



School of Information Technologies
Department of Computer Systems

Altamash Jawad Chaudry

Human Behaviour in VR:
Special automotive based environment

Master's Thesis

Aleksei Teplyakov
Ph.D.
Research Scientist

TALLINN 2020
Declaration of Originality

Declaration: I hereby declare that this thesis, my original investigation and achievement, submitted for the master's degree at Tallinn University of Technology, has not been submitted for any degree or examination.

Deklareerin, et käesolev diplomitöö, mis on minu iseseisva töö tulemus, on esitatud Tallinna Tehnikaülikooli magistrikraadi taotlemiseks ja selle alusel ei ole varem taotletud akadeemilist kraadi.

[Altamash Jawad Chaudry]

Date: January 19, 2020

Signature:

Abstract

The research done in this dissertation was to study the human behaviour during their driving chores. To make this happen, a certain kind of driving environment was designed in VR using the Unreal Engine 4 game engine, once the driving environment was ready, we took participants on voluntary basis and let them proceed with the driving test assignment. We collected data off from that to read their driving pattern. The important thing is that the environment we designed had a sudden road hazard where drivers had seconds to react and keep the safety of themselves and road users intact. Every driver came across the road hazard and their readiness and driving lines were studied from that. The research and the data collected gave us a variety of results depending from driver to driver.

The thesis is in English and contains 39 pages of text, 8 chapters, 22 figures.

Nomenclature

VR	Virtual Reality
HMD	Head Mounted Display
VLE	Virtual Learning Environment
UE4	Unreal Engine 4
BP	Blueprint
AI	Artificial Intelligence
AnimGraph	Animation Graph
CSV	Comma Separated Values

Contents

List of Figures.....	6
1. Introduction	7
1.1. Research goal.....	9
1.2. Relevance and probable research outcome	11
2. Background	13
2.1. Related work.....	14
3. Theoretical Framework.....	17
3.1. Key concepts	18
3.2. Evaluation	18
4. Methodology.....	19
4.1. VR Environment Design and Characters.....	21
5. Experiments and data collection.....	26
5.1. Data collection and graphical representations.....	28
6. Results and discussion.....	33
7. Conclusion	35
8. Bibliography	37

List of Figures

Figure 1: A depiction of a VR system.....	8
Figure 2. Above equipment is a components division in which will form a system of the driving simulation.....	10
Figure 3. The participants' survey that if they would prefer a VR based training environment that trains them for real world hands-on tasks	12
Figure 4. The participants' chose if they would learn more about VR and if they would introduce it into their lives.....	12
Figure 5. Flowchart of applied methodology	20
Figure 6. Animal Blueprint that is already embedded with the animations. The image shows a circular pattern around it which is the collision dimension of the animal.	21
Figure 7. Locomotion graph of the AnimGraph	22
Figure 8. Trigger event followed by the blueprint function attached to it called in by the Cast to function.	23
Figure 9. Vehicle blueprint.	24
Figure 10. Console input mapping.....	24
Figure 11. Animation Blueprint EventGraph.	25
Figure 12. AnimGraph, embedded with the Locomotion Statemachine	26
Figure 13. Using the VR driving simulation	26
Figure 14. Cockpit view from the model car (VR Simulation)	27
Figure 15. CSV taking data from the vehicle coordinates in level blueprint.....	28
Figure 16. Depiction of drive line on the road map taken by users.....	29
Figure 17. 2D model of drivers' path (collective representation of all the tests)	30
Figure 18. Animal crossing area placement in the driving path of participants	30
Figure 19. Test 14 (pink line), shows the deviation of the path when confronted with an animal crossing, the driver lost the control of the vehicle here and were not able to keep track of the road.....	31
Figure 20. Test 14, shows the driver, losing control of the vehicle after coming across the animal crossing and driving off the road (dataset showing the x,y coordinates and the timestamp).....	32
Figure 21. Default Path versus Test path 14 and Test path 15 in a 2D representation, also note the representation of the animal crossing instances during the path of their drive and how it affected their performance.....	32
Figure 22. Survey questionnaire results.....	34
Figure 23. Participants rated their VR simulation experience	35

1. Introduction

VR (Virtual Reality) can provide our minds with direct access to digital media in way that seemingly has no limits (Jerald, The VR Book, 2015). Imagine, you are about to go through a situation where you are nervous about but somehow there is a hack that you can go through that same situation, a close to real life simulation without actually being a part of it, thus training yourself on how to tackle it in the real world. VR is the use of computer technology to create a simulated environment, unlike conventional user interfaces, the VR places the user inside the experience where the user can interact with the 3D world (Bardi, 2019). In the VR realm, the mind and body interact with a digital world designed by humans, keeping in mind a certain perspective or the need for the environment, though it feels almost like being in the real world scenario there are a lot of aspects that need to be kept in mind while designing a VR based environment. The world of VR that is booming today, humans making their own virtual worlds and using them towards their advantage is a challenge and at the same time it is a huge leap forward in the advancing technology, thus equipping humans and machines better for those scenarios. VR systems have come to be a part of our world where humans can interact with anything, designed by themselves to get the optimum results for a task before applying it in the real world. Giving away more understanding of the VR world, in technical terms, it uses a generation technology of 3D graph, multi-sensor interaction technology and high-resolution display technology to generate simulative 3D virtual environment (Yu, 2011).

The VR technology has entered our lives, ranging from home entertainment solutions to helping people through their post-traumatic stress disorders (PTSD) and many applications in between. The total number of active VR users worldwide is focused to be around 171 million as of 2018 (Statista, 2020). The users interacting with the VR environment use a head mounted display (HMD) from which they can see the virtual environment and their mind starts to calibrate with this new world in terms of sense and direction. The inputs taken, and the outputs given to the environment is the communication going on between the user and the VR environment, these are exchanged from an input device which can vary depending on the environment the person is using, it can be an input-glove, joystick, racing wheel, game pad etc. This enables the user of the environment to become a part of this environment for the time being and can interact with it as it was intended. The user experience should be very immersive so the person

using it can experience the VR fully in order to reach the expectation intended from the system. An ideal VR system enables users to physically walk around objects and touch those objects as they were real (Jerald, The VR Book, 2015). Displayed below, Figure 1 shows how the VR system is designed in context, the user interacts with the system and his interaction is taken as an input by the application designed. The rendering of the environment depends on what we need from the environment. The communication done between the user and the system gives out the output and the diagram below shows the cycle that is followed (Jerald, The VR Book, 2015).

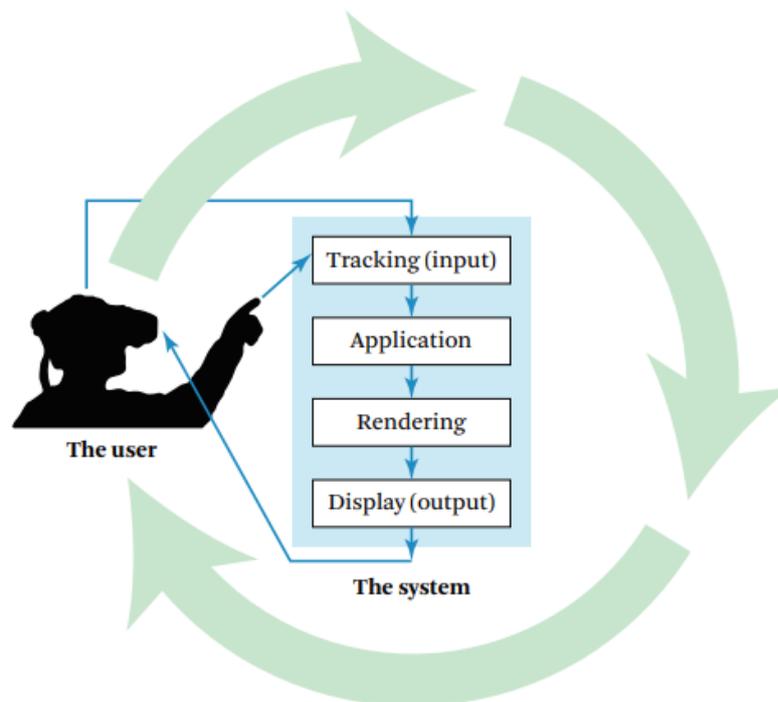


Figure 1: A depiction of a VR system

We see vehicles every day, they have become a part of our lives and unless we are living in a remote island in some remote part of the earth, it is inevitable that we are going to interact with them on daily basis. Autonomous cars are still a long shot right now, the computers in them need to be fed a very diverse data to make them independent to drive in daily, as well as special environments. Or even environments that require immediate response in order to avoid accidents. They still need a huge amount of data in terms of different scenarios that we experience on the road in order for them to be independent on the road and act in a certain situation accordingly. Though, vehicles with semi-autonomous driving systems where the driver can switch between autonomous control and take over when it is needed is a very interesting topic of research. The Society of Automotive Engineers (SAE) has though provided taxonomy for such vehicles in which

they have modelled the system in terms of actors. The (human) user, the driving automation system

and other vehicle systems and components (SAE International Standards, 2018). Readers of this paper might be driving for a long time or encounter vehicles on daily basis. We have often found ourselves on the road, in our cars where some unexpected situation arises and have seconds before we can make a decision where we have to keep our and others' safety at priority one.

1.1. Research goal

The basis of research done, presented in this paper is focused on getting data from human drivers once they are put in a certain driving condition using a driving simulator, their response time and readiness to the situation. Though the driving simulation was introduced in 1970, it has come a long way and developed a lot over time (Richter, 1974). The potential in learning in a 3D virtual learning environment (VLE) has an edge to the user of the environment. An article published in a British Journal of Educational Technology gives an insight in this area, where they discuss the learning benefits of 3D VLE. The authors are biased to the continued development in 3D games, virtual environments and simulations for educational purposes. In this research the author also emphasizes on the design principles of the VLE development to get out the best results from the environment. The author also states that the design principles figuring are on trial and experimental basis, the author also points out that there is no such research based models currently that define the design principles of the VLE (Dalgarno, 2010). Another research conducts the idea where there is a possibility to study more emerging educational practices that have led to serious games as a new form of educational and training purposes. There is a huge potential in this field that can supplement the traditional form of educating and learning. The authors and research team at the Serious Game Institution (SGI) in the UK is bringing together different lines of research in educational research (Liarokapis, 2011).

We intend to 20 participants and read off the data from them when they are put into a situation where they will experience the designed driving conditions and how they process the driving situation will be recorded and evaluated. We have developed such environment where the driver (human) is going to be prompted with a certain situation while they drive normally in their car. But the research done in this dissertation, the

drivers will be driving in a 3D VR based simulation system. The combination of the equipment is shown in Figure 2 (a) Oculus Rift (Andrew London, 2015), (b) Logitech G29 Racing Wheel Console (Ebay, 2020), (c) PlaySeat Driving Seat (PlaySeatStore, 2020). The participants will be equipped with Oculus Rift HMD and Logitech G29 Racing wheel attached to a PlaySeat, the drivers will also be given the option to choose between 3 vehicles of their choice.

The following figure shows the equipment that was used in the research:

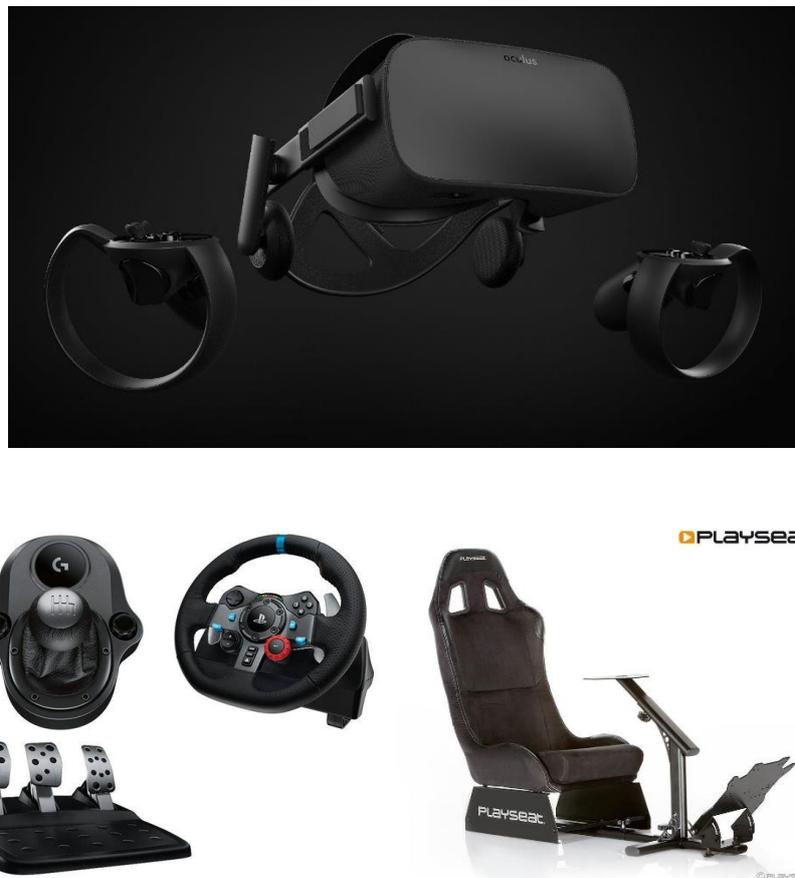


Figure 2. Above equipment is a components division in which will form a system of the driving simulation

The PlaySeat is mounted with the Logitech G29 Racing wheel as an input device, the drivers will be able to brake, accelerate and turn the vehicle normally as they would with their normal driving practices. The use of HMD has a very important factor, which can offer huge level of immersion in our experiment. Moreover, it has been proven that VR that is supported by HMD is more effective compared to other training systems .The

environment designed is a rural one and the drivers will be asked to enter the VR system and they will be asked to drive around as they would drive normally. The simulation design is done in the gaming engine Unreal Engine 4, we used the version 4.23. The users of the system will drive around in the simulation, they will be prompted with a certain road hazard situation where they will have to respond according to their driving capabilities and how they respond to that particular situation. It cannot be ignored that the environment will have some impact on their response to the hazard they might encounter on the road. Once the simulation comes to an end, they will be assigned a questionnaire where they will answer a few questions to see how they reacted, and we intend to get the results from that. We might be able to deduce the result from the perspective of what kind of conditions the driver might feel comfortable and what kind of responses will these environments bring from the driver. A study was done into how the environment affects the driver and his cognitive responses in a certain environment. The study suggests that the impact of road characteristics on drivers' attentional resources may depend on the presence of natural elements. The research done in this paper was done with participants who were asked to drive in a VR simulation, rural versus urban environment, and it was assessed that which environment caused more fatigue, which would directly affect the response (Cassarino, 2019).

1.2. Relevance and probable research outcome

A general survey was done among the people if they would like to learn more about the VR experiences and introduce it into their life. The importance of this survey was to study the perception of the people on VR and also, how would they interact with it. As all the applications of VR are designed depending on the user requirements, thus such data was deemed important for this dissertation. Following this, another question was asked via a survey that if they would think about the idea of using VR to train them for real world tasks. Following are the results of the survey done among 40 people:

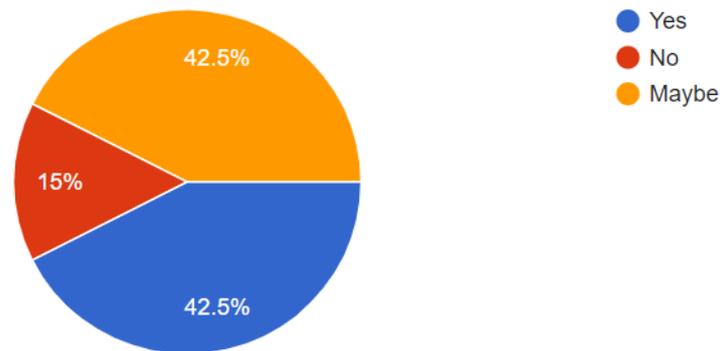


Figure 3. The participants' survey that if they would prefer a VR based training environment that trains them for real world hands-on tasks

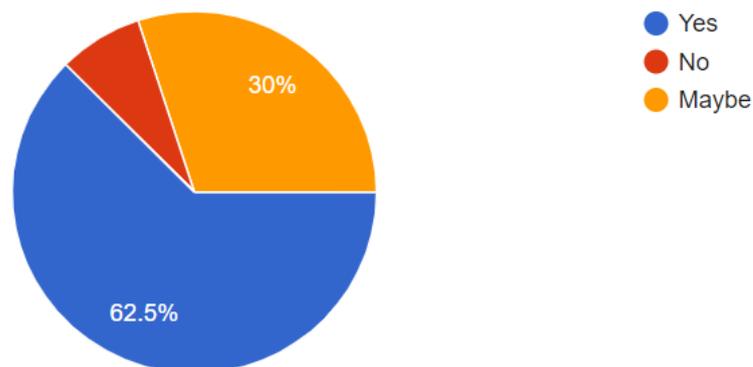


Figure 4. The participants' chose if they would learn more about VR and if they would introduce it into their lives

From the data collected and visually represented in the Figures 3 and 4, we can see that most of the people are interested in learning the VR applications and would give it a chance to engage with VR applications in their lives. Reading off this data, there is a huge potential already present there to introduce people with VR applications ranging in various fields.

The objective of research in this paper is that we intend to take data from the results that is being applied to the parameters of safety in autonomous cars, as they are currently a hot topic in the automotive industry. The European New Car Assessment Programme

published a technical paper in 2017 where they provide their plan where they are integrating technology for safety of passengers and other road users as well. They provide a thorough plan till the 2025. In this paper an assessment for automated vehicles was proposed where they intend to reduce some important problems that cause distraction to the driver through impairment caused by alcohol or fatigue etc. In addition, the driver monitoring system is also capable of checking driver's behaviour if they are fully indulged in the driving or they are distracted by something. It is by the Euro NCAP that the automated driving can hugely eliminate the errors caused by the drivers. The automated cars will be also be categorized to some level of safety such as the type and degree of assistance/automation offered (NCAP, 2017).

The vehicle manufacturers can also benefit from this data in order to design or make advancing changes to current safety features of a vehicle. The participants of the project will behave uniquely in give situations and we can know the readiness of the drivers a spontaneous situation. Many advanced developments are being done in advanced driver assistance system (ADAS), which have significantly improved and tested (John M Scanlon, 2017). A research refers to safety of driving environment including factors such as, human, environment and vehicle. The methodology used in the research evaluates drivers in 5 specific conditions by machine learning algorithm, from them assessing the situation and what can be done in order to avoid the accidents. The research done is in order increase vehicle safety (Aksjonov, 2019).

The following contents of this research gives a little background from the work done on VR previously, as this is a technology that has emerged in very little time but has the potential to go very deep into our lives, researchers throughout the world are still trying to experiment with it in different aspects of their lives, seeing where they can use it at its best or even for entertainment purposes. Because this technology directly interacts with human mind and is hugely dependent on how the humans will behave when they come into interaction with it, this technology is very, very diverse and will change rapidly according to the best setting where the human mind can be most comfortable with it.

2. Background

In this section we will provide a thorough background literature review done on the VR driving simulations and their applications that are being used in the industry today. Most of the simulations fall into the category of training where the data from the drivers is

analysed and others go into the entertainment industry, such as driving games. Every tech industry has its challenges and it takes some time to make it adjustable to humans and to have them find the best place for the technology in their daily lives. Though there are a lot of issues that are being conquered in the realm of the VR, some of the issues being faced are: The price is too high, the making of the VR gear is pretty expensive and the manufacturers cannot reasonably decrease the price, lack of content, it is suggested that the VR technology still needs a landmark app that is enough to gather audience market, lack of business model is one challenge VR is facing right now, the users do not know where this technology will be in the long term from a business perspective, VR industry is still uncertain about the health issues it might cause in the near future, it is perceived that the VR will cut off its workers from the environment and the potential hazards. There is still no conclusive aftermaths of long term VR usage but it is considered to have side effects such as blurry vision, nausea, motion sickness etc, if it is over used (Wolwort, 2020). On the contrary, VR is having its immense benefits in the real world industry: uses in architecture and urban design, where the users can virtually simulate an architecture and see what it feels like before building the actual model, VR model is being used in the training exercises without the consequence of being failing and training over and over, such applications include: flight simulations and vehicular applications, medical applications such as complex surgeries and even military exercises (Wikipedia, 2019). The following section presents some researches done in the current field and how the researchers are applying the technology in different aspects of lives.

2.1. Related work

As mentioned above, the part that the VR plays in the driving simulations and road safety is a very diverse topic of interest and research. People are still getting used to it and the scientists and VR designers are looking for ways to make this application at its best. The area needs deep study when it comes to Human Computer Interaction (HCI) and the communication with the environment so the people or participants learning from them can be best benefitted from this.

VR driving simulations helping people coming over driving phobia and PTSD caused by driving

VR related driving simulations are helping people come over driving phobias, fear of driving or getting into an accident and even agoraphobia, according to a research done in 2012. The research explores certain areas: People with post-traumatic stress disorders caused by a driving accident or even witnessing one are being helped recover by VR driving simulations. It is stated that 15% of people involved in driving accidents develop phobias (Blanchard, 2000). The research finds that this turned out to be helpful for most of the patients and they are planning to continue their work with VR simulation and extracting fear from the drivers who have driving-related issues (Wiederhold, 2012).

Comparison of driving simulation: VR HMD versus Flat Screen View

A study in May 2017 was done to evaluate VR driving simulation from players' perspective, where there was a comparison done between the flat screen TV set driving simulation versus the VR HMD. As we are still getting used to this new technology it is inevitable that a lot of experiments will be done on this topic. The results showed that wearing the VR HMD significantly increases the immersion level and cuts the drivers off from the real world compared to the flat screen televisions. There were 20 participants involved who were asked to fill in the simulator sickness questionnaire to see what they felt while driving in the VR HMD (Walch, 2017).

Evaluation of road crashes at stop signs on the road

In another research, an evaluation was done of drivers on how conscious they are about following the stop signs on the road. The U.S department of Transportation (DOT) found that many fatalities occurred at traffic signals and stop signs. It is stated that stop signs markedly involve more fatal crashes, yielding a total of 13,627 fatal crashes in 1999-2000 (Najm, 2001). The research done in this paper is directed to change or alter the traffic guidelines in order to minimize the crashes and such accidents. The target participants in this research work is also the people who have acquired brain injuries and it is assumed that their driving skills might not match the required cognitive responses needed for driving.

Comparison of driving simulations: 3D versus 2D

A comparison was done on the driving simulation to check whether the drivers of the system will be more comfortable with the 2D simulation or the 3D simulation. The book also covers a huge aspect of transport infrastructure and all the technical aspects needed to make the transport better and safe (Siergiejczyk, 2020). The article in which the research on VR driving simulations was done had the aim to find out which of the two simulations are better keeping in mind the aspects of motion sickness, immersion levels and the demands of dynamic driving. The authors of this particular chapter in the book also point out that the conventional driving training is time demanding, tedious and cost a lot because of the personnel involved in it whereas the VR training in contrast is better and can support future training for driving, replacing the traditional schools (Gąsiorek, 2020).

An evaluation of performance of young drivers and educating them to drive using VR driving simulator

Another research took place in Turkey where the drivers were aimed to be educated in real life traffic situation. A study that they did was that 70% of the road accidents are caused by young drivers between the age of 17-24, according to the report by Organization of Economic Cooperation Development (OECD), (Organisation for Economic Cooperation and Development (OECD), 2006). They developed a tool to educate the drivers in which the environment followed the norms of Turkish traffic rules and students had to take a test in that environment.

Studying the driver behaviour while driving in VR simulation using eye tracking and attention span for automated vehicles

A very interesting and dynamic research is being carried out at University of Iowa, National Advanced Driving Simulator (NADS). It is estimated according to a recent report it is estimated that 90% of road accidents are because of human error (NHTSA, 2016). The key areas of the research are to understand how the driver behaves and performs and it is being monitored to check the Driver State Detection (DSD) and how the driver will interact with connected vehicles as well as autonomous vehicles of the future. The research being done here is also being used to evaluate the advanced vehicle systems and their

coordination with the driver. One of the most important topics in autonomous vehicles is the transfer of control (TAC), on how does the car gives control to the driver and how does the driver give control to the vehicle. The researchers are this facility believe that the core cause of the accidents which is human error can only be overcome by autonomous vehicles. The main focus here is on the driver, road and vehicle. One more interesting experiment is that they monitor the driver's visuals and check the alertness and their focus on the road, this evaluates the limitations they have in terms of cognition, for example what activities might distract the driver and what countermeasures can be taken to prevent them. They are also speculating on what kind of feedback; messages can be presented that will be effective for driver alertness. The source of information was from a YouTube video presented by the following researchers: Dr. Chris Schwarz, Omar Ahmad, Dr. Tim Brown, Dr. John Grasper and Dawn Marshall, (NADS, 2014).

Studying driver attention and distraction span on variety of roads using VR driving simulation

The Malaysian Institute of Road Safety Research developed a fixed-based driving simulator which has the option to suit various road safety environments. The objective of their study was to measure the driver distraction depending on the road the participants were on and when they were assigned secondary tasks. They studied this behaviour on three different kinds of roads: expressway, off-ramp and a curved road. The drivers were asked to drive on the simulations and were assigned secondary tasks to perform while they were driving, such as; recall number, surrogate reference task, navigation and texting. As a result, the response times in their experiments increased as a function of road segments as well as exposure to the secondary tasks. This study was obtained by using a VR simulation and which was a huge plus (Siam, 2015).

3. Theoretical Framework

The theoretical framework of the researches done in the VR driving simulations are done mostly on evaluating if a VR environment can be helpful in training drivers to avoid accidents, overcome fear of road and traffic, help the post traumatic patients who have been involved in an accident to get back on road and drive as best normally as possible. Also, a very wide research is being done on training new drivers in VR based driving

simulations. Though, this idea may not ever replace the real driving training done by professionals but it sure can be used as an auxiliary and an area to research about.

The study of human behaviour in a VR driving simulation plays a very important role while developing one and also using one in for applications. To make the idea of VR driving successful, the host (driver) has to be as comfortable as he would be in a car driving out on the road and then and only then, the VR can serve its full purpose in driving simulations and any other field it may be applied to. The study of this behaviour is a very wide field itself and many researches are being done in it.

3.1. Key concepts

- a. VR Driving Simulator: This is the basis concept where the driver is put in a VR environment. The environment is designed in a gaming engine as close to what your target environment is, in this research, Unreal Engine 4. So, moving on the environment designed is a road on which the driver will drive in this simulation in a car that has all the key features as a normal car would. The interaction of the driver would be as close to the real world one from which we can read a lot of data because we would be recording the actions and the reactions of the driver in a certain given environment.
- b. Reaction time: This is the time in which the driver will be confronted with a certain incident, an entity crossing the road, the light turning red etc. The time in between the event occurred, T_e , and time it took the driver to react according to the event, T_r , can be called as reaction time.

$$\text{Reaction time} = T_r - T_e$$

- c. Driving Environment: Defines the specific environment where the driver will be put in and how that environment demands the driver's response and capabilities depending on the data that need to be studied or read according to the situation.

3.2. Evaluation

The literature review done in this dissertation explains that despite the VR is not a replacement to the real world scenarios but they better prepare us to face the real world

tasks by extensive training and continual improvement of the environment and other concepts such as immersion level and communication between the user and the VR system. The simulations done in the VR can also provide immense details on the attention, alertness and the readiness factor of the driver depending on the road situation. The majority of the studies done in the researches above mentioned in the Section 2 are done as follows:

- A driving simulation is prepared, the simulation is usually classified in the form of types of roads, terrain, city driving etc. It entirely depends on what the researchers intend to study. The environment design also vary country to country depending on the country and the region.
- Once the environment is set and ready to be tested, a number of participants are called upon to perform the simulation test and their data is collected off the test.
- When the data is collected the researchers extract the results off the data and draw the conclusion whether the data provides the information from the drivers' part and the simulation.
- Information regarding the simulation set ups have also been brought under research that to which simulation set up do the participants are most comfortable with to get the most real results off from the simulations.

4. Methodology

The methodology used in this dissertation is of the type explanatory and quantitative methods were used to extract the result data. The aim for this research was to address a practical research problem. This method was chosen because this gives us a very diverse data as every human has a different perception to situations and how they handle their daily driving chores, thus this diverse data showed us a certain behavioural pattern through the data on how they coped up the situation prompted to them.

In this dissertation this is where we study the data taken from the drivers about their readiness to prompt situations that they can encounter in their driving. As mentioned in the first section of this research, it was stated that we will be collecting our data off from 15 participants. The participants differ from ages to 20 to 34 and all of them hold driver's license and are daily drivers, this was a base requirement while selecting the participants just so they are familiar with the driving process and so the training session could be avoided to be time consuming. The participants were given a short training via slides,

making them aware of the conditions and give them a know-how of the environment, controls and getting them set up with the PlaySeat and the VR. The participants had a choice to choose between three kinds of vehicle types: sedan, SUV and a hatchback. Once everything was set and they were comfortable and ready to test, the test was started. The driving simulation is a simple road with curves and turns in a mountainous area. Once they started to drive in the environment the coordinates of their vehicle were being tracked as X, Y and Z coordinates. The methodology used here is that the Unreal Engine 4 supports a function in the Blueprint functionality that we can print the string along with the project running, this piece of information is printed in real time for whatever information is needed to be extracted from the project. The coordinates are stored in the CSV files, which will store the coordinates, and they will be extracted as graphical representation in the data that we have collected. Each participant had their own CSV file which shows a graphical representation on how they acted in the situation that was assigned to them. The Figure 5 is a flow chart of how the methodology of the project is working to give a clear insight of the workflow.

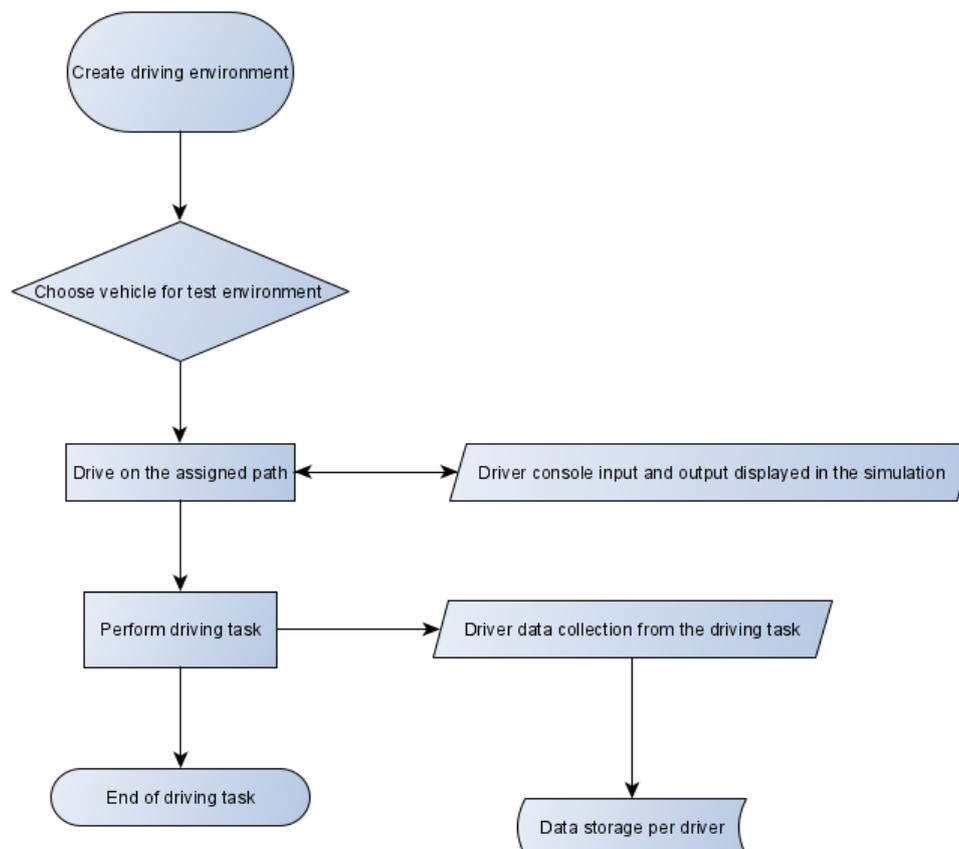


Figure 5. Flowchart of applied methodology

4.1. VR Environment Design and Characters

The concept of designing the environment was crucial to the whole task. For this task the Unreal Engine, provided by Epic Games Technology was chosen. The Unreal Engine is widely used outside of games, such as architecture, product design and filmmaking, it is widely known for its photorealism (Dealessandri, 2020). The immersion level and the reality factor, close to the real-world was kept in mind.

The layout of the road on which the users drove the vehicle and all the key aspects, such as physics and texture of the road was kept into consideration of the environment design. The calibration of the drivers' input via the Logitech G29 console with the Unreal Engine was done using the mapping of the Raw Input plugin of the Unreal Engine (UnrealEngine, docs.unrealengine.com). The idea was to make the driving experience as real as of a car and the steering wheel inputs, combined with brake and gas pedal inputs as well. The drivers were allowed to choose between their cars and whichever car they chose is used in the test from start to the end of the test. On a certain road, while driving the vehicle the drivers were prompted with a situation where an animal jumps out of the woods that are on each side of the road and they are expected to react according to the situation that includes their safety and the animal's as well, in the best case scenario.

The Unreal Engine Marketplace offers variety of 3D models that can be used in a project depending on the context (INC). The animal used in our project was taken from the market and placed and was used in the environment as a real-time animation entity, Figure 6.

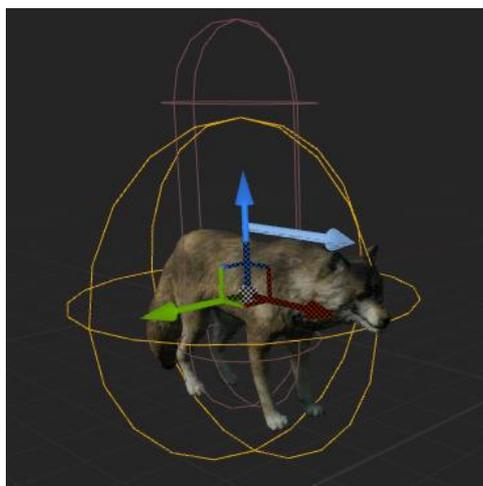


Figure 6. Animal Blueprint that is already embedded with the animations. The image shows a circular pattern around it which is the collision dimension of the animal.

The process of designing the animation and having it perform certain tasks is included in the package that was downloaded from the Unreal Marketplace. The animal blueprint has different states of animation that a normal animal would possess, for example, idle, run, bite, sleep, die etc. We designed the animation in the sequence which would best fit our context, refer to Figure 7. The figure shows a locomotion graph which uses the inter states of the animation and is inter-transferrable.

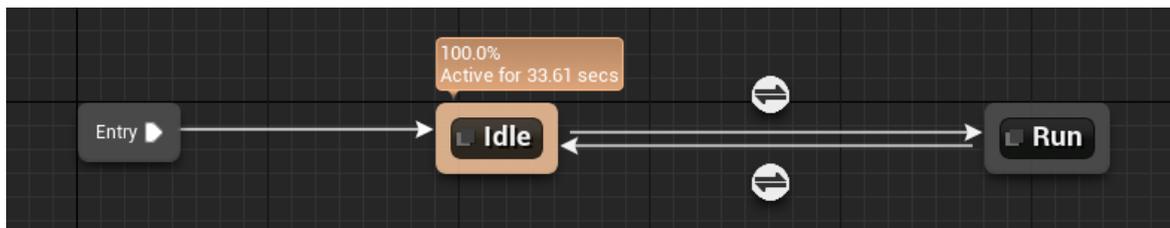


Figure 7. Locomotion graph of the AnimGraph

The animation was then triggered using blueprint (BP) depending on the location of the car. BP can be thought as a form of visual programming in UE4 which is the basis of all the designs, interactions, whether it may be animation or adding effects to your project, all of it is done using the blueprints. Blueprints is the visual scripting system inside UE4, instead of having to write code line by line, you do everything visually: drag and drop nodes, set their properties in a UI and drag wires to connect (Tran, 2017). The blueprints provide the mechanism to make an event in the system, these events need to be called. The events can be called normally in the environment as soon as the environment is played or there are other ways to call an event as well. For this mechanism to work, the UE4 has the concept of Trigger Actor. Triggers are Actors that are used to cause an event to occur when they are interacted within the level, they are present (UnrealEngine, docs.unrealengine.com). There is a special event that can be called by a trigger named as ActorBeginOverlap, which literally means that when an Actor in the environment is overlapping the volume of the trigger, this event will take place. Another crucial function in the making of this project is the Cast to function, where let's say we have created a blueprint of a character, which has variables or objects, and we need to call it in by a specific event, this is where the Cast to function is used (UnrealEngine, docs.unrealengine.com). Refer to Figure 8 to see how trigger overlapping and Cast to function work in the project, notice that we have already created the blueprints of our driver and the animal, in this case, a wolf. Notice that the environment that is mentioned previously comes into play here, meaning, as soon as the vehicle enters the triggers which

is deployed on the road, the animal animation will occur. This will prompt the driver of the vehicle which is what we intend to do in this experiment.



Figure 8. Trigger event followed by the blueprint function attached to it called in by the Cast to function.

The character car used in the project was used as an overlapping actor which interacted with the trigger actor. The entire procedure is applied using blueprints. Once the car overlaps the trigger box in the level, it triggers the animation of the animal which is to have it jump out on the road and promptly in front of the driver.

In the following sections we will be describing how the blueprints of our characters were created and the figures will help understand on the deeper level with a perspective of blueprints on how the visual scripting works. The following figure shows the blueprint of the vehicle and the two events that monitor the movement of the car: InputAxis MoveForward and InputAxisMoveRight. Both of the events are followed by the functions that which take the input from the console. This is where the console mapping comes into play, which are the values that are already mapped in the Engine Input of the UE4. The values are float type and need to be calibrated according to the console being used. The following Figure 9 shows the blueprint of the vehicle and Figure 10 shows the axis mapping to give a better understanding of the parameters being used while calibrating the console.

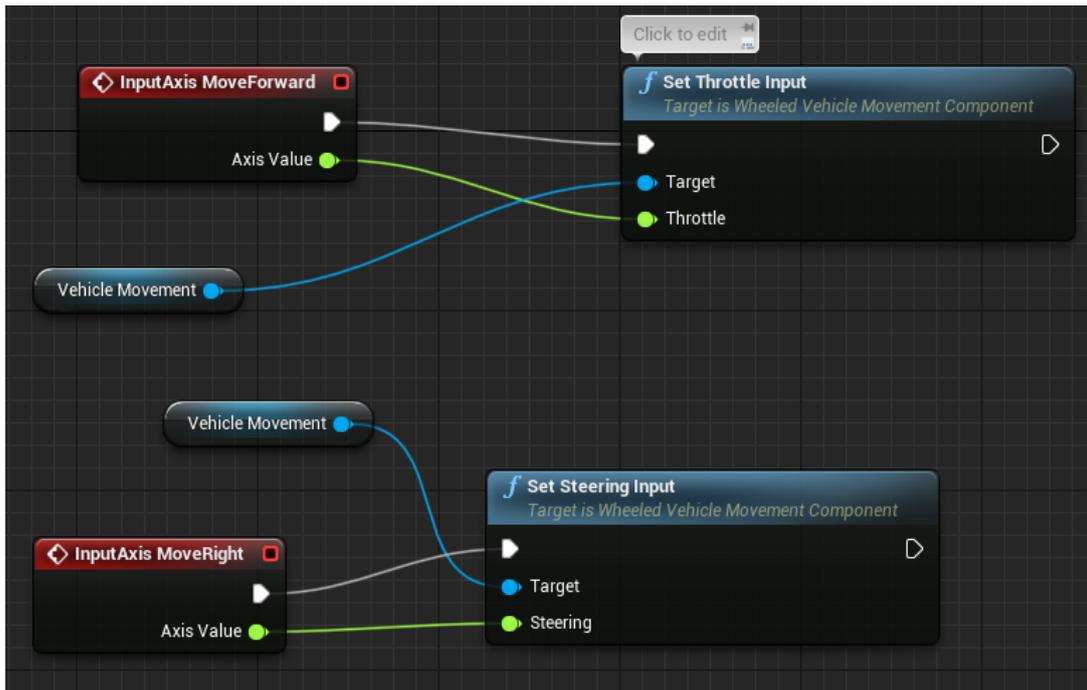


Figure 9. Vehicle blueprint.

Figure 10. Console input mapping.

The UE4 offers numerous types of console inputs that can be used once in the project, again keeping in mind the importance of immersion of users we chose the Logitech G29 as console input using the RawInput Plugin. The Logitech G29 Racing Wheel is not a default input method in UE4, thus it is embedded with this plugin which can read specific devices that do not conform to XInput standards (UnrealEngine, docs.unrealengine.com).

Moving on, the logic used behind the animation blueprint is what controls the skeleton of the animal. An Animation Blueprint is a specialized blueprint that controls the animation of the Skeletal Mesh. Graphs are edited inside the Animation Blueprint Editor where you can perform animation blending, directly control the bones of a skeleton, or set up logic that will ultimately define the final animation pose for the Skeletal Mesh to use per frame (UnrealEngine, docs.unrealengine.com, 2020). The Figure 11 shows the animation blueprint used in the project. Following that is the concept of AnimGraph, Figure 12, by default, each Animation Blueprint has an Animgraph which may have Animation Nodes, in our case, as mentioned above; idle, run, walk, die etc. The nodes are used to sample the Animation Sequences or perform animation blends (UnrealEngine, docs.unrealengine.com, 2020).

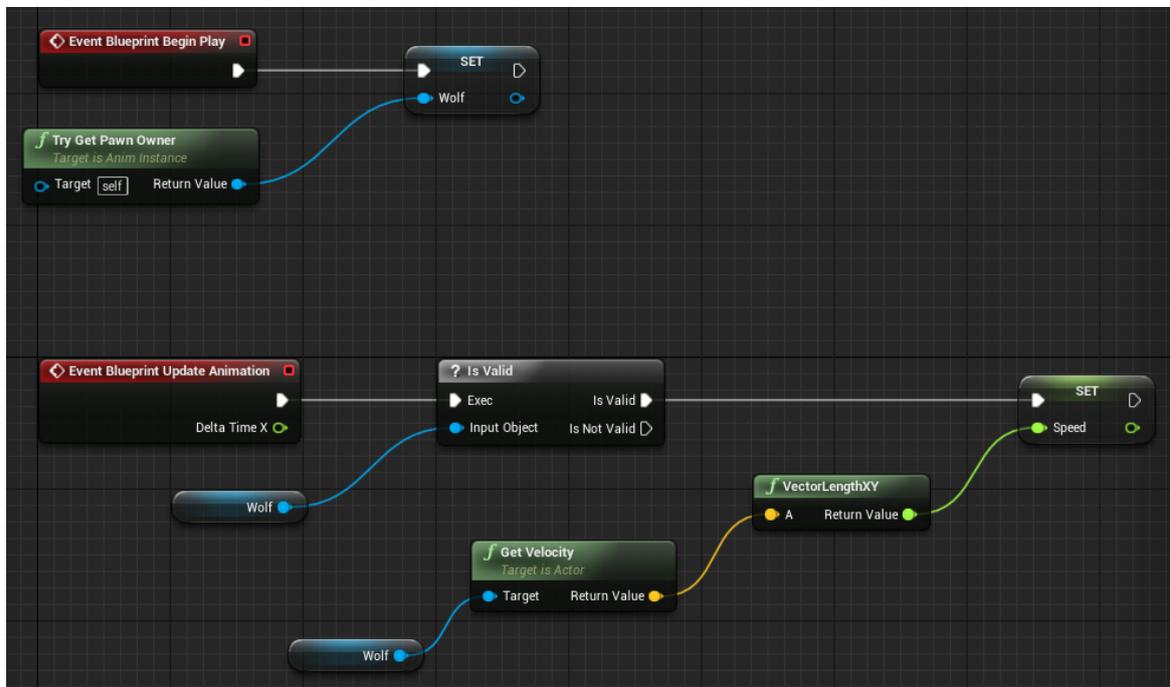


Figure 11. Animation Blueprint EventGraph.

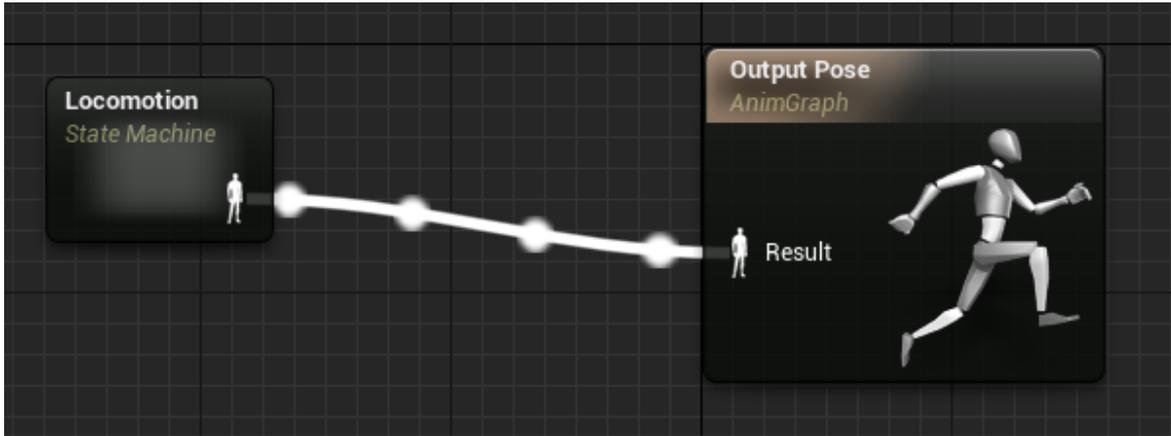


Figure 12. AnimGraph, embedded with the Locomotion State Machine

5. Experiments and data collection

Once the environment was set, the participants were asked to participate in the test and from there we collected the data that was coming off from their driving. The participants came to the VR lab one by one; each had a consent sign formed and were told that their driving information will be recorded. Then they were given a short introduction about their task and how to get them used to the VR system and adjust them in the PlaySeat where they would be performing their driving task. Below Figure 13 shows the VR driving simulation in use. Figure 14 shows the VR simulation view from the cockpit when the driver is in the vehicle during their driving test session.



Figure 13. Using the VR driving simulation



Figure 14. Cockpit view from the model car (VR Simulation)

The UE4 supports plugins that can be used auxiliaries to perform all kinds of functions that you desire from your project. In the level blueprint we collected the data from the vehicles that were used by the drivers, the vehicle is driving in a Navigation Mesh that is embedded in the map. This gives off the location of the car as it would give in a simple 2D graph, plotting the location of the vehicle on x and y coordinates. The coordinates are mapped with timestamps and each location on the graph shows a timestamp against them. The plugin is placed in the content folder of the project and it can be called into the blueprint function. What we did was fed the coordinates of the vehicle into the CSV file and the CSV files are being made in real time. The plugin installed in the blueprint writes the files and creates them every single time the project is run. The CSV file is stored into the project folder. For every participant that participated in the driving simulation, a separate CSV file is generated which is a unique data file of the participant's driving task. The installation of the CSV plug in shown in the blueprint is shown in Figure 14.

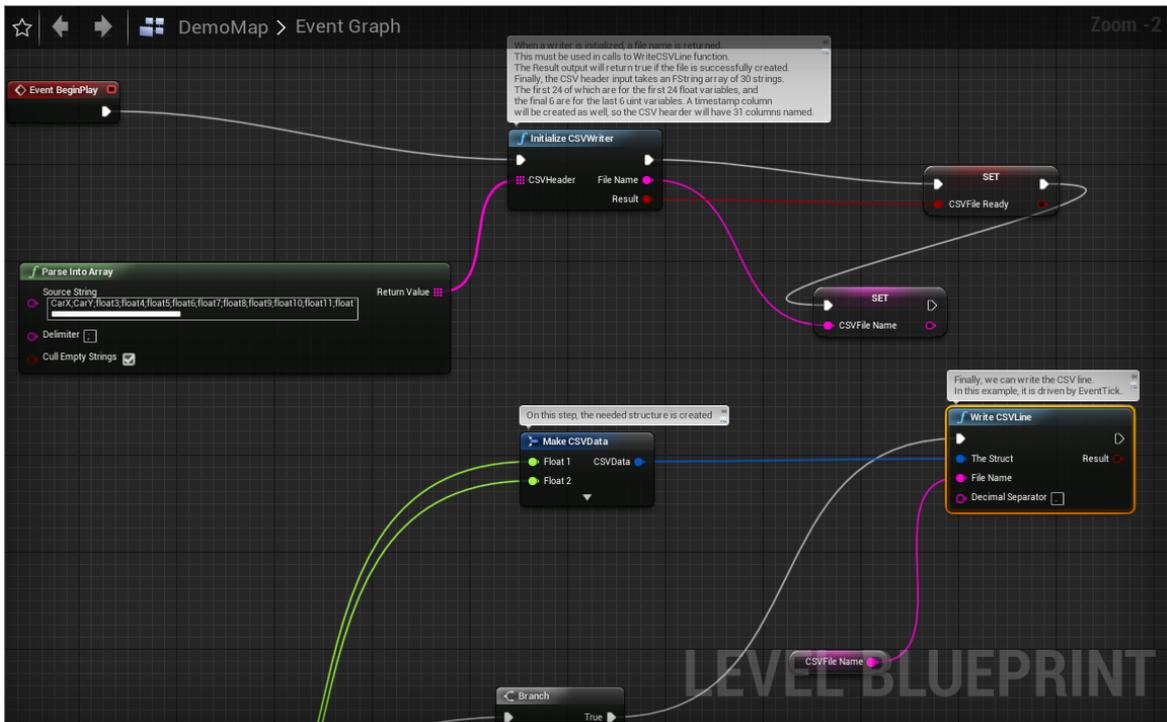


Figure 15. CSV taking data from the vehicle coordinates in level blueprint

As shown in the Figure 15, when the event BeginPlay (when the simulation is started) is called it starts the CSV writer which writes into a CSV file. The data that we needed to put into the CSV is given in the function of blueprint- Parse Into Array, for this research the coordinates of the vehicle, labelled Car X and Car Y with the timestamps were necessary, which were fed as return values from this function into the CSV writer function. Throughout the journey of the vehicle, the coordinates were pumped into the file and for each test we generated a CSV file, showing the progress of the driver. The code made for the plugin to generate the CSV files was run in Synder. Spyder is an open source cross platform integrated development environment for scientific programming in Python Language. Moving on, this data was built into graphs which showed a better view and data analysed of the tests.

5.1. Data collection and graphical representations

In this section we will go into more detail of how the graphs were made using the CSV files. The plugin used in to generate CSV files was written in Python. Further graphs and integration were developed in Python's library, Plotly. Plotly is Python's graphing library

which makes interactive, publication quality graphs (Plotly, 2020). Spyder assembles specific stack of packages that are used in the scientific Python stack (Wikipedia , 2020). The graphs generated from the CSV files are also unique and they show the progress of the participant along their driven task. During the test there was one of the tests performed which was up to mark. Which was set as Default Path in the graph represented below and then the rest of the tests were compared to that Default Path shown in a graphical form. The graph is a 2D representation of the tests performed, Figure 17 shows the collective representation. The graph was plotted with the x coordinates of the vehicle on the x-axis, labelled as Car X and the y coordinates were plotted on the y-axis labelled as Car Y. Before, Figure 17, Figure 16 shows a depiction of the path that was taken by the users. The road map shown in the simulation is shown and a rough black line represents the line of drive. Looking at the line of drive we can see a similar pattern in the driving from the 3d graph shown in Figure 17.

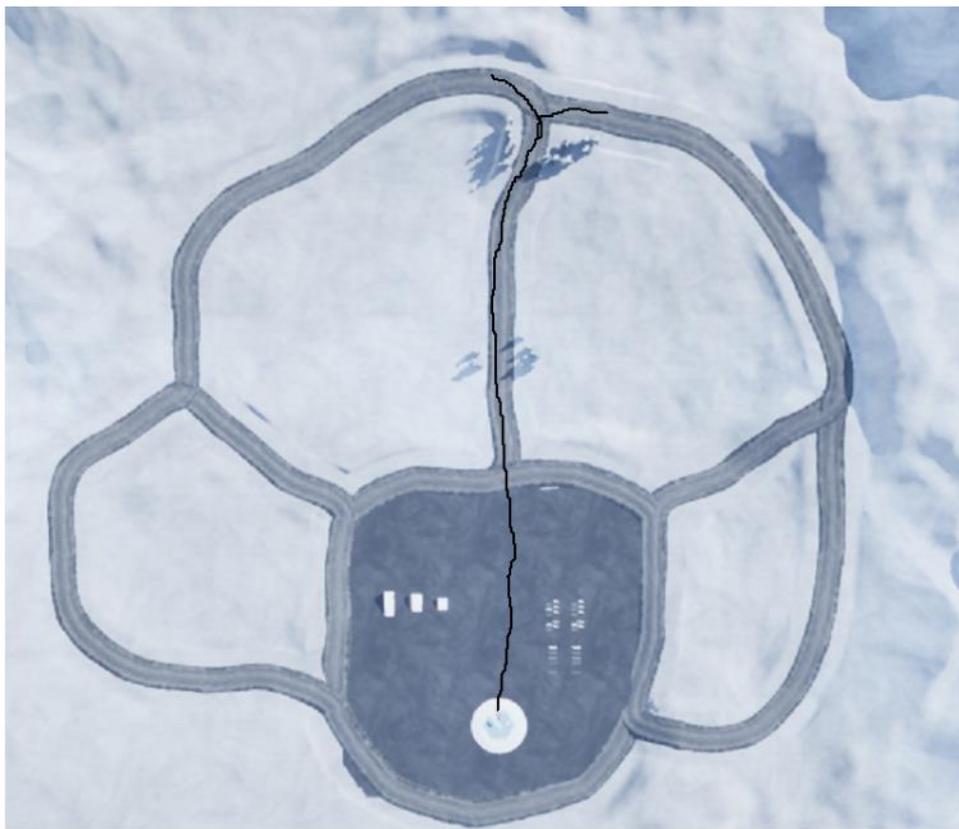


Figure 16. Depiction of drive line on the road map taken by users

CarX vs CarY

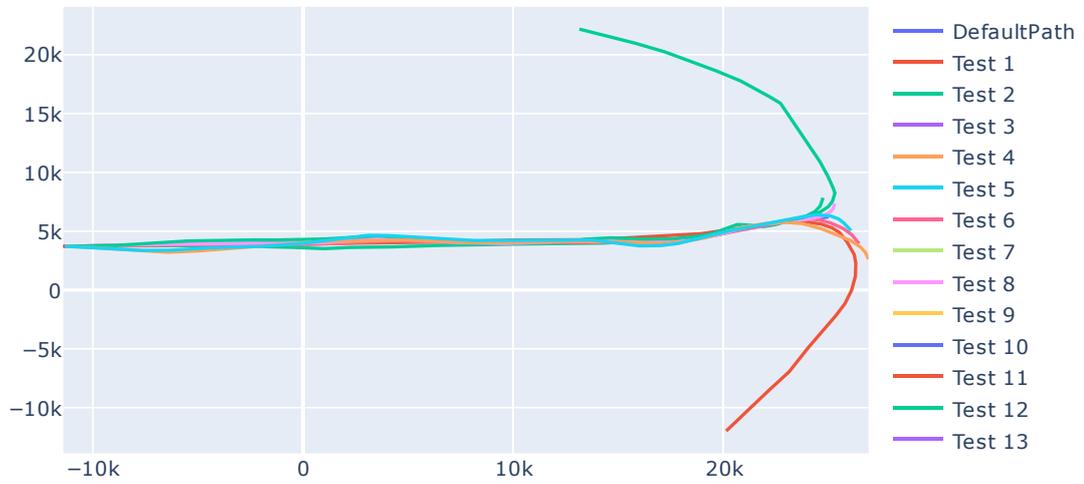


Figure 17. 2D model of drivers' path (collective representation of all the tests)

Another representation of the same graph shows where the animal crossing occurred on the road while the participants were driving in the simulation, refer to Figure 18.

CarX vs CarY

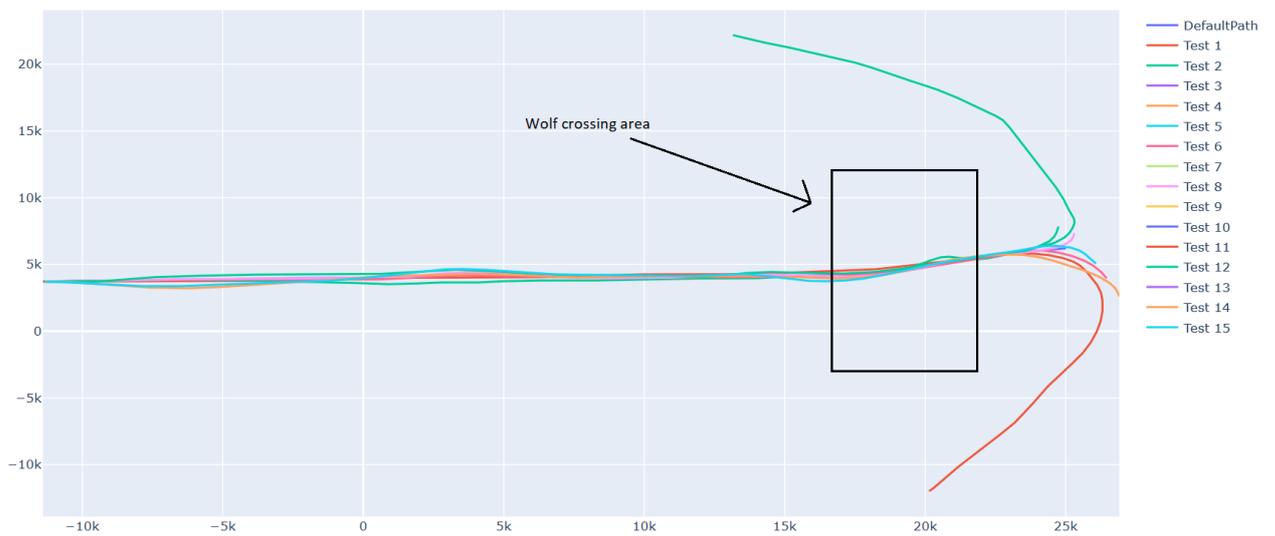


Figure 18. Animal crossing area placement in the driving path of participants

We can see from the Figure 18, the deviation in the path of the Test 2 (pink line), zoomed out in Figure 19, that when the animal jumped out on the road, the drive path of the vehicle was substantially changed. In this driving reaction there was a huge chance the vehicle could have gotten out of control, in the Test 14 result we will see this happening. Another notable change in the path of drive is Test 14, where the drive could not keep control of the vehicle after confronting the animal and they drove off the road path, Figure 20. Notice the change in the paths of both driving lines.

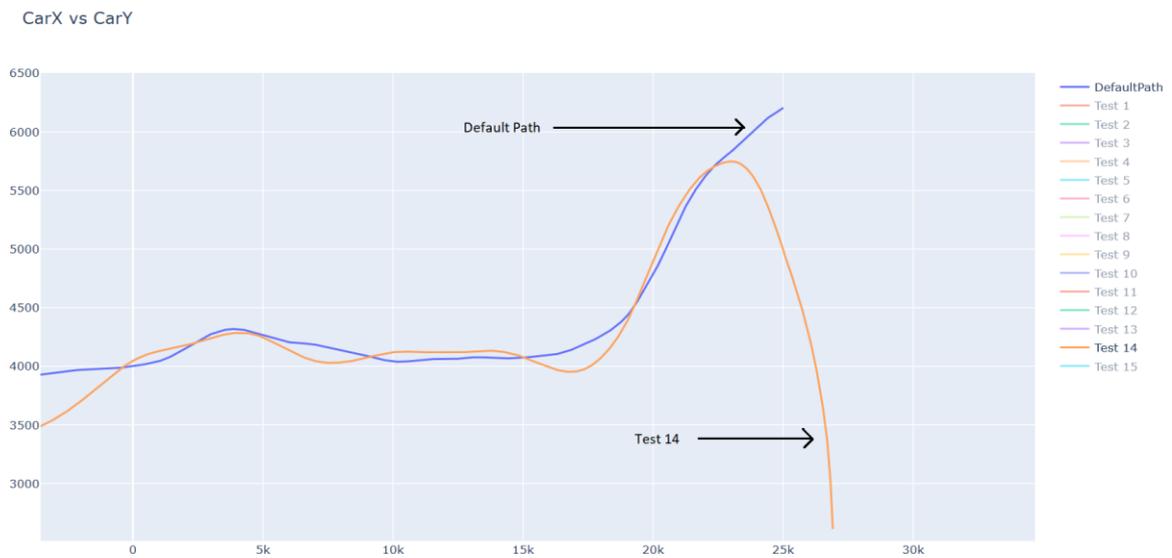


Figure 19. Test 14 (pink line), shows the deviation of the path when confronted with an animal crossing, the driver lost the control of the vehicle here and were not able to keep track of the road

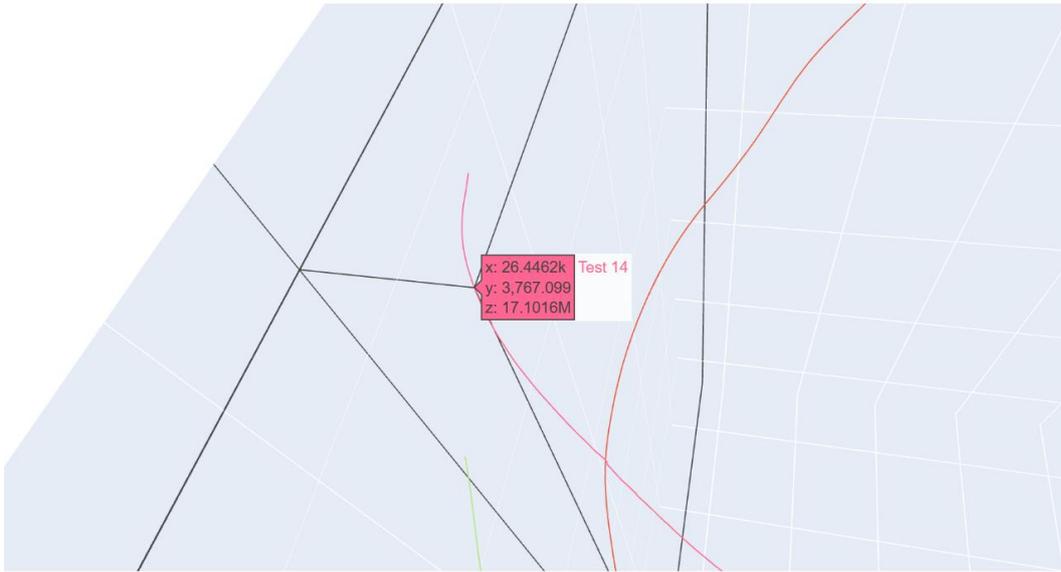


Figure 20. Test 14, shows the driver, losing control of the vehicle after coming across the animal crossing and driving off the road (dataset showing the x,y coordinates and the timestamp)

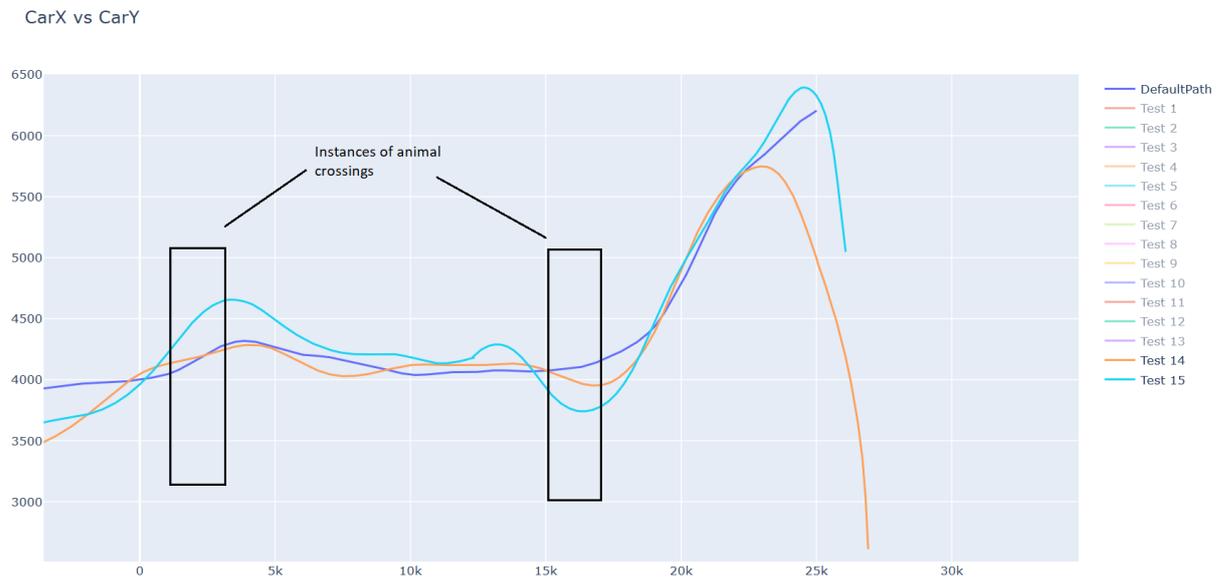


Figure 21. Default Path versus Test path 14 and Test path 15 in a 2D representation, also note the representation of the animal crossing instances during the path of their drive and how it affected their performance

Another 2D representation of the Test 14 and Test 15 for reference against the Default Path. Here you can see the difference between the paths taken by both the drive tests with the animal crossing instances. The graph on the map shows the performance challenge faced by the hazardous situation installed on the road.

This representation of graph in a 3D model was informative, the model also has the ability to read off the coordinates and timestamps at any instance of the drive line and shows a clear path taken by the drivers in the driving VR simulations and also the results of maintaining their vehicle control (drive line) when they were put across a sudden road situation (animal crossing, as shown in figure). As we were keen on knowing how a sudden road hazard situation could affect the driver's performance, the 3D graph along with 2D model helps a lot in showing the performance and maintainability, compared to other drivers and as well as the default path embedded in the map.

6. Results and discussion

After the tests were complete there was a survey sheet filled out by the participants where they were asked a few questions. There were total of 15 participants and were asked 4 questions in total. The survey results are given below after the participants completed their tests, the list of the questions are given below:

1. Was the VR driving simulation experience enjoyable?
2. Did you feel dizzy or nauseous when you exited the simulation?
3. Do you think these kinds of simulations can be used in the future for training drivers?
4. Do you think these simulations can help benefit drivers from your country?

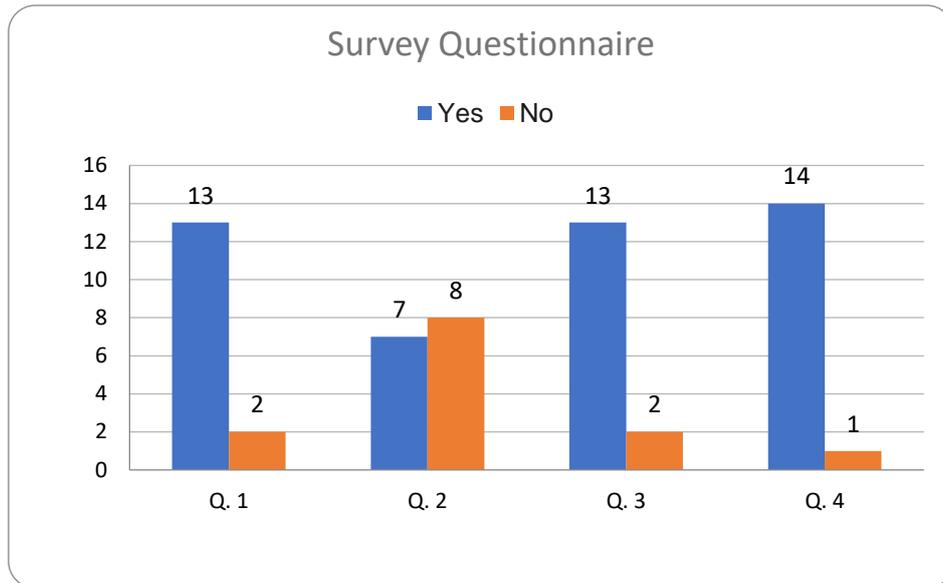


Figure 22. Survey questionnaire results

Also, a rating was asked from them to check how their overall experience was with the whole simulation (from 1-10). The results from the first 4 questions is given in the Figure 22. The blue bar shows the number of positive answers that were given by the participants. The next Figure, 23, shows the information on what the user rated their experience as. A pie chart provides a result on how they assessed the overall experience.

Most of the people had a very good interest in the driving simulation and majority liked the experience a lot. In one of the test cases, Test 14 had thrown the vehicle off the road and if it was a real life scenario it could have been a very damaging incident for the driver and other users of the road, but there is a chance that the driver can be well prepared beforehand by making them go through sudden obstacles over and over until they feel comfortable and in control while driving. Thus, in my opinion and the data shown from the research there seems to be a lot of potential in the learning from VR. A lot of work still needs to be done in this area and this is an evolutionary process that will unfold as more work will be done on this. As VR building and studying has a lot of aspects to cover and give time. This line of work will need extensive work and more hands-on approach to get the best results of it.

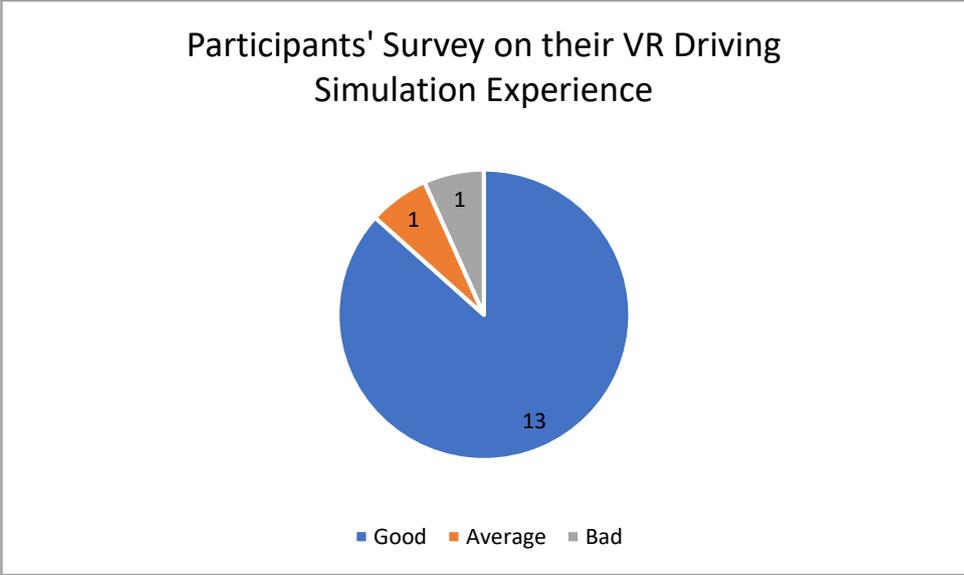


Figure 23. Participants rated their VR simulation experience

The results gained from this experiment were useful but they could have provided more parameters. There were some shortcomings in the VR driving simulator such as, the immersion level and realism factors were not very high. The graphics could have been developed more to give the participants a feeling of being 'actually' present in the environment. There were some parts of the environment which did not give a real feel, as well as there were some shortcomings of the PlaySeat, as this was a low level set up, a high level setup has the hydraulics installed in the driver's seat which provides movement and as the person would be really in a car and driving on certain situations. Also, in my opinion the drivers have a limited span regarding using their senses in the VR driving simulations which somewhat changes their reaction to hazardous situations, all of these things can be improved by evolving technology and a lot of research work done on the factors such as immersion level, realism and the communication between the user and the system.

7. Conclusion

To conclude this dissertation, the variance of the tests done by the volunteers and the data taken off the tests when they were put under prompting situation is very diverse and depicts how every individual would act under a circumstance. The VR driving simulation done using the UE4 more of a reading of how drivers would act in close to reality driving situations when a responsive and alert behaviour is required by them, whatsoever the

situation that may come on the road. The UE4 has much more options to choose from when it comes to designing the environments of any kind. This area still has a lot of research potential as we can see from the data and methodology that this was just a test and run situation for collecting data. This field can come in handier in daily life of drivers if it were to prepare them for their daily driving tasks and if they are prepared with continual training in other diverse dedicated situations involving more road users. This would not only let benefit the drivers concerned with road safety but will protect the road users as well equipping them for safer and better future of road safety. At this stage the collected statistics from the experiments are exemplary and concrete conclusions could not be drawn from them at this stage considering the current situation in which the experiments were performed. Though to derive an actual pattern and result a larger number of participants were required (over 100) which is currently not possible considering the current situation. However, as a result of this thesis, an immersive and innovative experimental set up was created such that can be further expanded and improved upon. It will allow us in the future to collect more experimental results verifying various driving-related hypothesis leading this way into a coherent solution for devising plans for complicated road problems, involving the road users as well thus and bringing about plans for safer roads.

8. Bibliography

- Aksjonov, H. B. (2019). On Driver–Vehicle–Environment Integration for Multi–Actuated Ground Vehicles Safety Advancement. *IEEE ICCVE 2019*, (p. 7). Graz.
- Andrew London, M. F. (2015, July 25). *techradar*. Retrieved from [techradar.com: https://www.techradar.com/news/oculus-rift-2-release-date-news-and-rumors](https://www.techradar.com/news/oculus-rift-2-release-date-news-and-rumors)
- Bardi, J. (2019, 03 26). *Marxent 3D Commerce*. Retrieved from [Marxentlabs: https://www.marxentlabs.com/what-is-virtual-reality/](https://www.marxentlabs.com/what-is-virtual-reality/)
- Blanchard, P. A. (2000). *After the Crash: Psychological Assessment and Treatment of Survivors of Motor Vehicle Accidents, Second Edition*.
- Cassarino, S. S. (2019). Testing Attention Restoration in a Virtual Reality Driving Simulator. *Frontiers in Psychology*.
- Dalgarno, M. J. (2010). What are the learning affordances of 3-D virtual environments? *British Journal of Educational Technology*.
- Dealessandri, M. (2020, January 16). *gamesindustry.biz*. Retrieved from [gamesindustry.biz: https://www.gamesindustry.biz/articles/2020-01-16-what-is-the-best-game-engine-is-unreal-engine-4-the-right-game-engine-for-you](https://www.gamesindustry.biz/articles/2020-01-16-what-is-the-best-game-engine-is-unreal-engine-4-the-right-game-engine-for-you)
- Ebay. (2020). *pinterest.com*. Retrieved from [pinterest.com: https://www.pinterest.com/pin/215539532145548506/](https://www.pinterest.com/pin/215539532145548506/)
- Gąsiorek, K. (. (2020). Virtual Reality Technologies in the Training of Professional Drivers. Comparison of the 2D and 3D Simulation Application.
- INC, P. (n.d.). *Animal Variety Pack*. Unreal Engine .

- Jason, J. (2009). Scene-motion-and latency-perception thresholds for head-mounted displays.
- Jerald, J. (2015). *The VR Book*.
- Jerald, J. (2015). *The VR Book*. Association for Computing Machinery and Morgan & Claypool Publishers, 2015.
- John M Scanlon, R. S. (2017, May). Models of Driver Acceleration Behavior Prior to Real-World Intersection Crashes.
- Liarokapis, d. F. (2011). Serious Games: A New Paradigm for Education? *Serious Games and Edutainment Applications*.
- NADS. (2014). <http://www.nads-sc.uiowa.edu/media.php>. Retrieved from <http://www.nads-sc.uiowa.edu/>: <https://youtu.be/rfG2VkrYMJI>
- Najm, J. D. (2001). *Analysis of Crossing Path Crashes*. Massachusetts: U.S. Department of Transportation.
- NCAP, E. (2017, September). euroncap.com. Retrieved from EURO NCAP: euroncap.com/en/for-engineers/technical-papers/
- NHTSA. (2016, March 1). [Injurylawyer.com](http://injurylawyer.com). Retrieved from <https://www.injurylawyer.com/car-accidents/majority-of-traffic-collisions-are-caused-by-human-error/>
- Organisation for Economic Cooperation and Development (OECD), E. C. (2006, January). Young drivers: The road to safety.
- PlaySeatStore. (2020). playseatstore.com. Retrieved from playseatstore.com: <https://www.playseatstore.com/playseat-evolution-alcantara.html>
- Plotly. (2020). plotly.com. Retrieved from plotly.com: <https://plotly.com/python/>
- Ragland, D. R., & Zabyshny, A. A. (2003). *Intersection Decision Support Project: Taxonomy of Crossing-Path Crashes at Intersections Using GES 2000 Data*. Retrieved 3 24, 2020, from <https://escholarship.org/uc/item/0201j0v2>
- Richter, B. (1974). *Driving Simulator Studies: The Influence of Vehicle Parameters on Safety in Critical Situations*. SAE International, USA.

- SAE International Standards. (2018, June 15). Retrieved from SAE International :
https://www.sae.org/standards/content/j3016_201806/
- Siam, M. H. (2015, July). Measurement of Driver Distraction in Malaysia's Traffic Environment: A Driving Simulator Study. *Journal of Mechanical Engineering and Science*.
- Siergiejczyk, M. K. (2020). *Research Methods and Solutions to Current Transport Problems*. Ryn.
- Statista. (2020, Feb). *Statista Department of Research*. Retrieved from Statista.com:
<https://www.statista.com/statistics/426469/active-virtual-reality-users-worldwide/>
- Tran, T. (2017, April 20). *raywenderlich.com*. Retrieved from raywenderlich.com:
<https://www.raywenderlich.com/663-unreal-engine-4-blueprints-tutorial>
- UnrealEngine. (2020). *docs.unrealengine.com*. Retrieved from docs.unrealengine.com:
<https://docs.unrealengine.com/en-US/Engine/Animation/AnimBlueprints/index.html>
- UnrealEngine. (2020). *docs.unrealengine.com*. Retrieved from docs.unrealengine.com:
<https://docs.unrealengine.com/en-US/Engine/Animation/AnimBlueprints/AnimGraph/index.html>
- UnrealEngine. (n.d.). *docs.unrealengine.com*. Retrieved from docs.unrealengine.com:
<https://docs.unrealengine.com/en-US/Gameplay/Input/RawInput/index.html>
- UnrealEngine. (n.d.). *docs.unrealengine.com*. Retrieved from docs.unrealengine.com:
<https://docs.unrealengine.com/en-US/Engine/Actors/Triggers/index.html>
- UnrealEngine. (n.d.). *docs.unrealengine.com*. Retrieved from docs.unrealengine.com:
<https://docs.unrealengine.com/en-US/Engine/Blueprints/UserGuide/CastNodes/index.html>
- UnrealEngine. (n.d.). *docs.unrealengine.com*. Retrieved from docs.unrealengine.com:
<https://docs.unrealengine.com/en-US/Gameplay/Input/RawInput/index.html>
- Walch, J. F. (2017). Evaluating VR Driving Simulation from a Player Experience Perspective. *CHI '17 Extended Abstracts*.

Wiederhold, M. D. (2012). *Emerging Communication: Studies in New Technologies and Practices in Communication* 9.

Wikipedia . (2020, April 5). *Wikipedia*. Retrieved from Wikipedia: [https://en.wikipedia.org/wiki/Spyder_\(software\)](https://en.wikipedia.org/wiki/Spyder_(software))

Wikipedia . (2020, April 28). *Wikipedia*. Retrieved from Wikipedia : [https://en.wikipedia.org/wiki/Qt_\(software\)](https://en.wikipedia.org/wiki/Qt_(software))

Wikipedia. (2019, December 29). *Wikipedia* . Retrieved from Wikipedia.org: https://en.wikipedia.org/wiki/Virtual_reality_applications#cite_note-eff-1

Wolwort, K. (2020, March). Retrieved from Innovation Enterprise Channels: <https://channels.theinnovationenterprise.com/articles/5-major-challenges-of-vr-industry>

Yu, X. (2011). Research and Practice on Application of Virtual Reality Technology in Virtual Estate Exhibition. *Procedia Engineering*.