bunch of players smashing together in the center and no camera being able to see what is happening between them. More cameras could help solve this, and adding a overview camera directly above could reduce this problem further.

It is not only football that could benefit from real world spectating. It might even be more suited for smaller scale games that do not require a lot of movement, like volleyball and basketball. They spectator could easily position themselves somewhere close to, or on the field and can watch the entire game without moving. Spectating real world events in person are limited by the fact that you need to sit a bit far from the action. VR spectating could allow anyone to be anywhere they want and bring the game closer than ever.

7.5 Spectating non-Virtual Reality content using Virtual Reality

The focus for this master was on spectating VR content using either VR or not, but VR spectating of non-VR content could be just as important. A good example of this is how a VR spectator could join into a non-VR game like Overwatch and stand side by side with their favorite team as they hold of the enemy team at a choke point. This could make the game more immersive for the spectators than the player. A usual counter argument to adding VR to a game not designed for VR focuses on how the game play is not easy to adapt to VR as VR requires its own type if controls. One example of this is how many first-person games rely on movement using a controller or wasd. All this constant movement could easily lead to motion sickness as the VR player is moved in VR, but not in the real world. However, this is easily avoided for a VR spectator as they do not need to move as much as the players, especially at a choke points where action tend to concentrate. The VR spectator could just position themselves at a key location and observe the action. The giant model from the prototype could be used to help the spectator get an overview. Another alternative is to add a mini-map to one of their hand as the giant mode can cause VR sickness. Adding such a spectating mode to a competitive game like Overwatch could only be done for non-live events as the unrestricted VR spectator could cheat on behalf of their team by ghosting, also known as reporting enemy position back to their team. Watching a 3D game unfold in VR would enhance the experience for the spectator and potentially make them more immersed in the action to the benefit for both parties.

7.6 Projections for the success of Virtual Reality as a platform

7.6.1 Critical mass

Virtual reality as a platform is struggling to reach critical mass due to several key factors. Critical mass in this context is when the environment becomes self-sustaining in regards to user and developer adoption. A system, like a VR platform needs to reach a certain number of units sold to reach it critical mass. This is the point where new users purchase the system based on an already sufficient number of games and developers release new games based on an already sufficient number of player/users. This is critical for the future of VR spectating, and VR as a platform. VR is unfortunately a fragmented platform currently with several competing solutions like HTC vive, Oculus Rift, and PSVR. The different systems are too different for one game to work without any modifications on all platforms, and exclusivity deals are common which restrict a game to one platform. Sales numbers are difficult to gather, but some good estimates have sales for PSVR on the top with around 900 000 units, vive with around 400 000 and rift last with around 250 000 (see 6.6). These numbers are still small compared to modern console systems like the PlayStation 4. The key problem is that any VR title needs to be developed for VR, and usually just for one of the platforms with caps the sales at the number of sold systems, and no game will reach 100% of users. The PSVR has a significant advantage due to number of units sold due to a lower price point, and ease of use as it just needs a PlayStation 4 and a camera.

VR sales are still increasing, but is insignificant if we compare it to a similar gaming platform; the Wii U. This is not a perfect comparison, but both are still video game platforms that require custom designed games for their systems that are significantly different to the other game systems, like the Xbox and the PlayStation. The Wii was released after the immense success of its predecessor; the Wii. The Wii U build upon the previous consoles functionality and design, but never reached critical mass in terms of users, and games. The system was a failure due to several factors including a small games catalog at launch and outdated components in the console. The console sold over 13 million units (see 6.6.1), but was still considered a failure due to the lack of games and less than expected sales . For comparison, its predecessor the wii sold over 100 million units (see 6.6.1). This highlights the challenge for VR as a platform. With no system, still over a million units it could easily end up with the same fate as the wiiU with have sold over 13 times more units than the PSVR. Therefore, more competition is bad for VR. Fragmenting the already small user base further across many similar, but still significantly different system does not help at all. Developers will have a hard time deciding to commit to making VR games with the low user count. A platform need many strong, good games for users to purchase the system, and developers need many users on a system in order to make a profit. This is usually solved in new console releases with first party content which is games developed by the console/system manufacturer. This is a solution to the system, but HTC vive's partner Valve have not released any large triple A game for the platform yet. This could be a sign than they are not confident in the platforms future. PSVR has an advantage her as it is developed by Sony what can pay both first and third party developer to make unprofitable games for the platform to attempt to reach this critical mass of games.

VR spectating is highly dependent on the success of the VR platforms. VR spectating requires both a VR player on a VR system with a VR game, and a VR spectator on a VR system to work. This limits the available spectators to the number of units sold, and decreases it further since only a fraction of system users will and can spectate at any given time. Using the theory of diffusion of innovations we could estimate that the virtual reality system is starting to pass from innovators to early adopters as more than hard core enthusiasts are starting to user VR systems. Determining the point for critical mass is hard, but it is highly likely further along on the axis, maybe all the way into early majority. Reaching this point and making the system self-sufficient is a challenge for both users, system designers and game developers. Any large term investment into VR spectating is a major risk until this point is reached, or clearly reachable in the foreseeable future. The future for VR is uncertain at this point.

Adoption of VR systems is limited by a few factors currently including device specifications and cost. The current first generation VR devices are still limited by their sub optimal resolution and tracking. All the devices suffer from resolutions that makes individual pixels visible to the user, which in turn reduce immersion in the VR world. However, solving this by increasing screen resolutions is not an optimal solution as cost of both the device, and a system to run it on is already high. A computer running the vive or rift needs already to be a high end expensive computer. Device manufacturers then have two choices; either increase resolution for better immersion, but also maintaining the high cost, or to not increase the resolution and allowing computer graphic cars to catch up to the specifications. This is effectively a choice between the innovators and the early adopters. Innovators are willing to invest in high end systems, and would feel left behind if VR systems don't become more powerful. However, early adopters would feel left out if specifications increase beyond what they could invest as not everyone have the money to purchase a high-end VR computer. Failing to deliver for the innovators pushes away the most vocal and active user base that have helped to popularize the system thus far, and they will also be the most vocal opposition to the changes. However, no system can sustain itself just based in the early innovators, and need the early majority to work towards reaching the critical mass.

7.6.2 Hype curve

The hype curve is divided into several key groups with their own characteristics. It has finally started to reach the "Slope of Enlightenment" as of 2016 (see 6.6.2) with the release of the first consumer level VR generation. Earlier systems, and prototypes was not designed for the mass market, but in 2016 we saw the first VR systems for the mainstream users. Per Gartner, the creators of the hype cure VR have already passed the other phases of the hype curve and are approaching mainstream adaptation. The major technical challenges of VR have been solved already, and the only needed improvements currently are incremental improvements to already existing solutions. One example is how the tracking of the headsets, and drift, is solved in a satisfactory manner, but these tracking systems still have a potential for improvement. The current generation is advancing rapidly with Valve already discussing and starting development on the next version of the HTC vive (see 6.6.3). VR is approached "Plateau of Productivity" acording to the most recent hype curve, with potentially large scale market adoption within one or more generations of VR systems.

7.6.3 General discussion on the projections

Predicting the conclusive future for VR was not the goal. The intention was to evaluate where VR is using well known theories and assessing it current trajectory. VR still have some challenges left including reaching critical mass, ascending the slope of enlightenment, and creating a positive user to developer loop. There are large corporations currently backing VR like HTC, Valve, Facebook/Oculus and Sony. These companies can promote VR even at a loss for several years as they build a sustainable user base for VR. Large scale triple A developers cannot invest time and energy into VR games currently without any large investment from one of the companies behind a VR platform. This is also known as platform exclusivity deals where platform holder subsidized development of games to accumulate more high quality games. This is done to both reach critical mass, and creating the positive user to developer loop. No VR platform creator should expect to earn money based on VR for the next years.

The multitude of different VR systems with slight alterations are suboptimal for the future of VR. Each of the systems work independently of each other, and games/programs need to be ported to each system independently. This will lead to a potentially fragmented market, as is the case with the current console generation (Xbox one and PlayStation 4) where some games, and user/players only exclusively exist on one platform. Multiplatform games and programs will need to self-fund the development process as platform holder only pay for platform locked games and programs.

VR spectating could be an important part of VR's success as a platform. It provides a clear benefit over the alternative modes when spectating VR content. The challenge would be that VR spectating system could be locked to one platform due to the exclusivity deals, effectively reducing the content variable for spectating. With only one large console manufacturer currently developing a VR platform (Sony) it could end up with Sony outcompeting the competition due to their knowledge from PlayStation, and the money they could use to get system exclusivity deals.

Reaching a sustainable user base for VR is possible with no major, unsolvable challenge percent currently. It will take time, risk and large investments from both the early adopters user base, and form the developers willing to take a change on this new emerging technology, and platform.

7.7 Future work, and research

7.7.1 The Gathering 2017

Scaling up the prototype

A subject was repeatedly discussed at The Gathering 2017. Scaling the prototype up from its current max of 7 spectators, to any large-scale implementations of thousands of spectators are a significant challenge. Finding a solution to these problems requires further defining what the end goal of the system is. The initial goal was to make a personal spectating system, as found in many modern computer games, like for example Overwatch[72] where you can join in on a friends game as a non-interactive spectator. This mechanism for spectating causes extra strain on the game server, as each spectator needs to communicate with the main game server always, to spectate the ongoing gameplay. This would not be a problem when there are only a few spectators, but will quickly cause problems with a larger number of spectators than the server can support in players. This can be solved by having one or more "mirror" servers that act as a middleman between spectators and the actual game. The theory is to have one server duplicate action happening on the main server and, then allow spectators to join this mirror server. This is like how content delivery networks functions on the Internet. These mirror servers can grow in a pyramid like structure outwards, or just have one large and powerful central mirror server. This is possible as all spectators only spectate in an active, but not interactive manner. No actions caused by the spectator can influence the game directly. Another similar example of this is live streaming services, like Twitch where only Twitch communicates with the streamers machine and all spectators just communicate with Twitch's servers.

This solution has a major flaw if the game being spectated as a VR spectator is competitive. Watching a friend play a game can allow the spectator a peek at what the enemy team is doing. This can cause problems due to illegal information sharing from the VR spectator with limitless access to the players, also known as ghosting. This is of not a problem for single player games, or competitive multiplayer games with no hidden information. Large scale esport events could solve this by just blocking any external communication for the players when they are playing, but it a problem for more average gamers. This is solved in other spectating systems like Overwatch's system by not allowing free movement for the spectator. They can only watch in first or third person for teammates of the team that they joined in by. For example, if you friend is playing in team A, you could only join in as a team A spectator, and only spectate team A players. This is not a good solution in VR as restricting movement of the VR player is not advisable at all. Preventing, or force the player to move, could potentially cause VR/motion sickness.

Key frame system

The feedback and ideas by the TV student focused on expanding the prototype by adding more control over the cameras. The idea is to change the VR spectator into a VR stream moderator. They would use the cameras to create a continued live stream, just as real TV stations does for their live streams. They should be able to que up different cameras and change the position and parameters for cameras during play, as well as before starting. Only partial solution to this is the key frame system where each camera could be programmed to change position and orientation at certain key times during play. Other aspect could be programmed into the cameras as well including field of view and live filters. The end state would be a team of two or more people where one is playing, and another, on VR handling live what camera is being streamed out to the spectators. Another option is output all the cameras as the same time (in addition to the main moderated stream) to allow spectators to select their favorite camera.

The challenge of outputting all cameras is related to the computational resources needed to capture high quality video on all the cameras at the same time. It would quickly require a high end expensive computer just for a few active cameras. This scaling issue can be solved by scaling vertically, or scaling horizontally. Scaling vertically is achieved by having a computer with more powerful components, and scaling horizontally is achieved with one extra average computer for each camera. Solving it by scaling vertically is a good solution for smaller scale setups that only need a few cameras and do not the space or money to invest in a cluster of computers. This would work best for small and mostly independent streamers, even if it would decrease the number of available angles for the spectator. Switching to the cluster, horizontally based scaling solution would be appropriate when the stream reaches a certain size and the benefits outweighs the cost. Defining a clear border between the two is hard, and needs to be done on a case by case basis as each streamers need are different. Not every streamer would need to have this cluster in their own studio, but would rent server capacity at for example Amazon Web Services

AR/AV mode

One suggestion proposed focused on an augmented reality mode for VR spectating. The term was used incorrectly and the proper term intended was augmented virtuality which is a far less known. As defined earlier, augmented virtuality(AV) is the opposite of augmented reality(AR) where AR takes the real world (for example a camera feed) and adds virtual elements. AV is the opposite where elements from the real world, like a camera stream is placed inside a virtual world. The suggestion was to replace the VR cameras that recorder inside the virtual world with real like cameras recording in the real world. This could have a wide range of applications from entertainment to virtual security stations or camera control rooms for TV/film production. It would not be possible to move to the camera's position as easy any longer, but each of the cameras could be integrated in all the other ways like hand preview and sticking it to a large screen. This could allow for the same system as the virtual stream moderator, just for real life content, like for example a football match. Setting up a control room for a sports event required a lot of expensive equipment like screens and switching boards. All of this could be done in VR where adding new screens and controls are free of charge except for the initial cost of the VR system. This is not an exhaustive list and other applications could be numerous.

7.7.2 From the main experiment

There were some interesting correlations in the data. All participants that did not prefer the VR mode had one aspect in common; all of them reported playing video games each day, or more often. This does not mean all frequent gamers did not prefer VR, but all that reported not preferring it had that trait in common. It is a challenge to discover a cause for this correlation especially as only 4 out of 24 people did not prefer VR. Several potential explanations exist. One of the simpler are that they randomly had bad experience with the VR prototype for some reason. They might have experience VR sickness, or the controls could have been confusing. Another far more interesting explanation is that they have a preset preference for spectating. Some of them reported being interested in esports and this might mean they spend a significant amount of time spectating other, professional players. This could mean they prefer watching video game content on services like twitch where it is like the mirror and 3D mode. They might also be more experienced with spectating and could see effectively past the novelty factory of the VR spectating system. More data, and experiments are needed to further investigate this correlation.

Four dimensional control of recordings/playbacks

Transforming the spectator into a four dimensional being is a potential solution to the problem of maneuvering a recording/playback. This is only possible on a non-live setting as all the game needs to be accessible for the VR spectator to travel back and forth in time. This could be implemented in several ways including giving them the ability to "drag" time by grabbing it, somewhat like big slider and move it in the direction they want to travel. Other option could be to hold down a button which changes time based on if they are walking forward, or backward. The result could be a proficient spectator that are just as able to traverse 3D space as 4D space, allowing them to replay and skip what they want in the recording. Developing a system for this is a significant undertaking, but it is possible as some games and game engines already allow for game session recording, playback and time dilation. Developing a 4D spectating system could help to increase the value of VR spectating significantly and draw in more users, helping to reach a more sustainable user base.

7.7.3 Assessing streamers personalities impact on Virtual Reality spectators

A streamers personality is a key factor in a streamers success, as discussed in 2.14. There are some streamers that entirely rely on skill, like speed runners. However, the majority of streamers get their success at least partially from their personality while streaming. This might be as relevant for VR streaming, or potentially more important. VR spectators are immersed to a higher level, compared to 3D and mirroring spectators as they are in VR, in the same virtual world as the player. This could potentially increase the bond between streamers and their spectators, make the experience more personal. This is a key area of research as VR spectating becomes more popular with services like VREAL and silver TV.

8 Conclusion

8.1 Research questions

The following subsections address each research question (from 1.4) and concludes on each of them based on previous results, and discussions.

8.1.1 RQ 1, Preferred spectating mode for Virtual Reality content

The primary RQ for this thesis was to evaluate and test how spectating a VR player was different for mirroring, 3D and VR, as well as which mode was preferred by participants. The experiment supports that the VR mode was the preferred mode across all of the experiments and questions. There was no clear preference between mirroring and 3D.

Several solutions for the first sub RQ 1.1 (Real world VR spectating) has been discussed. The solutions differ as a factor of the level of virtual reality (as defined in 3.2). 3DoF real world spectating can be achieved with 360 cameras, but any higher level of VR systems need some form of digital reconstruction of the game/event in VR, or some form of Augmented Virtuality. The next sub RQ 1.2 (Revenue from spectating) focused on assessing the current state of revenue for spectating, and its potential translation to VR spectating. Advertising is one of the critical factors in the revenue of e-sports and video gaming spectating. This could be just as important for VR spectating, but no system for VR advertising exist yet. Creating a stable revenue source for VR streamers is a critical factor in the long-term success for VR spectating. As part of Sub RQ 1.3 (core elements of a streamers success) there was found support for competence to be a non-critical factor in a streamers success. E-sport players and speed runners rely heavily on their in-game competence, but a more traditional streamer rely more on their personality and ability to captivate their audience. Not all spectator are interested in the high-level play of e-sport players, and some want a more relaxing experience with more average streamers.

Scaling up the prototype, as is the focus for sub RQ 1.4 was a challenge with only a few solutions. The prototype developed supported eight simultaneously players (or spectator). Scaling this up to support more spectator were discussed, and resulted in two primary solutions; scaling up, and scaling out. Scaling up involved one large server/computer with better hardware, and scaling out involves adding more independent computers. Scaling up is a reasonable short term solution, but scaling out is the only valid solution for truly large scale VR spectating.

The future of VR spectating is depending on the success of VR as a platform.

This was the research goal for sub RQ 1.5 (critical success factors). Several theories and relevant methodologies were used to evaluate the projected success of VR as a platform. VR is still below the critical mass, where user adoption becomes self-sustaining. It also has a weak user to a developer feedback loop. The platform creators should help to subsidize the development of VR games until a critical mass is achieved. VR is not currently a profitable area of business, but it has the potential of becoming self sustaining, and profitable over the next few years with the correct investments in both technology, and software/games.

8.1.2 RQ 2, Restricting spectators movement

Restricting the spectators movement did not provide any positive impact on their game understanding. Most participants reported wanting more freedom of movement in the first VR experiment, where the VR spectating mode did not have manually teleporting. The clear majority in the second experiment reported they wanted more control over movement in the 3D mode. This was changed for the last experiment, where only a small portion of participants reported wanting more control. Participants were on average more satisfied with no restrictions placed on their movement options for any of the modes.

8.1.3 RQ 3, Spectator game understanding

Several placements models were evaluated and tested during the development process. Every participant understood the games based on the spectating modes, thus making it impossible to promote one model over another. The results were inconclusive, but all participants understood the game and its game sequences which is a partial success.

8.1.4 RQ 4, Technical challenges of implementing Virtual Reality spectating

It is possible to develop a custom game engine with support for VR to make games in, but the most beneficial choice for the prototype in this thesis was to use one of the two already available engines with VR support. The engines used was the Unreal Engine and Unity 3D. The development process (as described in 5) describes the development process, and the major challenges. Developing a VR prototype is a significant challenge as all engine features related to VR are on the cutting edge of technology.

8.1.5 RQ 5, Whether 3D spectators prefer an active or passive approach

No statistically significant correlation was found between the participants preference for one spectating mode, and their preference for active versus passive spectating.

8.1.6 RQ 6, Demographics and its impact on the results

Only two out of three experiment had any women in them, and the numbers were below 17% percent for both. The age range among the majority of the participants was between 20 and 30 years old, which reduced the ability to analyze the results based on demographics. No statistically significant results were found due to an over representation of males in their twenties.

8.2 Hypothesizes and null hypothesis

The experiments supported H1 and H3 (VR > mirror and VR > 3D), as the VR spectating mode provided a clear statistically significant benefit over the other modes in all metrics measured. However, no clear preference was found between the 3D and mirroring mode, thus finding no support for H2 (3D > mirror). H2 was thus rejected, while H1 and H3 was confirmed. No conclusive support was found for H4 (VR versus 3D depend on user preference for consuming passive media), as no significant correlation was found between VR versus 3D, and no preference for passive VR versus active spectating. More data is needed, but the hypothesis is not proven in this thesis.

The null hypothesis 1, and 3 (VR <= mirror, and VR <= 3D) was rejected as VR was superior to the mirroring and 3D mode in the main experiments. The second null hypothesis was not rejected as no statistically significant results were found between mirroring and 3D. The fourth null hypothesis (VR versus 3D has no dependency on user preference for consuming passive media) was not rejected as no correlation was found between VR versus 3D, and preference for passive versus active spectating. Null hypothesis 5 (sample 1 = sample 2) was rejected for the evaluation between VR and the other modes (mirroring and 3D) as a significant difference was found using Wilcoxon signed rank test. However, no statistically significant difference was found between mirroring and 3D. The last null hypothesis, 6 (Group 1 != Group 2) was also rejected as group order had no significant impact on the results.

8.3 Future work

Future work for this thesis, and its prototype, can be found under 7.7. Spectating in VR provides a clear benefit over the alternatives, but the technology is still below critical mass, and a few years away from main stream adoption. VR spectating has the potential of becoming a driving force behind VR sales, and VR game sales. Further work, and research, are needed to properly assess each element of VR spectating, and VR as a platform.

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9 Appendix

9.1 Source code of the prototype

The source code of the prototype can be found at Gitlab at: https://gitlab.com/JGH153/IVR-Connection14

9.2 Mini TP experiment question

What is your gender?
What is your age?
Have you tried immersive VR before?
How interested are you in virtual reality How enjoyable was the overall experience?
How much did you have a sense of “being there” in the virtual environment?
Did you prefer full freedom of movement using manuel teleporting?
How much did you like the camera placements?
Any comments on the VR spectating mode?
Any last comments?

9.3 Main experiment question

Participant number What is your gender?
What is your age?
Have you tried immersive VR before?
How interested are you in virtual reality How do you prefer to spectate sport/game events?
Do you prefer to spectate sport/game events alone or with others?
How often do you play video games?
Do you watch video game streamers on twitch or youtube?
If so, do you passively watch, or also actively engage by commenting, discussing and sharing?
How enjoyable was the acctivity/game you watched?
How was the quality of this paricular spctating mode?
Is this the first time you are seeing a VR game beeing played?
How much did you have a sense of “being there” in the virtual environment?
Which group are you in?
How enjoyable was the acctivity/game you watched?
How much did you have a sense of “being there” in the virtual environment?

How was the quality of this paricular spctating mode?
Did you want more freedom in where you could move in the world?
Did you preffeer to switch spectating angles/modes, or stick to one?
Any comments on the 3D spectating mode?
Which group are you in?
How enjoyable was the acctivity/game you watched?
How was the quality of this paricular spctating mode?
How much did you have a sense of “being there” in the virtual environment?
Did you feel a lack of control (the ability to move to where you wanted)?
Did you want more freedom in where you could move in the world?
How much did you like the camera placements?
Any comments on the VR spectating mode?
Which group are you in?
How enjoyable was the overall experience?
Which spectating mode did you prefer?
Which spectating mode did you dislike/like the least?
What was the goal of the game?
Did you experience that the action withing the game was consentrated in spesific places?
Anything you felt was missing from the 3D or VR based spectating mode?
Any last comments?

9.4 Followup experiment question

What is your gender?
What is your age?
Have you tried immersive VR before?
Did you participate in the previous study?
How interested are you in virtual reality How do you prefer to spectate sport/game events?
Do you prefer to spectate sport/game events alone or with others?
How often do you play video games?
Do you watch video game streamers on twitch or youtube?
If so, do you passively watch, or also actively engage by commenting, discussing and sharing?
Which group are you in?
How enjoyable was the acctivity/game you watched?
How much did you have a sense of “being there” in the virtual environment?
How was the quality of this paricular spctating mode?
Did you want more freedom in where you could move in the world?

Any comments on the 3D spectating mode?
Which group are you in?
How enjoyable was the acctivity/game you watched?
How was the quality of this paricular spctating mode?
How much did you have a sense of “being there” in the virtual environment?
Did you feel a lack of control (the ability to move to where you wanted)?
Did you want more freedom in where you could move in the world?
How much did you like the camera placements?
Any comments on the VR spectating mode?
Which group are you in?
How enjoyable was the overall experience?
Which spectating mode did you prefer?
Anything you felt was missing from the 3D or VR based spectating mode?
Any last comments?