EVALUATION OF THE PERCEIVED SENSE OF SPEED IN A DRIVING SIMULATOR

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Abstract

In this project we evaluated the perception of speed in a driving simulator. The study provides a preliminary survey that focuses on how human beings can perceive moving in space. We have developed and implemented some techniques to study how we modify the perception of speed in a driving simulator. We targeted the driving perspective, trying to create certain effects in order to affect the perceived sense of speed. Changing the contrast of the scene we studied how the perception of the speed has been modified. Testing this modification we saw a change in the perception of the speed by the driver, who noticed an increase of the perceived speed through the alteration of the contrast of the scene.

**Keywords:** drive simulator, sense of speed, background pattern, prospective speed, contrast
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1 Introduction

Since the early years of the nineteenth century, the way in which humans perceive the sense of speed is a study that has intrigued many scientists. The study of how human beings can perceive its space navigation was founded on observations of how the human body uses a combination of the different senses, such as the auditory and optical ones (Gibson, 1938) to involve the nervous system and in particular neurons (Sclar, 1990; Albrecht & Hamilton, 1982). The creation and development of information technology has created, then, a new environment in which the human being has been found to have to interact and engage, i.e. the virtual environment. Factors such as the way we navigate in a virtual environment have become new objects of study especially when the virtual environment is designed for faithful reproduction of behaviors as if taking place in the real world such as driving a car. In 2002 the idea of using of computer games for purposes beyond entertainment became more and more popular. This new branch of computer science is known as serious games (Gudmundsen, 2006). The focus in this type of game has been moved from simple fun to reproduce, as close as possible to real-life, issues in order to stimulate and facilitate people in circumstances such as training, education, health and the economy. One of the areas of serious games that became increasingly popular was that of driving simulation, thanks especially to the great training benefits that this type of simulation resulted in as demonstrated in military and aviation fields. One of the key aspects for a high sense of realism in a driving simulator is the sense of movement, along with the sense of speed that the driver is able to perceive (Kaptein, 2007). The reasons behind this study, therefore, is based on finding a link between studies in the early 1990’s on the way humans perceive speed in the real world and on the way they do it in a virtual world. To do so we used a driving simulator that uses a real car as joystick around which was shown a virtual urban environment, so you have a field of view of 360°. In this way, the driver is put in a situation very similar to the actual driving experience and through some changes made to the virtual environment we studied how these would impact on his perception of speed.

This thesis is organized as follows: Chapter 2 describes the background and theoretical foundations of the thesis. Chapter 3 focuses on the problem of the importance of the perceived speed in a driving simulator and what method we used to study and test it. Chapter 4 describes how the driving simulator software has been implemented. Chapter 5 show the technique used to modify the contrast of the scene to modify the perception of the speed. Chapter 6 describes the test phase and shows the result of it. Finally Chapter 7 analyzes the result of the test.
2 Background

In order to understand the study that we are facing, we need to define and explain various elements: serious games, how the human being perceives speed, state of the art of driving simulators, and finally, Unity3D.

2.1 Serious Games

In order to understand what a serious game is, it is possible to start from the description given by the Serious Games Initiative (seriousgames.org, 2013):

“The Serious Games Initiative is focused on uses for games in exploring management and leadership challenges facing the public sector. Part of its overall charter is to help forge productive links between the electronic game industry and projects involving the use of games in education, training, health, and public policy.”

It all began in 2002 when the U.S. Army created the video game America’s Army (Gudmundsen, 2006). Following this, in 2006, the Woodrow Wilson Center for International Scholar, in Washington D.C (www.seriousgames.org), founded the Serious Game Initiative. Thus began to use the term "Serious Game", although its meaning is still not well-defined. According to Susi, Backlund and Johannesson (2007, p. 3) we can say that it "usually refers to games used for training, advertising, simulation, or education that are designed to run on personal computers or video game consoles". Nowadays, serious games make more and more space in the video game industry. The turnover in 2012, according to the Association's Executive Director, serious games, Sue Bohle, stands between 2 and 10 billion dollars1. In the same article Bohle has stated that:

"We are engaged in the process of defining the industry, and that needs to be done on a global basis. Large centers of development exist in Europe, and Asia is catching up. While we can clearly identify the major market segments, parallel work is being done under tags like gamification. So getting our arms around total spending for the creation of non-entertainment games is challenging."

China, in fact, is expected to become the leading country in which serious games will be purchased between now and 2016, followed by United States and South Korea 1. This new way of conceiving the videogame activity arises from some psychological studies which have shown how they can help improve key aspects, such as attention, memory and practice. It was noted that the use of video games can deliver improvements in virtual reality as well as in everyday practice. An e compared expert gamers and beginner gamers. The results obtained have shown that expert gamers were able to follow moving objects with more ease, performed tests on short-term memory with better results, and finally, the switch between tasks was carried out easier and more immediate (Boot, 2008). Another of the key advantages is to be able to carry out targeted training, with the possibility to try and try again several times, without special exercises and without worrying about possible consequences resulting from mistakes. The fields in which we are experiencing the concept of serious games are varied: ranging from military to human rehabilitation, as well as Higher

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Education and corporate training.

In the following, we will describe some examples of serious games. We can refer to works such as Supercharged! (MIT Comparative Media Studies, 2002) that deals with the improvement of learning physics; VR Phobias (Wiederhold, 2004) that focuses on the research of possible phobias like fear of the dark or of spiders; the simulator training for dealing with terrorist attacks Biohazard (Carnegie Mellon Entertainment Technology Center et al., 2004); or Sidh a game-based firefighter training simulation (Backlund et al., 2007) developed by University of Skovde in collaboration with the Swedish Rescue Service Agency, for the training of firemen. One of the areas in which we are developing projects related to serious games is driving simulation. Some early instances of serious games in driving simulation appeared in the 1980s with the work carried out by Daimler-Benz in Germany (Drosdol & Panik, 1985). This work was born thanks to the growing development of flight simulators in the 70’s. These two types of simulation may look completely different, but are designed to solve the same problems i.e. safety and costs. Consider that you can simulate a landing or a takeoff without worrying about possible human or environmental disasters, or study the effect that alcohol has on driving reflexes without the risk of causing fatal accidents. All of this has created a strong interest that, coupled with the lowering hardware costs, has given rise to numerous projects. They range from works like "TruckSim" (Grace, 1998) which has as its objective the optimization of driving safety keeping under control the human aspects as fatigue, using a sophisticated system of simulation with a horizontal field of view of 180° and a reproduction system of g-forces. "IC-DEEP" (Garvey, 2012) is a web-based Simulator that aims to explore how all the optional present in today's cars can affect the driver's concentration. "Learning Agricultural Machinery" (Qin, 2012) that solved the growing problem of China in forming specialized personnel in maneuver agricultural machinery.

2.2 Simulated Driving

The main benefits of driving simulation are that it allows you to perform specific tests and targeted training to maximize efficiency, costs, security and data collection (Nilsson, 1993). Just think of the fact that you have an opportunity to learn and improve the driving style, as well as the possibility to repeat specific critical real life scenarios without having to worry about the consequences from possible driver errors. Another acclaimed application area is to create qualified personnel in a specific field at a low cost. In the field of military aviation, for example, drivers carry out a part of their training in a simulator. According to the TER (Transfer Effectiveness Ratio) three hours in a simulator can replace an actual time of flight to the 54% of the activities. In the experiment FDT&E (Apache Longbow Force Development Test and Experimentation)2 analysed data from two different types of training, one carried out in real life and one in a simulator. When analysing the "cost" you can see that the cost for the simulator was $ 0,712M, while the total expenditure for the training was $ 4,049 M. To this we can also add the savings achieved in terms of gasoline and artillery. Another interesting note in this report is that safety in drive simulator is estimated as "No Risk", while training in the field has "Moderate Risk".

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2 http://www.trainingsystems.org/publications/simulation/roi_effici.cfm
Significant improvements can be achieved through a driving simulator regarding training as well as prevention of accidents (Ivanicic & Hesketh, 2010). It has been showed that simulator training could have concrete results with regards to, for example, braking distance (Roenker, 2003). Another concrete example of development of a driving simulator comes from China, where it was decided to develop a virtual system in order to carry out the training of the use of agricultural machinery (Qin, 2012). The serious game created resolves the principal problem that was the basis for training of personnel: costs. By creating a virtual environment that reflect the interior of an agricultural machinery it is possible to do some specialized training for personnel, which may include specific instructions on changing gears or speed control, and completion of missions. This simulator is of interest for our study because it makes use of the same virtual development environment as we have used, Unity3D, for reproduction of agricultural machinery cabin and environment.

Furthermore, more sophisticated and expensive simulators such as the Ford Driving Simulator (Cathey, 2000) or the Daimler Simulator (Drosdol & Panik, 1985) fail to perfectly reproduce the feedback that normally warns the driver in the real world. These simulators are not part of the category "low-cost" and use specific equipment to simulate g-forces, sounds and feedback. These differences between the virtual system and reality increase if you go to consider the world of a low-cost simulator like the one adopted in this study. According to Green (2005), the first objective that you should pursue in designing a driving simulator is "Replicated real driver behavior and performance" (p. 211). Around this lens rotates all the analysis that the author makes about how the quality of simulators can be improved, highlighting problems like "Subject drive too fast" (p. 216) and "Speed are too steady" (p. 217), i.e. the speed in the simulator does not take in consideration environmental variables like wind that it can change the velocity. This may involve a misperception of speed.

The behavior and performance of a driving simulator is based primarily on two factors: fidelity and validity. The validity concerns the physics and behavior, on reproduction of actions and reactions, trying to approach as closely as possible to real ones (Stuart, 2001). For example, how to slow down a car should be perceived in the same way in a simulator as it happens in real life. Fidelity with respect to physics, however, is based on how the machine is used and how it responds to or emulates the laws of physics (Triggs, 1996). An example of fidelity could be how the perception of speed in a driving simulator is perceived.

The definition of fidelity according to Champion & Higgins (2002) as cited by Wyatt (2007) is:

“The degree of similarity between the training situation and the operational situation which is simulated” (p. 2)

According to Wyatt (2007), there are three types of fidelity: Equipment Fidelity, Environmental Fidelity and Psychological Fidelity (Figure 1). The Environmental Fidelity refers to how the Simulator can reproduce the surroundings, in our case the road; the Psychological Fidelity deals with the difference between a property as it exists in reality and how it is perceived in the Simulator. In this study we focus primarily on the general concept of fidelity, with respect to the way the user perceives the sense of speed in a simulator that makes use of a real car as a joystick. We will manipulate the Environmental Fidelity in order to be able to study its effects on Psychological Fidelity in terms of perception of speed.
Nowadays, various types of driving simulators can be summed up in three categories: low-level, medium-level and high-level. The main differences that characterize the three different types are based on the type of hardware used, ranging from simple PC with a monitor and a joystick, passing through simulators equipped with floodlights and a real machine, up to devices equipped with a field of view of 360 degrees and to equipment for playing physical effects (Kaptein, 2007).

![Figure 1 Types of Fidelity from Wyatt (2007)](image)

2.3 Sense of Speed

The human being, by nature, does not lend special attention to actions that usually repeats every day without noticing. You might consider, for example, breathing. How many of us know what actually happens during respiration? Yet a grown man breathes on average 14 times per minute. The same question can be reformulated in terms of movement and a sense of speed. Consider, constantly moving objects; we ourselves move continuously in a well-defined space, but how do we perceive everything moving? In the first instance, there is the vestibular apparatus, a human organ dedicated to perception of movement of the head and body in space. It is mainly composed of two parts: the semicircular canals, sensitive to angular accelerations and otoliths organs, sensitive to linear accelerations and dealing with perception and motion analysis of the head: the vestibular apparatus is not the only one dealing with the self-motion, but works in symbiosis with the optical apparatus to re-create the sensation of movement. The optical apparatus makes use of the main body of navigation data acquisition, i.e. the eyes. It provides a diverse amount of information regarding the management of movement.
Gibson (1938) was the first scientist who identified and correlated these two perceptual organs, which he called the focus of expansion (FOE). The Visual movement in the optic array surrounding a moving observer expands radially from a single point in the direction of the head. Gibson (1938) also noted that the retina of the eye is movable relative to body movements and these two types of movements overlap. According to this he created a model of retinal movement that consists of two variables, translation (body movement) and rotation (eye movement). Since, however, our field of study is virtual reality, everything must be related to a scene featuring a 3D layout. To correctly translate movements and eyepieces, the scene must contain certain information. The motion of distant points can be used to stimulate the rotation of Gibson’s model, while the motion of nearby points may be useful to get information about the translation of Gibson’s model (Lappe, 1999).

Another factor that influences the feeling of speed is contrast. In this case the neurons to take on a leading role. Considering a map of all possible directions, each neuron in the visual cortex keeps track of one of these. To increase contrast, stimulus also increases the response of these neurons (Sclar, 1990; Albrecht & Hamilton, 1982).

Thompson (1982) sought to study the effect of contrast on perception of speed through the magnitude. Considering two grids, one high and one low contrast, it was noticed noticed that, around 8 Hz, the high-contrast grid seemed to move faster than the low-contrast grid, albeit the two grids moved to the same speed. Thompson’s (1982) study, however, was related to a difference in contrast of the two grids by only 17% because that was supported by technology. Therefore, on this basis, the study was replicated by Thompson & Stone in 1991. The experiment is a task that measured the relative velocity perceived through two grids with same speed, but different contrast. The two grids are projected onto high-resolution digital monitors and 6 participants are involved. 5 of 6 participants noted that low-contrast grid moved more slowly than the high-contrast grid, although the two moved to the same speed. As a final result of the study it is noted that the perception of speed is different if two grids that move at the same speed have a contrast difference that varies between 2.5 and 50%. The low-contrast grid will be perceived as slower than the high-contrast one.

2.4 Unity3D

Unity 3D is a development environment designed for building games that adapts to most situations: games in 2D, 3D, for Mac, Iphone, PS3, etc. The interface allows you to control and manage all the elements of the game, from the project browser, the inspector, at the scene, to preview the animation in real time with just one click. The engine is developed by Unity Technologies and enables you to manage all aspects of the game: sound, light effects, physical simulations, until the implementation of networking for multiplayer games. It also has a scripting system that allows you to build a logic linked to every aspects of the game. Unity is based on three programming languages: Javascript, C# and Boo, that run on the Open Source Mono platform³.

2.4.1 Game Object

³ http://unity3d.com/unity/workflow/
Unity3D consists of several subsystems that allow you to manage all aspects of video games: from sound to GUI, from video to shaders, as well as other features. The whole concept is based on the use of "game object", which can be easily handled inside Unity3D, making a simple drag and drop in the virtual environment. As you can read in the study of Hu Wenfeng (2012), each game object has a behaviour in line with the laws of physics thanks to the physics engine in Unity. It has a hierarchical structure that includes a root consisting of the "Physics" Component, to which the item "Rigidbody" representing the parent of all other components is attached. It is possible to simulate collisions between objects (Collider), add forces (Constant Force), interlinking between the adjacent parts of the model (Joint). Through the use and manipulation of these components connected to the Rigidbody you can then simulate any physical effect on objects in the virtual environment.

2.4.2 Unity3D ShaderLab

Unity3D has at its core a language similar to Nvidia’s Cg for shader programming, the ShaderLab. The way in which an object is represented within the scene depends on three factors in Unity3d: Material, Particle and Mesh Render. The Mesh represent the geometry of objects, while the Particle Render go to work on Particle System that handles options for brightness and shadows of scenes. The Material is used in conjunction with the Particle and Mesh Render and defines how an object is displayed in the scene using a shader that goes to render the Mesh or the Particle Render. The shader so it has access to all the elements exposed by the Material, such as color, brightness, 2D textures etc.

2.5 Hardware

The hardware that will be used in this project is a mid-range driving simulator created by the University of Skovde (Lebram et al., 2007). The driving environment consists of seven panels that surround a real car, a Volvo S80 (Figure 2), which is screened on the virtual environment. The structure and layout of these screens are represented in Figure 3, in which it can be seen that five of the seven panels are used to reproduce the front and side environment, while the remaining two panels are used to project what the rider can see.

Figure 2 Drive simulator University of Skovde
looking in the rear-view mirrors. Each of these panels is handled by a dedicated projector and each of them is, in turn, controlled by a single computer. The global architecture, then, consists of seven clients dealing with the display of the virtual environment and a server which has the task of managing what the various clients must display, in addition to other computational tasks. The computers are connected to each other via an Ethernet LAN, while the machine is connected through a USB port. So basically, the car is seen as a sophisticated joystick. Being a low-cost simulator, it does not use sophisticated mechanisms to simulate force feedback, but you use the optional of the car to create them. The virtual environment and noise of the engine is played by the car sound. Furthermore, the the ventilation system is used to try to simulate the speed by increasing the fan with higher speed. In addition, in order to recreate the feedback of the steering wheel, thrust bearings were placed beneath the front wheels of the car. In this way, it is also noticed that the machine undergoes a slight move during maneuvering, creating thereby some additional feedback. We must add, finally, that the system uses a “ButtKicker” to transmit the vibrations to the entire passenger compartment and behind the wheel.

### 2.6 Sense of speed in driving simulators

Several studies have established that the quality of a driving simulator is based on two fundamental aspects: the driving task and quality. Behavior compared to real world driving is evaluated primarily through two variables: lane-keeping and driving speed (Kaptein, 2007). These two aspects are crucial to verify the sense of speed is returned by the driving simulator. The study on the maintenance of position along the road of the Simulator we’re going to use has already been addressed and the results showed how the drivers are able to maintain the proper course within the roadway (Backlund, 2010). Then we will focus on other fundamental aspect shown by Kaptein (2007): the sense of speed. According to studies of Stone and Thompson (1991) one of the things that alter the speed perception is definitely the contrast. This will be changed by manipulating the high contrast areas and low-contrast
areas in the virtual environment. To choose the size of the two areas we can take the study by Chatziastros (1999) as a reference. The experiment was conducted in two sessions with a drive simulator: the first session was developed with one monitor with 40° horizontal field of view and, subsequently, at the second session, on a screen with 180° horizontal field of view. Comparing the two sessions, Chatziastros (1999), come to the conclusion that, at a certain speed, there is no big difference of perception of movement. The area of high and low contrast will vary progressively according to the driving speed, bearing in mind the limits of Chatziatros (1999).
3 Problem

The sense of speed is one of the bases on which the rest the efficiency and quality of a driving simulator rest. It is without doubt one of the most characteristic aspects of the experience and driving style in a virtual environment. The simulator that will be used has already been implemented and tested in a previous project (Backlund et al., 2010). One of the experiments carried out had as goal to chase an ambulance in a motorway, keeping a certain distance and taking variables like: speed violation, short headway distance, rearview mirrors use, number of lane changes etc. into account. Analyzing the results it looks like 10 drivers of 27 have exceeded the speed limit by more than 10 km/h. Exceeding the speed comes from the fact that drivers have had some difficulty to maintain the correct distance from the ambulance and to retrieve the correct proximity, they exceeded the speed limit (Backlund et al., 2010). This motivates an improved perception of the meaning of speed produced inside the driving simulator. Another fact emerged from the experiment of Backlund et al. (2010) is related to the sense of nausea: 8 participants have been affected. The way navigation in a virtual environment is one of the factors that influence the sense of nausea; a bad perception of the orientation can represent one of the causes.

The driving simulator in question does not use tools that emulate the gravitational forces that can return a sense of movement, hence we must rely entirely on the virtual environment.

The aim of the project is to evaluate the perceived sense of speed in a mid-range driving simulator. This will be tested by manipulating the contrast to see how the sense of speed is perceived by the subjects.

The main objectives that this work will pursue will be:

1. To analyze and study how the software handles multi-monitor mode and locate the right angle of field of view on which you want to apply the changes to the virtual environment.
2. To apply effects to the virtual environment which alter the contrast of the scene by creating high-contrast areas and low-contrast areas to alter the perception of speed. A similar study is conducted by Chatziastros (1999) who seeks to study the accuracy for keeping the car in the center of the road in a virtual driving simulator, coming to the same conclusion.
3. To test the user feedback on the new virtual environment after making changes to the contrast of the scene. In particular, to analyze the degree of perceived realism from new scene to maintain the validity of the simulator, road visibility and eyestrain that might be caused by alteration of the virtual environment.
4. To test speed perceived by users in the simulator without them knowing the actual driving velocity. To do this, the various speed measurement instruments in the dashboard of the car will be disabled. During the test session, drivers will be interrogated in random plot points about the perceived speed. To each question the actual driving speed will also be noted and then comparative tests will be carried out.
5. To test the user feedback on the perception of speed in three different types of tests. A first type of test will be carried out, in which no changes will be applied to the virtual environment, in order to have a neutral test. A second type of test will include changing the contrast of the scene and, finally, the last type of test will contain both a change in the contrast of the virtual environment, the presence of other cars on the track that will move and will interact with the driver through an artificial intelligence.

3.1 Method

Objective 1: to analyze and study how the software handles multi-monitor mode and locate the right angle of field of view on which you want to apply the changes to the virtual environment. To accomplish this goal, we will focus especially on the studies carried out by Chatziastros (1999). The idea is to divide the scene in high contrast areas and low contrast, trying to locate the right breaking point. The boundary between these two areas must not be static, but will vary depending on the speed that the driver is holding. According with Chatziastros (1999) studies, the focus of a driver during the driving experience will not exceed 40°. From this figure will be determined two different areas. The boundary between these two areas must not be static, but will vary depending on the speed that the driver is holding. Initially, when the machine is stopped, the low zone contrast will occupy most of the field of view, and as the machine will increase its speed low-contrast area will return in a narrowing field of view of 40°.

Objective 2: to manipulate and to study the perception of speed in the driving simulator, we will start by building a virtual environment that represents a real environment as closely as possible. Buildings and skyscrapers are on either side of the road in order to accentuate the sense of movement for the driver. It is studied that static objects placed on the sides of the field of view of a person are essential to create a sense of movement especially if related to non-static objects as, in our case, for example, the driver and the other cars on the track. The creation of this type of virtual environment is made by using Unity3D which, through a full compatibility with several 3D graphics programs and use of game objects, allows the construction of the scene through a simple drag &drop. Finally, Unity3D manages the shadows and lighting of any building extremely easy and fast. In addition to this, will be applied a modification of the General contrast of the scene in agreement with studies exposed in the background. The virtual environment will be divided into a high-contrast scene and a low-contrast scene in order to alter the perception of speed in accordance with the studies by Thompson & Stone (1991). Alteration of the contrast will be through the use of two different Fragment Shader that will take care of high contrast area and low contrast. In order to implement this type of solution, you will use the Unity3D’s ShaderLab already presented in section 2.4.2.

Objective 3: modification of the overall contrast of the scene could result in a lowering of the visibility in the driver. The low-contrast area will be placed right in the center point of the driver’s eye sight and is therefore crucial to ensure that the alteration of the scene does not negatively impact on driving behaviour. At the end of each test the degree of visibility perceived by the driver will be evaluated through specific questions that will determine whether they noticed the changing the contrast in the virtual environment, and if the new scene has created problem in visibility of the road circuit. This is significant given the degree of realism that is returned by the Simulator, especially with the application of contrast filter.
Change the scene while still maintaining a good level of realism is the fundamental in according with the environmental fidelity of the simulator (Triggs, 1996).

Objective 4: the result that most interests us is whether changing the contrast of the virtual environment in our Simulator has significant effects on the perception of speed. It has been studied using an ad hoc testing method where we shut down the speed detection tools present in the vehicle, such as speedometer and tachometer. In this way the user will only be able to use reference points to establish its pace, its experience, the audio feedback of the machine and the virtual environment. Audio feedback is provided by a ButtKicker system that will cause vibrations and a background noise based on engine RPM. The driving experience will be evaluated through specific questions that take place prior to the start of the test, while the virtual environment will change through the application of modification of contrast. During the test session, drivers will be interrogated three times at different points of the track, at different speeds, on how they feel they perceive. The random nature of the data that we collect will allow us to have a collection of effective information for the study of the results.

Objective 5: the tests that will be carried out will be of three types and will be executed in a randomized order from person to person. This is because human perception of speed is related to several variables, as has been shown in paragraph 2.3. Randomizing the tests will give us more flexible and varied data that will be used to study more thoroughly the perception of speed when driving. There will be a neutral test in which no change shall be applied to the virtual environment. The driver will drive in a scene with no other cars on the road and without contrast changes. This test will help us to have a point of reference with which to compare the resulting data from the remaining two tests that involve substantial changes of the virtual environment. A second type of test will include the contrast filter editing, while the last type of test will be changing the contrast that the presence of other cars along the road. These machines will interact with the driver and will be guided by an Artificial Intelligence (Franco, 2013). The latter type of test was conceived with the objective to study how the perception of speed is influenced by other objects in the scene that move along with the driver, in an environment where it was also varied the contrast.

3.2 Ethical aspects

To evaluate our system we have been given access to the laboratory of the University of Skovde. To carry out the tests of our study were selected student volunteers of different nationalities with an aged between 19 and 28 years. Each participant was informed of the purpose of the study, the precise rules to be followed to perform the tests and the possible risk of nausea arising out of the use of the Simulator. Each tester was explained that the personal data and any data resulting from the tests will be held in confidentiality and used only for research purposes. All participants gave their written and informed consent to take part in the study.
4 Software Simulator Layer

This subsection describes the software base of the driving simulator to which we applied the effects mentioned in section 2.4 to assess the perception of speed. We used the Unity3d engine to implement the system. The creation of the car simulator was developed from scratch, but is based on the project Car Tutorial available on the AssetStore of Unity (Unity, 2013f). Substantial changes were made to fit the goals of the experiment and those will to described in the next paragraphs. Furthermore, resources had to be allocated to integrate Unity3d with the driving simulator used in the experiment. An overview of software architecture is presented in Figure 4 below and sections 4.1 – 4.4 proceed to describe its components in detail.

4.1 Road Environment

The ambience of the driving simulator was radically redesigned and simplified compared to the project "Car Tutorial" to fit our purposes. We used the skeleton that is located at the base of the project Car Tutorial called "Terrain", and used it to build a circuit of a four-lane motorway with two directions. The roads used for the construction of the circuit were taken from road objects package on this site4. The entire set consists of a many different types of roads, but for our project we only used items representing a straight road section of a motorway and three types of curves: 15°, 30° and 45°. In addition, we used a guardrail to delimit the road lanes. The final circuit was assembled by representing an oval figure without any slope, with a length of 150mt and average two long straights 960mt. Finally, each track has a width of 4mt. According to Felipe (1996) it was calculated the travel speed in the curve through the use of its 1.3 equation (p. 27). It is derived from a speed of around 120 km/h, but through an increase in lateral friction on the car you can follow a curve at about 150 km/h. This is to ensure that the Simulator is more user friendly, preventing excessive crashes that can cause frustration and repetitive interruptions during the experiment.

Figure 4 General software architecture

4 http://www.3dmodelfree.com/models/18622-0.htm
4.2 Physics Engine

The physics engine was completely adapted to the type of machine used in the driving simulator, a Volvo s80. As a point of reference we studied the actual values submitted from the same Volvo in the Volvoclub document, to which we tried to get as close as possible through interpolation. The main components were: remodel the engine torque, the engine friction, road friction, air drag and gravity. The engine torque makes use of a function that interpolates the angular speed of the engine that tries to get as close as possible to the real values of the motor (Figure 5). This will allow you to be able to realistically simulate the acceleration. The engine friction is represented by a linear function of the angular speed engine that tries to simulate the motor force that intervenes in a deceleration phase. The road friction is a force that goes to act between the wheels and the asphalt which in Unity is implemented through the use of abstract WheelColliders. For this type of force have not had standard values available to be inserted in the model. We performed several tests in the Simulator to get the results as close to reality as possible. We compared the acceleration time from 0 to 100km/h and the maximum speed reached by the Simulator, with those provided by Volvo. Based on the results we then proceeded to adjust the parameters of the function. Unlike road friction, air drag has been adapted to the length of the machine and calculated through a precise function $F = -kdv^2$, where $k$ is a vector of multiplicative values, $d$ represents the direction of the car and $v$ is the velocity. The severity depends on the mass of the car and we have therefore taken advantage of the data provided by Volvo, adapting them to fit the Rigidbody of Unity that is responsible for the main parameters of the car.

Figure 5 The real power engine and torque curve with our interpolation

4.3 Client – Server Infrastructure

The Simulator is based on a client-server architecture, as already specified in section 2.5, where each client is responsible for displaying a portion of the virtual environment on one of seven panels that surround the car. Unfortunately, Unity has no features inside that allow you to implement a similar architecture, so we had to create an ad hoc Protocol. The communication framework is based on the RemoteNode object that is used to manage the thread that sends and receives data on server and client. The first step to make a communication between two objects over the network requires that they register at the respective RemoteNode and we have an id that uniquely identifies them. Then the messages can be sent and received from various objects on nodes, which can deliver the information correctly. The type of communication used is buffered and asynchronous and based on UDP protocol, since we are in a closed LAN environment and not exposed to a risk of loss of packets. In this way we were able to secure the frame rate required for proper viewing of the video stream. A synchronous communication would have made the exchange of messages a lot slower and would have caused an apparent loss of frame rate. Managing packages from the server and the client was further enhanced through the implementation of a queue consumer – producer to handle the competition of various clients. The various threads that are generated on the server to speed up the creation of data for various clients were handled through the implementation of an ad hoc class, because Unity3d is a purely single-thread environment.

4.4 Projector Setup

Our experiment is mostly based on alteration of parameters such as brightness and contrast, and then it is essential to have a good initial setup of the projectors. The seven devices used in our simulator were initially reset to factory values, then proceeds to an ad-hoc manual calibration for each of them. In fact, we noted that, although the make and model are the same, each of the projectors returned with images and contrast completely different from each other, even with the default values. Each projector in our equipment communicates with its clients through a serial port that can receive a few commands. We have, therefore, created a special script that allows tonal values to set automatically whenever you turn on the projector and you want to start the simulation. In Figure 6 we can see the final environment after the calibration and without any modification filter.
5 Image Filter Layer

In this section we will illustrate the types of filters that are applied to the video stream to explore how the perception of speed in a driving simulator can be altered. Subsection 5.1 focuses on the applied filter at the Fragment Shader to alter the contrast of the scene, while in section 5.2 we will talk about how the Camera Motion Blur Filter was adapted to our project.

5.1 Contrast Filter

As mentioned earlier in section 2.6, one of the things that can alter the perception of speed is the creation of areas of high and low contrast. A high-contrast image will be slower than a low contrast image. Starting from this assumption, although the contrast variation has been applied to all panels in the Simulator, the noticeable effect appear mainly on the panels positioned in front of the machine, namely screens 2, 3 and 4 (Figure 3). It is this portion of the screen that is in the driver's focus. The areas of high and low contrast vary with the variation of the speed of the car, more precisely the more the car increases its pace the more the low-contrast areas (the ones that appear slower to driver) will decrease while increasing the high contrast area (which will appear quicker in the eyes of the driver). Initially, various hypotheses have been considered, the first involved the superimposition of a gray rectangular object with a certain degree of gradient that simulated a kind of lowering of the definition of the scene. The effect however, has not produced the desired results as the degradation of the image was too obvious and was going to restrict the driver's vision. In addition the adaptation of computing the size of the rectangle was made directly on CPU, weighing it down considerably. To resolve the problem of loading performance we decided to embark on the road of implementing a mathematical function that generate certain values that, by acting directly on the RGB channels of the individual pixels in the scene, would vary the contrast. To handle the peak calculated we decided to delegate the computations to the GPU, through the creation of a fragment shader. In the next three paragraphs we will expose the texture management and fragment shaders by Unity3d and then present the solutions considered and adopted.

5.1.1 Contrast Function

We evaluated several mathematical functions that could recreate an alteration in the variance going to recalculate the values of each pixel contrast. The first road to be taken was to use a cubic function that reflect the classic "S" curve typical of "Curves" in all photo editing programs (Figure 7). The soft nature of the curve at the ends would allow a gentle transition from low contrast to high contrast areas and vice versa. The function detected was:

\[ y = a x^3 + 2 x\left(\frac{1}{2} - 0.125 a\right) \]  (1)

where the variable should be taken between a specific range of values and can vary the contrast as follows: \( a = 0 \), no linear contrast variation \( a > 0 \) to increase contrast and \( a < 0 \) to decrease the contrast. The main problem encountered in this function was the excessive number of calculations, since it must occur before a transformation function in relation to
"x" and then be calculated as the inverse in order to have a curve that passes through the second and quarter quadrant of a Cartesian axis. Finally, this function must be applied to each RGB channel of each pixel in the scene. All this has led us to think about a new solution that requires fewer calculations and produce a result that is as close as possible to the curve produced by the function 1. Another reason for doing this is based on gradient that is applied to the extreme zones of the scene to adjust the contrast to the speed of the machine and to cancel the extreme values of the curve. Undoing these areas, the resulting function appeared more like a straight line and then we explored a simpler linear function (Figure 8). The extreme parts gradient is applied through the use of the lerp, in the Mathf library\(^6\) that performs a linear interpolation between two points with a precise step defined by the user.

\(^6\) http://http.developer.nvidia.com/Cg/lerp.html
5.1.2 Function Implementation

This section will explain the various steps required for the implementation of the change in contrast on screens, taking also into account the speed of the machine in detail. This section is divided into two subsections as the shape with which the contrast varies is different on the front panel of the car than those at the sides. The values of max and min contrast of each panel are saved in a configuration file and each client accesses this information to calculate their own variation.

5.1.2.1 Front Panel

The front panel of the simulator is the one which the driver has the major focus on when increasing speed. To this we add the "central" nature of the Panel, which then must submit a variation of contrast that depart from center stage and spread in all directions. We thought then by applying a radial diffusion (Figure 9). This was done by calculating for each pixel of the scene its distance from the center point and later a lerp between the two extremes of contrast with a step equal to half of the diagonal of a square. Finally the resulting line is calculated from the value provided by the lerp and applied to each pixel's RGB channels of the scene.

![Figure 9 Radial diffusion](image)
5.1.2.2 Side Panels

In the side panels the contrast gradient was easier to manage, because it was making a simple horizontal linear gradient from one extreme to another. The lerp has proceeded to do the blending between the two extremes of contrast with a step equal to the horizontal width of the scene. The resulting contrast value was used in the calculation of the line that produced the new RGB values of each pixel in the scene.

5.1.3 Adaptive Contrast Variation

The variation of contrast is conditioned in all panels by the car's speed. In the Figure 10 we can see the environment while the car is in stop, the low contrast area cover all the front panel. More the rider will increase the speed of gait and more low-contrast area will decrease to facilitate the high-contrast area (Figure 9). To create this gradual variation we used a lerp that calculates new values max/min ratio, with a step equal to the current speed of the car. These values are then assigned to the contrast function described in paragraph 5.1.3 and the last step is to copy the new render textures on the original texture through the use of the blit method of Unity3d (available only for the pro version of Unity).

![Figure 10 Environment with car in stop](image)
6 Evaluation study

Having introduced how human beings can perceive the sense of displacement in their surrounding environment and how the software was developed with which we want to study how these perceptions can be affected in a driving simulator. In the following, we will apply the method by which it is sought to study the effects produced by the software system. Finally, we will analyze these results to see if and how the perception of speed was affected.

The test group consists of people between 20 and 30 years of different nationalities and with different levels of driving experience both in the real world, and in the virtual world. The sample also includes the participation of two people without a driving license and two people with previous experience in driving simulators. In total, the group amounts to 18 subjects, of which 13 are male and 5 female. Their driving has been evaluated through three different types of tests. A first test does not foresee any changes in the surrounding environment: the driver is to drive along a path of a 4-lane motorway with traffic in 2 directions in an urban environment consisting of numerous houses, buildings and skyscrapers. The second trial tests the performance of the same virtual environment, but with a progressive change of the contrast of the scene depending on driving speed as described in section 5.1. Finally, the last test provides, in addition to changing the contrast of the scene, the presence of other traffic on the road section which interact with the driver through the use of an Artificial Intelligence (Franco, 2013). The testers were assessed through a questionnaire to assess various aspects of the Simulator (Appendix A). While driving the driver was questioned about her/his perception of speed and three times in three different points of the track to check the degree of perception of speed. The question they had to answer was "what was your perceived speed?" For each occasion a note was made on the perceived speed and throughput. At the end of each test session, the driver was asked to evaluate other general aspects of the Simulator as the visibility and realism of the Simulator expressing a value between 1 (minimum) and 7 (maximum). We evaluated the visibility of the road to check if the modification of the contrast of the scene created problems to the driver while driving. To evaluate the visibility of the road, the driver had to answer the question: "How is the visibility driving feel in general in this test?", while with regard to the realism the question posed to the driver was: "Can you give a rank on the realism of simulator?" The driver was also asked to assess the perceived speed inside the Simulator as compared to perceived speed in reality answering the question "The felt speed of the car in the simulator was lower/higher/different than in the reality?" Finally the driver was questioned about their state of health, particularly if they experienced eyestrain or other disorders.

The test sessions took place in coordination with another study regarding human interaction with other vehicles on the road driven by an Artificial Intelligence (Franco, 2013). The total duration of the test session is approximately 30 minutes in which sessions 6 subtests which were 5 min long are carried out: three of these represent the test relating to the work of this thesis and the other three are tested for the study by Franco (2013). The two general types of tests were interleaved where usually the first session was my study; then three tests concerning the study of Franco (2013) and finally the last two test sessions for my study. The idea of combining the two different types of tests in this way was born with the intention of depriving the driver of possible points of reference and to avoid the risk that s/he can easily get used to the type of virtual environment. After the first test, in fact, the driver is in a virtual environment like this but with other vehicles on the track that will significantly impact on his perception of the speed gained in the first session. The three tests for my
study, moreover, are executed in random order from tester to tester, producing additional data that will deepen the study of the perception of speed. In agreement with Franco (2013), however, it was decided to avoid making a first test session including other traffic, doing alternate only tests that involve the application of contrast and change the test without any modification of the virtual environment.

6.1 Data

In this section we're going to expose the results of the questions presented in the previous paragraph. Answers about realism and visibility have been organized in graphical form where the x-axis represents the testers, while the y-axis represents the rank of the response. For each of these aspects was also calculated the average. Regarding the answers to the perceived speed during driving session data is represented by graphs the results from the study of linear regression and the numbers 5-summary.

![Figure 11 Answers about the realism. On the x-axis we can see the drivers and on the y-axis we can see the answers of the drivers between 1 (low) – 7 (high)](image1)

![Figure 12 Average of the answers about the realism](image2)
As you can see from the graph in Figure 1, the degree of realism has remained almost equal after applying the contrast filter. Values about the realism have decreased when applying the contrast filter and in the presence of other cars on the track because the decrease of contrast discolored the car and they appear unrealistic to the driver.

The data on realism are closely related to those relating to visibility. As can be seen from Figure 13 the general visibility of the scene is considered to be very positive on average and tends to decline slightly after applying the contrast filter. Again, we see a decline with the addition of the cars all this is mainly due to the fact that the point of attention moves from the street to the other cars. They appear discolored and less defined than the other tests due to the application of the contrast filter and visibility is perceived as low. In general, however, it was not perceived as a problem by the drivers. Only 2 subjects of 18, admitted to having difficulty driving related to visibility (Figure 12). There is a difference in perceived realism and in visibility during the test that came with changing the contrast and the presence of other cars on the road. It can also be seen from the data that many subjects did not notice the changes in the virtual environment. Only 4 participants noticed the presence of the low-contrast area, while 8 participants noticed differences in the environment that also included the presence of other cars. Finally only 2 drivers have noticed changes on the screen with the presence of cars and contrast editing. An interesting point is the fact that two drivers have not noticed the low contrast area but the high contrast area. The two drivers have no driving license (the only two in the group) and one of them is female. It is well known that the FOV is broader with female than male and amounts to about 70-80°, whereas the male FOV is about 40°. The fact that this has been noticed only by those who are not in possession of a
driving license, moreover, suggests how different the point of attention may be for those who already have a driver's license.

To study data about the perception of speed than the reality, a part of the drivers that has always been perceived as speed not exceeding 100 km/h in all three tests has been isolated from the entire group. This is because their perception of speed may be based on benchmarks that the simulator does not possess, such as G-forces or engine noise higher than that reflected in the virtual environment, causing a lowering of the sensation of speed. In this way we have a group of 5 drivers that have never felt a speed exceeding 100 km/h, even going so far as to touch speeds between 130 and 170 km/h (see Appendix B).

The data results from remain group of 13 testers are more homogeneous: in particular, for 5 drivers the perceived speed than the reality in simulator did not change in all three tests and was perceived as similar to that of reality. For 4 drivers there was an increase in felt speed in both tests in which changes are made to the virtual environment. For 2 drivers the speed was perceived as slower than reality in all three tests, while one participant the car had a slower pace only in the test by applying both the contrast filter which cars and, finally, to a tester you warned a slowdown in both tests involving changes to the virtual environment. In the latter case, the slowdown coincided with a different scheduling of tests that included the first and second test with the presence of changes to virtual environment and finally the test without any manipulation (see Appendix B).

To analyze the resulting data from the three questions regarding speed perceived by the driver at different points of the track, it will rely on linear regression analysis and will be taken into account all the sample meters. In this way, we will be able to evaluate the expected value using as dependent variable the actual speed of the simulator and as independent variable the values perceived by the drivers. In Figure 15 you can see the regression analysis of the test without the contribution of virtual environment changes and you can see how the values are slightly scattered than the regression line that represents the reference point and is calculated based on the real velocity of the simulator. You can see very distant points from the main line, which signify a great scrap of difference between the perceived speed and the actual speed.

![Figure 15 linear regression without any modification in virtual environment. On the x-axis we can see the real speed of the car and on the y-axis we can see the felt speed of the car by the driver while driving](image)
Figure 16 represents the linear regression test with a single filter applied to change the contrast. Comparing these values with those of Figure 15, the amalgamation of the points near the regression line can be seen. In addition, you can see that the values with maximum gap between perceived speed and actual speed is less and less far from straight. In Figure 17, finally, the linear regression with the filtering and the presence of other cars on the circuit is presented. In the latter location test, the amalgamation of the points near the regression line is even more evident, thus to further decrease the minimum waste. You may also notice an improvement of extreme values at the top of the line departing even further from the upper limit of 150 touched in the test without any filter. The same data behavior you can see in Figure 18, which represents the difference between perceived and actual speed through the 5-numbers summary. The median of this difference stands in all three tests on values lower than 50 km/h, as you can see from the black line. The grey section, on the other hand, represents the trend of the overall accuracy of results and validates what the linear regression analysis showed. You notice a slight improvement with the application of only contrast filter that is accentuated even further in the last test in which, in addition to changing the contrast, it also placed the car on the circuit.

![Figure 16 linear regression with contrast filter and cars on the road. On the x-axis we can see the real speed of the car and on the y-axis we can see the felt speed of the car by the driver while driving](image-url)
With respect to simulator sickness, no participant experienced a sense of nausea and had to stop the test. Only in one case, the driver was suffering from a slight lightheadedness during the first session, but it was not necessary to leave the test and during the subsequent sessions the effect disappeared. Probably this is due to the fact that the general test is broken into short term subtests, which favoured the acclimatization of the driver to the virtual environment. Having said that though, the absence of simulator sickness was also favored by a high degree of realism of the simulator, as most users tested confirmed (Figure 12). Only some of the subjects have pointed out the lack of a real feedback that help to perceive the sensation of acceleration and braking, while all of the participants have found this type of simulator fun and exciting and nobody has claimed to have been bored during the whole duration of the test. There has been no problem in recruiting testers thanks to a dense positive word of mouth about the simulator. The sample analysed could be far more extensive, but the lack of time to perform other tests forced us to exclude volunteers.

Figure 17 linear regression with contrast filter only. On the x-axis we can see the real speed of the car and on the y-axis we can see the felt speed of the car by the driver while driving

Figure 18 5-numbers summary result. The values under the line are the difference between the real speed of the car and the felt speed of the drivers while driving
7 Analysis

From the analysis of the overall results we can see how objective 3 about maintaining a high level of realism and visibility, while changing the contrast of the scene, has been achieved. Using the linear math function to modify the low-contrast area in combination with the lerp function, the low contrast area appears not too much invasive on the screen. In fact only 8 drivers notice the low contrast area and it didn’t appear as problem while driving for them. Therefore the environmental fidelity defined by Triggs (1996) has been respected also with adding the modification of the contrast scene. The use of contrast filter and cars on the track has lowered these values even though still remaining at levels more than acceptable in the media. Another goal achieved was to be able to test users to figure out how they were influenced by the perception of speed in the driving simulator. The total absence of simulator sickness and good degree of visibility and realism in almost all of the tests made it possible to carry out all three sessions without any problem and without interruptions, managing to provide all the necessary data.

Regarding the alteration of perception of speed, the main objective of our study, we can say that the drivers react positively, even if not flagrantly, to the stimulations produced by changing the virtual environment. The proof of this statement is given by the linear regression analysis and the 5-number summary, in which we highlight improvements in establishing its driving performance even with the application of contrast filter. The results are even more positive when we apply both the contrast filter and the placing of cars on the track. The gap between perceived and actual speed remains high, but the most interesting and valuable is that there is a rapprochement to the actual speed. It is interesting to note how, instead, drivers assess the overall speed of the simulator differently with respect to reality. The data seem almost reversed, and for many drivers the tests where both cars that contrast filter appeared to be slower. This is perhaps due to the fact that the cars on track are taken as the new focus point for understanding the subjects’ moving in space. Since the cars move along with the driver and did not represent a static point, this may result in a lower perception of sense of speed at a general level.

Ultimately, though, this is not relevant as the results produced by the 5 regression-summary numbers and linear regression which allow us to say that creating a high contrast area flanked by a low contrast, causes a change in the perception of sense of speed even in a driving simulator. It would seem, then, that studies of Stone & Thompson (1991) and Chatziastros (1999) are also confirmed in this driving simulator. Creating a low-contrast area flanked by high contrast areas makes the first appear faster in the eyes of the driver, as shown by the regression results 5-numbers and summary. It must be said, however, that the test portion should be made more robust, especially expanding the number of testers. The results seem to go in the right direction, but to get a more complete and reliable confirmation of additional work is required.

The management of the field of view for the Division of zones with low and high contrast confirmed for most cases the results of Chatziastros studies (1999), although two drivers have produced conflicting data. For the latter, in fact, the field of view went beyond 40° cited by Chatziastros and have proven it claiming to have noticed the high contrast area, placed between the 40° and 180° field of view, rather than the low contrast placed inside of 40°.
8 Future Work

The overall result may be considered satisfactory, but it can surely be improved and perfected with future studies. One of the features that could be implemented is the motion blur filter. This one is used in many video games currently on the market to change and enhance the sense of displacement. Unity3D has a standard filter called camera motion blur, but it is a very crude version which is applied to the whole scene. It would be feasible to instead implement a new type of filter that is able to reproduce the effect only on some objects in the virtual environment, such as buildings and the guard rail bordering the road, perhaps making it progressively according to the driving speed. Combining the contrast modification and the blur filter it would be interesting to test if the perception of speed in the driving simulator also changes and if the speed of the car appears faster.

Another aspect that can be improved is about the hardware side of the Simulator that for this study can significantly improve the results. The projectors used to play the virtual environment, in fact, are quite outdated and have a contrast far below the latest models available on the market and present a considerable chromatic aberration in the upper corners.
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9 Appendix A – Questionaire

Data: _______/_____/____

Type test A:_______________________
Type test B:_______________________
Type test C: ______________________

• Session Type A

➢ While driving

1. Ask the driver on the straight: what was your perceived speed?
   Driver Velocity: ______________ Real Velocity: ______________________

2. Ask the driver on the straight: what was your perceived speed?
   Driver Velocity: __________________ Real Velocity: __________________

3. Ask the driver on the straight: what was your perceived speed?
   Driver Velocity: ______________ Real Velocity: __________________

➢ After driving

1. Do you felt some difficults to take the turn?
   YES NO Comments:________________________________________________

1b. If the answer of question 1 is YES: the problem was that the perceived velocity was too low or too high?
   higher/lower NO Comments:________________________________________
2. The felt speed of the car in the simulator was lower/higher/same than in the reality?
   lower – higher - same

3. Can you give a rank on the realism of simulator? 1(worst) – 7(best)
   Rank:_____  
   3a. If the rank of the question 3 is low, ask the driver: the perceived speed of the simulator than the reality is one of the cause of the low rank?
   YES NO Comments:__________________________________________
   3b. If the rank of the question 3 is low, ask the driver: there are the other causes of low realism of the simulator than the reality?
   Comments:_________________________________________________

4. Do you feel eye issues?
   YES NO Comments:____________________________________________

5. Do you felt issues with the audio of the game?
   YES NO Comments:____________________________________________
   5b. If the answer of question 5 is YES: the volume is too high?
   YES NO Comments:____________________________________________
   5c. If the answer of question 5 is YES: there are other impressions about the audio?
   YES NO Comments:____________________________________________

6. Can you give me a rank of the visibility in this test from 1 (worst) – 7(best)?
   Rank:_____ Comments:____________________________________________

- Session Type B
  - While Driving

TIME:______________
1. Ask the driver on the straight: what was your perceived speed?
   Driver Velocity: _______________ Real Velocity: _______________

2. Ask the driver on the straight: what was your perceived speed?
   Driver Velocity: _______________ Real Velocity: _______________

3. Ask the driver on the straight: what was your perceived speed?
   Driver Velocity: _______________ Real Velocity: _______________

➤ After Driving

1. Did you perceive any difference on the screen between this test and the test type A?
   If YES, In what way??
   YES NO Comments: ____________________________________________

2. How is the visibility driving feel in general in this test? 1(low) – 7(high)
   Rank: _____ Comments: __________________________________________

3. This test was more invasive than the test type A?
   YES NO Comments: ____________________________________________

4. Can you get the turn in this test than the test type A?
   YES NO Comments: ____________________________________________

4a. If the answer of question 5 is NO: the problem was that the perceived velocity is too high or too low?
   High – Low NO Comments: __________________________________________

5. The felt speed of the car in the simulator was lower/higher/same than in the reality?
   lower-higher-same Comments: __________________________________________
6. Can you give a rank on the realism of simulator? 1(worst) – 7(best)
   Rank:_____

6a. If the rank of the question 6 is low, ask the driver: the perceived speed of the simulator
    than the reality is one of the cause of the low rank?
   YES NO Comments:__________________________________________________________

7b. If the rank of the question 7 is low, ask the driver: there are the other causes of low
    realism of the simulator than the reality?
   Comments:__________________________________________________________

8. Do you feel eye issues in this test?
   YES NO Comments:__________________________________________________________

• Session Type C

  ➢ While Driving

1. Ask the driver on the straight: what was your perceived speed?
   Driver Velocity: _________________________   Real Velocity:__________

2. Ask the driver on the straight: what was your perceived speed?
   Driver Velocity: _________________________   Real Velocity:__________

3. Ask the driver on the straight: what was your perceived speed?
   Driver Velocity: _________________________   Real Velocity:__________

  ➢ After Driving

1. Did you perceive any difference on the screen between this test and the test type A?
   If YES, In what way??
   YES NO Comments:__________________________________________________________
2. How is the visibility driving feel in general in this test? 1(low) – 7(high)
   Rank:_____ Comments:__________________________________________

3. This test was more invasive than the test type A?
   YES NO Comments:__________________________________________

4. Can you get the turn in this test better than the test type A?
   YES NO Comments:__________________________________________

5a. If the answer of question 5 is NO: the problem was that the perceived velocity is too high or too low?
   High – Low NO Comments:__________________________________________

5. The felt speed of the car in the simulator was lower/higher/same than in the reality?
   lower-higher-same Comments:__________________________________________

6. Can you give a rank on the realism of simulator? 1(worst) – 7(best)
   Rank:____

6a. If the rank of the question 6 is low, ask the driver: the perceived speed of the simulator than the reality is one of the cause of the low rank?
   YES NO Comments:__________________________________________

6b. If the rank of the question 7 is low, ask the driver: there are the other causes of low realism of the simulator than the reality?
   Comments:__________________________________________

7. Do you feel eye strain in this test?
   YES NO Comments:__________________________________________

8. Other overall impressions?
### Appendix B – Result of felt speed while driver driving and felt speed than the reality

<table>
<thead>
<tr>
<th>Tester</th>
<th>Felt Speed while driving</th>
<th>Felt Speed than the reality</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No Filter</td>
<td>Filter</td>
</tr>
<tr>
<td>1a</td>
<td>60 140</td>
<td>70 130</td>
</tr>
<tr>
<td>1b</td>
<td>90 130</td>
<td>100 140</td>
</tr>
<tr>
<td>1c</td>
<td>100 160</td>
<td>120 160</td>
</tr>
<tr>
<td>2a</td>
<td>70 140</td>
<td>70 110</td>
</tr>
<tr>
<td>2b</td>
<td>80 150</td>
<td>90 140</td>
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<tr>
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<td>100 130</td>
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</tr>
<tr>
<td>3c</td>
<td>130 160</td>
<td>100 160</td>
</tr>
<tr>
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