



EVALUATION OF DIFFERENT FEEDBACK AND REPRESENTATIONS OF AN IDEAL TRAJECTORY IN A DRIVING SIMULATOR

Master Degree Project in Informatics
One year Level 30 ECTS
Spring term 2014

Michelangelo Cianciulli

Supervisor: Per Backlund
Examiner: Mikael Johannesson

Abstract

The purpose of this study was to develop some kind of feedback in a driving simulator aimed at helping drivers in following the ideal trajectory and let human testers use it, in order to analyze which feedback is best perceived, and if it is also the one which allows the drivers to follow the ideal trajectory. The project implemented two different representations based on theories from traffic research which was compared in an experiment with 29 subjects. The first representation is a drawn trajectory and the second one uses drawn points near the tangent point.

This work is based on a driving simulator developed for a previous study using the Unity3D engine. Furthermore, the driving simulator is developed on a low-cost hardware infrastructure.

The test subjects generally gave a good feedback on the simulator as a whole and analysis of the data, even if biased by a mean high speed caused by a general low speed perception, shows a clear pattern in which the use of drawn trajectory leads to performances closer to the ideal trajectory. This representation has also been valuated as better in the questionnaire, and hence from the available data it seems possible to say that this kind of feedback is better perceived and leads to better performances compared to the other one.

Keywords: driving simulator, serious games, feedback, ideal trajectories, horizontal curves

Table of Contents

1	Introduction	1
2	Background	2
2.1	Serious Games	2
2.2	Feedback, entertainment and learning	2
2.3	Games for traffic education	5
2.4	Hardware Infrastructure	6
2.5	Traffic Safety	7
2.6	Horizontal curves and trajectories problems	8
2.6.1	Task analysis on curve driving	10
2.6.2	Curve perception and speed selection	12
2.7	Control of steering	13
3	Problem	16
3.1	Simulation Hardware and Software	17
3.2	Trajectory and representation of a point near the Tangent Point	18
3.2.1	Catmull-Rom Splines	19
3.3	Method	19
3.3.1	Ethical Considerations	21
3.4	Pilot Test	21
4	Results and Analysis	23
4.1	General Consideration	23
4.2	Comparison between the two representations	24
4.3	Data Log	25
4.4	Analysis	26
5	Conclusions	29
5.1	Summary	29
5.2	Discussion	29
5.3	Methodological considerations and limitations	30
5.4	Future Work	30
	References	33

1 Introduction

The movement of serious games seems to know no barriers. More and more studies have been carried out testifying the positive aspects of such kind of games. Both industry and academy research have focused their attention on the development and evaluation of serious games, that is games with purposes other than mere entertainment (Susi, Johannesson & Backlund, 2007). In particular, in 2006, Lebram, Engström and Gustavsson developed a simulation on a mid-range driver simulator which has been verified by Backlund, Engström and Johannesson (2006) and Backlund, Engström, Johannesson and Lebram (2010) to be a useful tool to help in training people to have better driving behavior.

In the context of traffic safety, the problem of ideal trajectories in horizontal curves is both interesting and important. Many studies have been carried out to find the tendencies of drivers in negotiating curves, and a natural tendency in cutting the curves has emerged. By contrast, the ideal trajectory in horizontal curves is exactly the center-line during the entire curve.

Already in 1979, the Michigan Department of Transportation made a study about tree-vehicle crashes aimed at classifying the profile of drivers more frequently involved in such kind of accidents, which, given the nature of the collision, are often cause of a significant amount of agony and pain to those involved in the accidents (Torbic, 2004).

High speed as principal factor causing loss of control of the vehicle has been investigated by Staplin, Lococo, Byington and Harkey (2001). Spacek (1998) investigated and classified vehicle trajectories at horizontal curves.

The entire process of taking a curve has been studied and analysed by Campbell, Richard and Graham (2008). Various steps have been found, each one composed by some tasks, that have to be accomplished in order to navigate the curve in a safe way.

The present work is based on the theories presented above but is applied in a virtual environment context, where a driving simulator has been used in order to evaluate the effects and the perception of two different kinds of feedback aimed at helping the drivers in the objective of following the ideal trajectory in curves. Participants' impressions have been gathered and compared to driving data from their simulator sessions in order to evaluate which feedback between the two is better perceived by the users and which one leads to better driving performances.

Such kind of evaluation can help in some choices to develop a more complex serious game aimed at teaching better and safer driving habits to the drivers with respect to the problem of ideal trajectories in horizontal curves.

Perhaps, a theoretical and practical understanding of this problem, even if only in a driving simulator, can lead to better habits for drivers in real life scenarios, where the risk of accidents increases while not following the ideal trajectory.

The thesis is structured as follows: Chapter 2 presents background and theoretical aspects of the thesis. Chapter 3 is focused on the problem investigated, and the research method used. Chapter 4 shows the data collected and the analysis carried out. Some final considerations, as well as a summary of the work will be made in Chapter 5.

2 Background

This section introduces previous results and studies on which this work is based. The discussion starts with a brief description about serious games, and continues by introducing the definition and importance of feedback in learning. A brief overview of simulated driving, of the hardware infrastructure for the simulator that has been used, and some previous works that analysed its potential as a traffic educational tool comes after. A description of the traffic safety problem, focusing on horizontal curves and trajectories concludes the chapter.

2.1 Serious Games

The use of the term serious games has become popular in conjunction with the release of the video game America's Army, in 2002. The Serious Game Initiative was founded in the same year and serious games started their spread (Susi et al., 2007). The website of the serious games initiative provides the following description:

“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”

(seriousgames.org, 2014).

Many sources, however, do still not have a proper definition of serious games; hence a key question actually is what the concept itself really means. A brief search of the literature, for example, reveals that there seems to be many plausible definitions available, but most agree on a core meaning that serious games are (digital) games used for purposes other than mere entertainment (Susi et al., 2007).

Serious games and simulated environments are very important, principally because they allow learners to experience situations that are impossible to experience in the real world for reasons of cost, time, safety, etc. (Susi et al, 2007). There are many possible skills that can be enhanced by playing computer games, such as spatial, strategic, and psychomotor skills, learning and recollection capabilities, and others, as discussed by Mitchell and Savill-Smith (2004). Lager and Bremberg (2005), point out the positive effects on motor and spatial skills. More specific positive impacts, in endoscopic simulation by medical students, have been reported by Enochsson et al. (2004). Negative effects, such as increased aggressiveness, are still not clear (Backlund et al., 2010). However, since there may be lack of evidence on how serious games increase one or more skills, is sometimes difficult to clearly state about the benefits of their use (Susi et al., 2007).

2.2 Feedback, entertainment and learning

Doherty and Balzer (1988) discuss the meaning of the word feedback. While the term feedback has been used in a variety of ways in different disciplines, by definition it involves “an environment that returns some measure of the output of a system back to the system which produced that output” (Doherty & Balzer, 1988, p. 163). The feedback hence allows the system to bring itself closer to an ideal state, allowing a comparison of the present state of

the system with such ideal state, giving the possibility to adjust itself in respect of that comparison. We can think of the system as a person and the environment as the serious game itself, who can give feedback to that person in order to allow him to learn something.

As explained by Rogers (2007), giving feedback is important in learning. Not giving the right quantity or quality of feedback is one of the main reasons why (adults) learning fails, so it is worth thinking about how to give it in the right way. Rogers (2007) furthermore points out that giving feedback in the wrong way is dangerous, as dangerous as not giving enough of it.

Feedback matters, and without it the learner is unlikely to improve. One example, carried out by Rogers (2007), is about a group whose objective is to complete some kind of task to a demanding standard. As the project goes on, the group does not receive any comment on whether or not it is hitting its quality targets. There is another group which does receive guidance. Of course the second group will have more probability of success. The first group is going to continuously make the same errors over and over again while the other group will steadily improve.

Another important factor, as expressed in Rogers (2007), is that adults come to learning in order to change and improve something, but if the performance does not improve, than all learners, and in particular adults, quickly lose interest. Their motivation disappears, and without motivation is much more difficult to have learning.

Feedback is therefore a critical part of learning, and Figure 1 shows the so called Improvement Cycle (Rogers, 2007, pp. 59-60). If this cycle is broken by failing to give the right kind of feedback then the learning will be unsuccessful but even just a little well-judged feedback can have great effects (Rogers, 2007).

Rogers (2007) also report that there is a simple rule about the optimum time to give feedback on learning: to give it as soon as possible. The reason provided by Rogers (2007) is that there is only a short time to correct the mistake without letting it harden into a permanent error.

An interesting report regarding learning feedback is from Ekanayake, Backlund, Ziemke, Ramberg and Hewagamage (2011). The classroom-based learning feedback can be given in two forms: summative and formative. Summative feedback comes as a quantitative measure of the learner's performance after the completion of a learning session. Examples in a game can be a scoring system, experience points, level progression, item collection, or combinations of the above. Formative feedback is a qualitative feedback given during the process of learning and allows the learner to formulate opinions and reflect on how to accomplish her or his goals (Ekanayake et al., 2011). The most common example of formative feedback in games is an adaptive game play, in which the game will adapt to the skill of the player. One important factor facilitating this adaptive game play is called the flow experience, that is, "the sensation of losing track of time and outside world while completely absorbed by the activity in which the player is currently engaged in" (Ekanayake et al., 2011, p. 4).

According to Ritterfeld and Weber (2006) there are three possible relationships between entertainment and learning. The first one directly connects the two, and increasing in entertainment means increasing in effective learning. The second one connects the two negatively. This means that entertainment distracts from learning, hence more of it means a

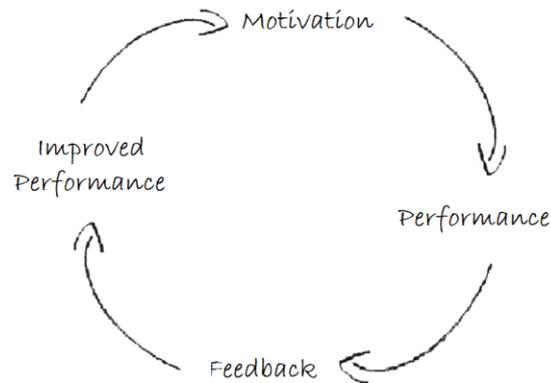


Figure 1 The improvement cycle, based on the figure shown in (Rogers, 2007).

decrease in learning performance. The last possible relationship argues that entertainment is beneficial for learning, but not over a certain point. If this amount is exceeded, all the added entertainment becomes counterproductive for the learning purpose. Since the effectiveness of games for learning does depend on the enjoyment of the experience by the players (Prensky, 2003), it seems that the third relation is the most likely to be true.

Breuer and Bente (2010), assert that to motivate players as learners it is necessary to find balance between entertainment and learning, and regarding the integration of entertainment and learning in digital games Ritterfeld and Weber (2006) identify three different approaches. The entertaining part of the game can be offered as a reward for successful learning, the entertaining game elements can be used to increase the learner's interest, or the learning procedure itself can be designed to be entertaining.

Another important concept is the transfer of learning. "Transfer of learning occurs when learning in one context or with one set of materials impacts on performance in another context or with other related materials" Perkins and Salomon (1992, p. 1). Two of the examples presented by Perkins and Salomon (1992) are about how learning to drive cars helps a person to later learn more quickly to drive a truck, and how experience of playing chess might for example make one a better strategic thinker in politics or business. Transfer is a key concept in education and learning theory and is what most formal education aspires to reach (Perkins & Salomon, 1992). Any learning, in fact, requires a little bit of transfer, and to claim that learning has occurred, the person must be able to display that learning later on, in a situation that can be more or less similar to the one in which the learning occurred (Perkins & Salomon, 1992).

To achieve good transfer is often not so easy and Perkins and Salomon (1992) define two strategies to foster transfer. The first one recommends that instruction must directly engage the learners to the performances desired. For example, a teacher, instead of only talking about exam technique, can give students trial exams. The second one encourages the making of abstractions, inspires for possible connections, and conscientiousness. The example carried out here is about the same teacher who might ask students to come up with an exam strategy based on their past experience. Instruction that incorporates both those strategies seems most likely to yield rich transfer (Perkins & Salomon, 1992).

The conclusion from Perkins and Salomon (1992) is that it seems that transfer is difficult to obtain. However, a more careful examination of the conditions under which transfer does and does not occur presents a more positive picture. Learning can achieve the desired transfer but it has to be designed to do so (Perkins & Salomon, 1992).

2.3 Games for traffic education

When it comes to the use of simulators and simulations, we can see that they are widely adopted in different fields. For example, the overall value of using flight simulators for training has been well established principally because simulators are cheaper to use than the real aircraft operations (Orlansky and String, 1977), hence they often substitute real aircraft (Eddowes and Waag, 1980). Military simulation also offers a potential training for learning and practicing combat skills (Alluisi, 1991). Many investigations and analyses using driving simulators have been conducted in the traffic engineering area, such as pavement marking effect (Horberry, Anderson & Regan, 2006), traffic signs (Dutta, Fisher & Noyce, 2004), gap acceptance behavior (Alexander, Barham & Black, 2002), passing maneuver (Jenkins and Rilett, 2005), crash avoidance study (Smith, Najm & Glassco, 2002), driving distraction due to mobile phones (Rakauskas, Gugerty & Ward, 2004), investigations on whether the driving simulator can be used as a valid tool to assess traffic safety at signalized intersections (Yan et al., 2008), and so on.

A study from Leitão et al. (1999) is about the development and use of a realistic driving simulator as a driving education method. The purpose of the study was to try to understand how and when the use of a driving simulator can be useful in the driving education process, in particular identifying the influence of the realism of the simulation on the learning. As pointed out by Leitão et al. (1999), one commonly accepted way in order to face the problem of accidents and deaths occurred due to traffic circulation in public ways is the improvement in driver's education and selection, and the use of driving simulators is growing in order to address those kinds of problems. Validations of the performances and of the realism of such simulators are two of the major concerns when developing a scientific driving simulator (Leitão et al., 1999).

It is common today to find, in driving education, the use of driving simulators both with training or evaluation purposes, but those simulators inevitably cannot be perfect. For example, vehicle's behavior must be simplified and cannot reflect exactly the real dynamic behavior, and also the surrounding scenario cannot include all the possible reactions to the driver behavior (Leitão et al., 1999). Those simplifications of course affect human driver reactions, but this is inevitable, and in any case it is accepted that the data acquired from driving simulators is still valid (Leitão et al., 1999). As a conclusion, Leitão et al. (1999), points out that simulated training is still far from a complete substitute to real experience, and hence decisions must be taken on how they should interact.

A more recent study from Weinberg and Harsham (2009) shows how is possible to develop a low-cost driving simulator using only off-the-shelf components. The level of fidelity of the system has been seen to be comparable with more expensive, custom-build research simulators.

Concerning driving simulation, in some more contemporary racing games, it is used by racing drivers to memorize courses (Walker, 2006). Driving simulation in games has hence reached a maturity level that makes them useful as driving simulators. The point is that even

if games are not realistic in all senses of driving, they seem to have an impact on some aspects of car driving anyway (Backlund et al., 2010).

Backlund et al. (2006) and Backlund et al. (2010) have developed games to help driving schools in providing traffic education. The games were running on a simulator developed by Lebram, Engström and Gustavsson (2006), and the usefulness of the simulator as a tool for training has been experimentally evaluated by analyzing driving logs and user opinions collected in a questionnaire as well as by conducting interviews.

In one of the games developed, the player is driving a car on a five-lane motorway and the goal is to follow an ambulance heading for a hospital. The level is considered failed if the driver loses the ambulance out of sight or violates traffic rules with respect to speed, lane-changing and distance to vehicles in-front. When a mission is completed the player receives a grade and advances to a higher level unless the grade is a fail. The levels differ in traffic intensity, fellow road-user behavior and weather conditions (Backlund et al., 2006).

As stated by Backlund et al. (2010), the experiment shows positive relations between gaming and some skill oriented aspects of driving, and gaming has positive effects on attitude oriented variables. Backlund et al. (2010) expect that games can be utilized to enhance driving skills concluding that further work is needed to fully understand the underlying mechanisms in order to utilize their positive effects.

2.4 Hardware Infrastructure

This work uses the simulator previously cited, developed by Lebram et al. (2006). The driver environment is an authentic Volvo S80 with original instrumentation. Being in a car is often associated with a sense of responsibility for both the car and fellow road users and this helps in giving a great sensation of realism. The functionality of the interface to the simulator is really easy to understand, since it reflects the behavior of a real car, and this helps to achieve even more a sense of seriousness to the driving. Seven projectors and seven flat screens render the scenes, as shown in Figure 2, covering the whole field-of-view for the driver, including the rear view mirrors (Lebram et al., 2006).

One of the most complex and crucial aspect of a driving simulator is the generation of physical feedback. A fixed-based approach has been adopted for the simulator at the University of Skövde, and hence no G-Forces are generated. The illusion of movement in the simulator is principally governed by the use of sound, vibrations and the car's fan. In particular, the sound is generated in the internal surround system of the car which, in addition to a "ButtKicker" (thebuttkicker.com), is used to generate vibrations in the whole body of the car, which are propagated up to the steering wheel. Another important physical property is that the wheels should strive in order to return in their original position. To achieve this, in the simulator, the front wheels have been placed on an axial ball bearing (Lebram et al., 2006).

The role of the internal fan in the simulator is fundamental since it is one of the most important feedback utilized to give the sense of speed. The fan is controlled by the software of the simulator, and the speed of the fan is linear to the speed of the car. In high speed situations, the wind and the noise from the fan contributes to amplify the sensation of high speed. The use of the fan is a simple but effective way to address a complex problem such as the perception of speed in computer generated simulations (Lebram et al., 2006).

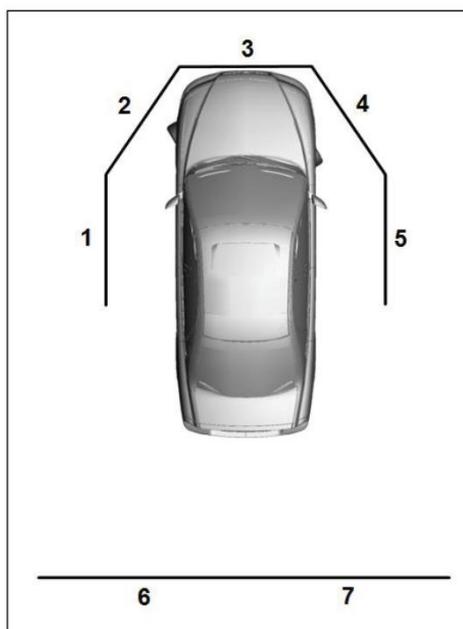


Figure 2 The simulator car and the seven screens (Lebram et al., 2006).

In addition, Procaccini (2013) showed how the use of a software filter can increase perceived speed on the same simulator. His result shows that despite the increased perceived speed thanks to the use of the filter, it remains lower than the actual one.

The visual representation gives an accurate impression of the position of the car. This is confirmed by Lebram et al. (2006) since, during their experiment, they found that drivers easily managed to position the car very close to the center of the lane. Lateral positioning is an important factor commonly used for validation of driving simulators (Lebram et al., 2006).

One problem to take into consideration when using simulators for prolonged time is the so called simulator sickness. This problem, who can affect as much as 30% of the users of simulators, is related to motion sickness and can cause symptoms severe enough to discontinue the use of the simulator. It is believed to be caused by difficulties in distinguish between perceived motion and the actual one (Lebram et al., 2006). Reports show that these problems were minor in the experiments carried on by the use of the simulator (Lebram et al. 2006).

2.5 Traffic Safety

According to Evans (2004), traffic accidents and crashes are one of the largest public health problems in the world. Approximately one million people are killed every year and the figure is expected to increase. Furthermore, the number of injuries is even bigger. An average human, as shown by Evans (2004), has a near two per cent risk of being injured in traffic each year. These are the impressive numbers of a real plague that is growing each year and this crescent trend will probably not stop according to estimates and forecasts.

The term traffic safety is used widely nowadays, and the use of such term is unlikely to generate misunderstanding, even though there is no precise definition of it. The general concept is “the absence of unintended harm to living creatures or inanimate objects” (Evans,

2004, p. 6). Traffic safety is measured using rates, that is, one quantity divided by another. For example we can think about fatalities per thousand registered vehicles, or fatalities per billion km of vehicle travel (Evans, 2004).

The danger placed on people's health, in the form of road traffic injuries, is the downside of road transportation. But road transportation is indispensable nowadays since it provides benefits facilitating the movement of good and people. Increased access to jobs, economic markets, education, recreation and health care are only few of the enormous benefits obtained, all having direct and indirect positive impacts on the health of populations (World Health Organization, 2009).

The rising trend in road traffic deaths and injuries shows how this is an important public health problem nowadays. Something has been done in order to face this problem, but many other measures should be applied in order to halt this problematic trend. Road traffic injuries remain an important public health problem and, among all, economic and social costs result from deaths, injuries and disability caused by road traffic crashes (World Health Organization, 2009).

2.6 Horizontal curves and trajectories problems

Horizontal curves are a very important and necessary aspect of roadway systems since they allow connecting two tangent segments. Rural curves, in particular, typically consist of two paved travel lines with or without shoulders. Even if traffic volumes are low, passing is usually not allowed, and in order to communicate to the drivers, the use of low-cost safety measures is needed to inform about the change in alignment prior to or within the curve. Typical low-cost safety measures include advance signage, chevron alignment signs, paved shoulders, centerline and shoulder rumble strips, and edge line pavement markings (Fitzsimmons, 2011).

There are four types of horizontal curves, as shown in Figure 3¹:

1. Simple: a simple arc of a circle. Small radius of the arc results in a sharper curve.
2. Compound: the composition of two simple curves curving in the same direction.
3. Reverse: the composition of two simple curves curving in the opposite direction.
4. Spiral: a curve with a varying radius that allows a smooth transition between various segments of the curve.

Statistics from the Fatality Analysis Reporting System (FARS) are pitiless, and indicate that approximately twenty-five per cent of the U.S. highway fatal crashes in 2002 occurred along horizontal curves. The average accident rate for horizontal curves is shown to be about three times the one for highway tangents (Campbell et al., 2008).

In more detail, among all the fatal crashes occurred at horizontal curves, are the ones in which the vehicle left the roadway, hitting a fixed object, or overturned, and those accounts for the major part, while the others are head-on crashes. Other types of crashes are the ones with trees in hazardous locations, and curve-related crashes (Campbell et al., 2008).

¹ Data and image based on information retrieved at http://engineeringtraining.tpub.com/14070/css/14070_237.htm

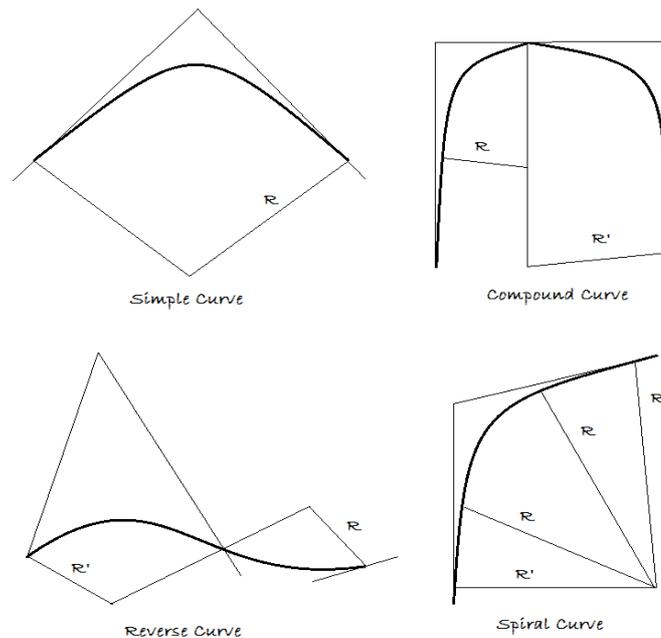


Figure 3 Different types of horizontal curves.

One important problem with accidents on horizontal curves, among the many, is that, because of the nature of the collisions, they cause a significant amount of agony to those involved in the accidents. In fact, approximately forty per cent of horizontal curves crashes involve some type of injury, and many of the fatal and more severe curve-related crashes occur mainly in rural settings, with about three quarter of the fatal accidents occurring in such rural areas (Torbic, 2004).

In order to investigate crashes at horizontal curves in Michigan, the Michigan Department of Transportation (1979) made a study about tree-vehicle crashes. Results show that over half of the tree-vehicle accidents in 1976 resulted in death or serious injury. Subsequently, abundant research has been made aimed at identifying, prioritizing, and tabulating the risk potential of many characteristics of tree-vehicle accidents. These fall into three categories:

1. Driver characteristics
2. The road environment
3. Trees and the roadside environment

Driver Characteristics: traffic-related research has drawn a profile of the driver most typically involved in run-off-road accidents: he's a young (20-25 years old) weekend driver, out during the early morning hours (2:00-4:00 am), driving faster than the posted speed limit. He may also be intoxicated and/or unfamiliar with the road. Drinking is a common ingredient in tree-vehicle accidents and unfamiliarity with road may also be a significant factor in tree-related crashes. Crashes are also more frequent during the winter months, suggesting some correlation with longer periods of darkness and maybe icy roads. While no method exists to determine the precise speed of a car upon impact with a tree, it is shown that the probability of accident involvement increases by a factor of 10 with a deviation of 25 km/h above or below the designated speed limit (The Michigan Department of Transportation, 1979). Even if this study has been undertaken some years ago, it is still very contemporary, since we can trace the profile of the driver most typically involved in run-off-road accidents nowadays and probably find more or less the same results.

The Road Environment: tree-vehicle accidents typically occur on winding rural roads, in which the vehicle leaves the pavement on the outside of a curve. The road type and various physical features of the road, as well as the driver characteristics described above, determine the probability of running off the road (The Michigan Department of Transportation, 1979).

Statistics show that seventy-seven per cent of tree-related accidents on curves occur at outside curves; that is, to the right of a left curve or the left of a right curve, as shown in Figure 4. Inside curves account for twenty-three per cent of the crash frequency, and most tree-vehicle crashes involve right departures at left curves (The Michigan Department of Transportation, 1979).

Successful curve negotiation is based principally on the choice of appropriate approach speed and adequate lateral positioning through the curve. Loss-of-control crashes result mainly from excessive speed which causes an inability to maintain proper lateral position through the curve, and this is principally caused by an inadequate deceleration in the approach zone. These problems derive from factors such as inadequate perception of the demands of the curve and poor anticipation of vehicle control requirements, induced by the driver's prior speed (Staplin et al., 2001).

Spacek (1998) investigated vehicle trajectories at seven two-lane horizontal curves in Switzerland. This study investigated how vehicles negotiate horizontal curves by collecting and classifying vehicle trajectories in both the inside and outside lanes of two lane horizontal curves. Spacek (1998) was also trying to determine if there were any relationships between trajectories and other variables such as crashes, speed, and lateral acceleration. The report created six distinct trajectory classifications as shown in Figure 5.

Other research studies states that the ideal path a vehicle can take along a horizontal curve is parallel to the center line and centered within the middle of the lane (Stimpson, McGee, Kittleson and Ruddy, 1977; Land and Horwood, 1995; Riemersma, 1981). Stimpson et al. (1977) also identified lateral placement and speed as the best indicators for assessing driver behavior on horizontal curves.

Felipe and Navin (1998) found that drivers tend to follow the center of the lane of large radii curves while they tend to cut the horizontal curve with small radii in order to minimize speed reduction.

Gunay and Woodward (2007) show that vehicles traveling in the outside lane of the horizontal curve shift towards the centerline while vehicles traveling in the inside lane of the horizontal curve shift towards the inside edge line. The researchers also concluded that the shift distance increased with a decreasing curve radius.

Decreases in curve radii results in decreases in curve entry speed and increases in curve cutting, as shown by Gawron and Ranney (1990) by the use of a driving simulator, with which was also extracted the vehicle lateral distance.

2.6.1 Task analysis on curve driving

An extensive study by Campbell et al. (2008) here reported has been made in order to identify the basic activities that drivers would typically be engaged in when trying to safely navigate horizontal curves. Figure 6 shows the different curve segments, as identified by Campbell et al. (2008), as well as the most important driving tasks and constraints. This is

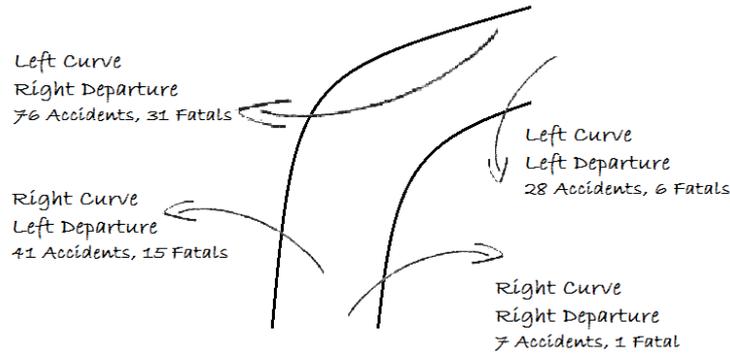


Figure 4 Based on the figure shown in The Michigan Department of Transportation study on tree-vehicle crashes (1979)

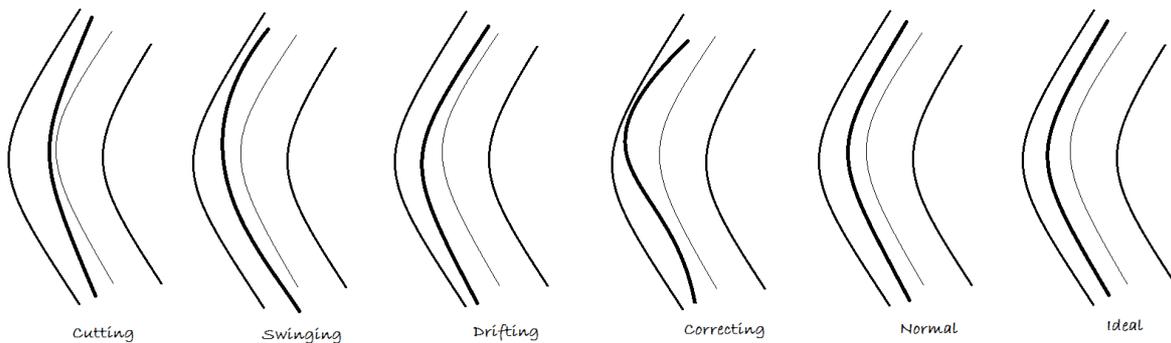


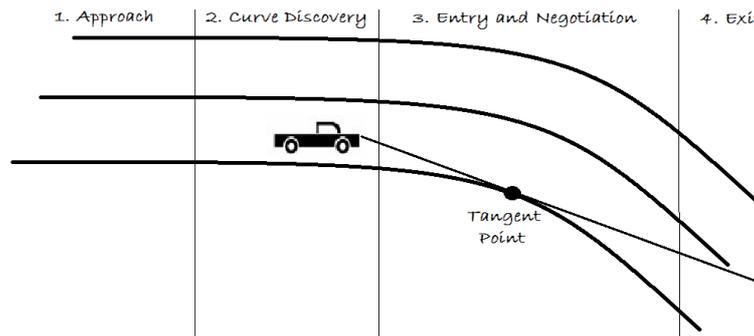
Figure 5 Outside lane vehicle trajectory classifications, based on the figure shown in (Spacek, 1998).

an example of a theoretical study about taking a curve in a safe way. Since the process of taking a curve rapidly becomes an automatic process, it is important to be aware of the fact that the whole process can be divided and analyzed in different steps.

Visual and vehicle-control demand are the first important concept for understanding the curve driving task. They refer to the extent of time that drivers are required to focus their attention on curve driving activities. This includes actions concerning the acquisition of visual information and actions that allow maintaining vehicle control (Campbell et al., 2008).

Visual demands: they start from low time and effort spent, in order to acquire information needed to safely navigate a curve during the Approach segment, and there is an increasing visual demand during the Curve Discovery, in order to obtain information needed to judge the degree of curvature. During the Entry and Negotiation segment, visual demands are at their highest level, while drivers spend most of their time looking at the tangent point, in order to keep proper vehicle alignment position (Campbell et al., 2008).

Effective information modes: this concept from Campbell et al. (2008) is interesting and explains how different type of sign/delineator information should be used in different curve segments. For example, during the Approach segment, drivers have more time available to read complex signs (e.g., speed limit signals).



	1. Approach	2. Curve Discovery	3. Entry and Negotiation	4. Exit
Key Driving Tasks	1.1 Locate bend 1.2 Get available speed information from signage 1.3 Make initial speed adjustments	2.1 Determine curvature 2.2 Assess roadway conditions 2.3 Make additional speed adjustments 2.4 Adjust path for curve entry	3.1 Adjust speed based on curvature/lateral acceleration 3.2 Maintain proper trajectory 3.3 Maintain safe lane position	4.1 Accelerate to appropriate speed 4.2 Adjust lane position
Visual Demands & Info Sources	Low/Flexible <ul style="list-style-type: none"> Primarily environment driven 	Med. Increasing to High <ul style="list-style-type: none"> Curvature perception cues Observing roadway conditions 	High <ul style="list-style-type: none"> Most fixations to tangent point 	Low <ul style="list-style-type: none"> Vehicle position information
Effective Info Modes	<ul style="list-style-type: none"> Advisory/message signs 	<ul style="list-style-type: none"> Non-verbal (e.g., chevrons) and direct info (e.g., delineators) 	<ul style="list-style-type: none"> Direct info only (lane marking; raised markers) 	<ul style="list-style-type: none"> No constraints
Vehicle-Control Demands	<ul style="list-style-type: none"> None 	<ul style="list-style-type: none"> Anticipatory positioning Curve cutting 	<ul style="list-style-type: none"> Continuous heading adjustment 	<ul style="list-style-type: none"> Lane position adjustments
Primary Speed Influences	<ul style="list-style-type: none"> Previous roadway elements & signage 	<ul style="list-style-type: none"> Expectations & curvature cues 	<ul style="list-style-type: none"> Expectations & lateral acceleration 	<ul style="list-style-type: none"> Posted speed or expectations

Figure 6 The four steps, based on the image shown in (Campbell et al., 2008).

In the subsequent Curve Discovery segment, instead, non-verbal information, such as chevrons, are more effective because drivers spend more time examining the curve and have less time available to read and act on text-based information. During the Entry and Negotiation segment, instead, drivers spend most of their time looking at the tangent point, and only direct information presented there (e.g., lane markings) or information that can be seen using peripheral vision can be used to communicate information (Campbell et al., 2008).

Speed selection: it is based on two factors: driver expectancy and speed-advisory sign information. Also, curve perception is crucial in speed selection and inappropriate curvature judgments. Once drivers are in the middle of the curve, lateral acceleration and vehicle handling workload provide the primary factors for adjusting speed (Campbell et al., 2008).

Expectancy effects: the visual image of the curve and also the lane width heavily influence speed selection, and expectations based on previous experience with the curve and roadway (e.g., previous tangent length) are all significantly factors that can lead to wrong speed selection. The most effective time in order to revise driver expectancies (e.g., via signage), is prior to the Curve Discovery segment (Campbell et al., 2008).

2.6.2 Curve perception and speed selection

Prior to curve entry, choices for speed and path to follow are made by driver's perception of upcoming curve's radius. Speed information from signs is taken into account, but only partially influences the choice, which is primarily influenced by roadway features and the apparent radius of the curve. In the absence of experience with a curve, drivers rely on their

judgments about a curve to select a safe speed for curve entry, and this can result in adopting a curve entry speed that is faster than the appropriate one (Campbell et al., 2008).

Speed selection is also affected by the type of vehicle, driver, and roadway factors. For example, it can depend on the power of the engine of the car, in which case, thanks to a greater acceleration, but also a better braking power, the approach to the curve can be completely different among drivers. It is shown that experienced and middle-aged drivers tend to perceive speed in a less accurate way than younger and less-experienced drivers along roadway curves. Variation in vehicle speeds along a road curve is highly dependent on the level of curvature, and is one of the important factors in speed selection (Campbell et al., 2008).

In general, drivers tend to cut curves. Almost thirty-three per cent of drivers cut left-hand curves and twenty-two per cent cut right-hand curves. In order to compensate for this, drivers tend to follow a trajectory with a radius that is larger than the ideal one (i.e., radius at the centre of the lane), with the vehicle traveling within little distance between the edge line at its apex. Higher crash rates are correlated with vehicle path radius at the point of highest lateral acceleration (Campbell et al., 2008).

Sharper curves mean an increase in workload for the driver, which significantly affects average lateral position error. This can result in an increase in edge line encroachment on the inside lane. Hence sharper curves, narrower shoulders, and steeper grades are more likely to lead to centerline invasion. However, high curvature has the greatest adverse effect on crash rates in horizontal curves (Campbell et al., 2008).

2.7 Control of steering

Once having the theoretical bases about curves and trajectories, it's probably a good idea to have a look at the literature in order to find the best models that allows describing driving behaviors in curves. In fact, it would be useful to have models and hints to suggest to drivers in order to apply, in practice, what the theory of ideal trajectories says.

Speed, steering and position in the lane are the key elements in order to successfully take a curve, where speed and steering are variables and position in the lane is the result. For the control of steering, the major methods currently discussed are gaze sampling and tangent point strategies, as described by Kandil, Rotter and Lappe (2009) and here reported.

Gaze sampling relies on retinal flow information. During the movement of an observer in an environment with various objects, the representations of these objects on the retina change, resulting in the so-called retinal flow information. Some parameters can affect the exact flow of each object, for example in the case of a driver, the momentary heading direction and the speed of the car, but also the structure of the environment rather than the fact that the objects are static or move themselves independently (Wann & Land, 2000; Wann & Swapp, 2000).

Given the movement of the observer, some optic flow lines will be produced. A simple example is when we are moving on a straight street with the gaze focused on a point straight ahead on the road. In this case, the resulting flow lines produced will be straight. By contrast, if we fix a point to the left of the lane, flow lines will be bent to the right and curved away from the point of fixation (Kandil et al., 2009).

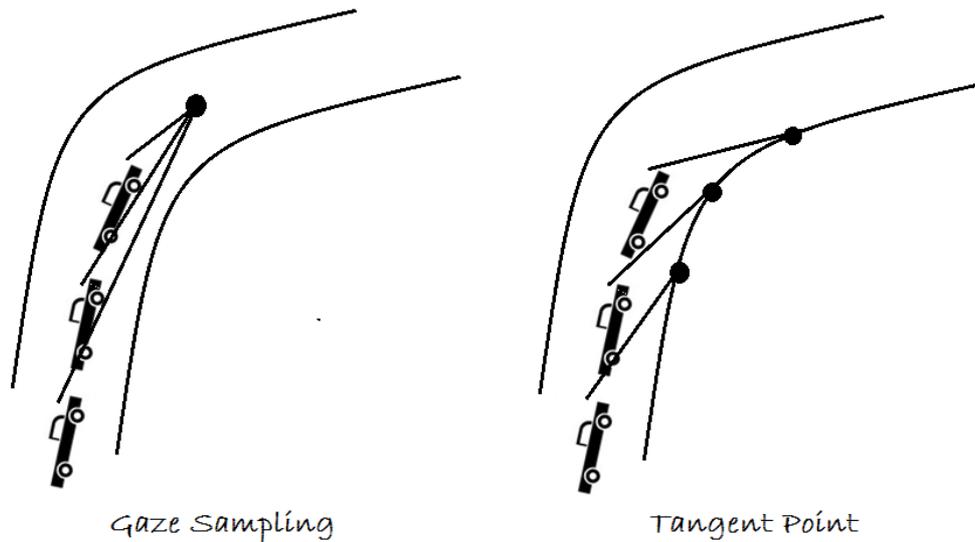


Figure 7 Gaze sampling and tangent point methods, based on the figure shown in (Kandil et al., 2009).

In order to use these flow lines for driving, drivers have to fixate a point that they want to traverse. If the steering is correct, then straight retinal flow lines should emerge. Understeering and oversteering, by contrast, will result in flow lines that will be curved out or bending into the curve, respectively (Kandil et al., 2009).

The tangent point strategy, conversely, does not rely on retinal flow, but rather on an estimation of the angle between the tangent point and the heading direction of the car in every moment. It is easy to detect deviations while one looks at the tangent point, keeping track of the tangent point itself and its position on the retina. The tangent point can be identified near the lane marking of the road or on the boundary between the asphalt and the verge (Kandil et al., 2009).

Here the task for the driver consists in fixating the tangent point (or an object near the tangent point) and estimating the angle between the momentary heading direction of the car and the tangent point itself. In order to obtain this, the driver can turn the steering wheel in a way so that the tangent point stays in a fixed position. Oversteering and understeering will let that point slip away and, in this case, the driver can steer in order to gain the desired position again (Kandil et al., 2009).

Studies comparing models with gaze sampling versus tangent point have reported different results. Some studies failed to replicate a very high percentage of tangent point fixations. For example, in a simulator study in which they compared free, fixed, and tracking gaze, Wilkie and Wann (2003) found no evidence for the use of the tangent point strategy. Another example is a more recent study made by Robertshaw and Wilkie (2008) which had the aim to revisit where people look when steering and to investigate whether imposed fixation of different road areas affects the quality of steering. So they carried out two experiments in virtual environments. In the first one, they investigated free-gaze patterns when steering with different widths and curvatures. In this case, they found that the gaze was mostly directed toward the center and the inside of the bend, with only a twenty per cent fixation of the tangent point. A second experiment was then conducted, where they enforced gaze fixation at specific points and noticed that fixating the tangent point zone did not bring a

significant improvement to steering compared to other fixation zones (Robertshaw & Wilkie, 2008).

Another interesting point in Robertshaw and Wilkie (2008) is their conclusion about the fact that, regardless of fixation condition, wider and curvier roads resulted in an incremented participants' tendency to oversteer. This finding is in line with real roadway situations where drivers usually use a corner-cutting strategy to negotiate curves, especially the narrow ones.

It might thus seem as if the tangent point method is not as effective as expected in some studies. However, this turns out not to be true. Kandil et al. (2009) argue that gaze sampling has never been tested in non-artificial scenarios. The point here is that flow lines that come out while driving in real streets are not as clear as in virtual reality, since the driver's head and body are moving due to the vibrations of the car caused by the imprecisions of the street. The sum of all these vibrations can result in problems in detection of curved flow lines. Kandil et al. (2009), then, aim at examining whether gaze sampling is used in successful curve driving and with what precision. They found confirmation for the hypothesis that the tangent point method allows the driver to drive in a smoother and more stable way than driving with the gaze-sampling method. Looking at the tangent point as orientation for curve driving allows the driver to stay closer to the ideal curvature as well as to take the curve in a smoother way, that is, with less unnecessary steering variation. The same has been found to be true for the car's lateral position in the lane. Moreover, the reliance on the tangent point has been observed for up to eighty to ninety per cent of the time. Gaze sampling, instead, showed a repetitive pattern of short periods of oversteering, with subsequent longer periods of understeering (Kandil et al., 2009).

As noted also by Kandil et al. (2009), there are some differences between studies performed in virtual reality and those performed in real streets. This can justify the differences between the results from Kandil et al. (2009) and the previous cited study from Robertshaw and Wilkie (2008) who, in disagreement with Kandil et al. (2009), neither found any evidence for extensive tangent point fixation nor any advantage as to more accurate steering thanks to the use of the tangent point method.

As concluded by Kandil et al. (2009), high average speed can introduce error factors such as variability in retinal flow that can render gaze sampling a very unreliable strategy for real-world scenarios. The tangent point method seems to be not only the default strategy for negotiating curves, but also, and even more important, the strategy that allows drivers to drive in a more safe and smooth manner through the curves. In contrast to virtual environment studies, the tangent point wins out against gaze sampling in these real-world experiments (Kandil et al., 2009).

Another study from Kandil, Rotter & Lappe (2010), this time on winding roads, was performed to compare tangent point method and gaze sampling. Results again shows that the time spent looking on the tangent point is high and increases with the closeness (shorter sight distances) of the bend, as well as a higher degree of curvature (Kandil et al., 2010).

3 Problem

As seen by previous chapters, horizontal curves and related crashes are an important problem nowadays. Drivers soon get used to the driving style that is the most natural for them, and driving becomes largely an automated process.

As shown by previously cited studies, the process of taking a curve can be divided in various steps, and can be seen as a trial-and-error process in which the driver tend to correct acceleration and lateral position in order to take the curve as comfortable and safe as possible. The ideal trajectory is about this, to take the curve at appropriate speed and minimize the probability of run-off-road or center-lane crossing accidents.

Despite all, curve cutting is one of the most common mistakes when taking a curve. This, in combination with high speed and other factors, can lead to subsequent center-lane crossing or almost run-off-road, and can easily lead to other mistakes in successive segments of the curve. Therefore, when it comes to horizontal curves and related trajectories, maybe a theoretical understanding of the problem can help drivers to get better and safer habits.

Hence, it would be interesting to correlate the field of serious games with the problem of the horizontal curves trajectories. Almost all previous works on horizontal curves involve the use of some kind of instrumentation to trace relevant data used in further studies (e.g. speed and lateral position during various points in the curve). This is one of the most important issues when trying to approach this field of study since the choice of such instrumentation have to be done carefully in order to obtain valid data (Fitzsimmons, 2011).

But this is where serious games shines, since the repeatability of complex experiments and collection of data are two strengths of this kind of games. The possibility to log player behavior, in fact, has a large potential in terms of debriefing and after action reviews.

How can those two fields be connected? The idea is to create a serious game in which the player is driving a car in a track with many horizontal curves to see if the use of the simulator can improve her or his driving skills with respect to the problem of ideal trajectories in horizontal curves. In order to obtain this, the player is initially introduced to the problem from a theoretical point of view, while driving in a simple track to become familiar with the controls and sensibility of the simulator.

As the literature shows, tangent point and gaze sampling are the methods actually in discussion and they both are good hints to suggest to drivers in order to help to apply the theory of ideal trajectories in the simulator. The choice of the tangent point method, despite the fact that it has been showed to perform poorer in virtual environments with respect to the other method in discussion nowadays, the gaze sampling (Robertshaw & Wilkie, 2008), seems to be a better solution because it is the natural strategy used in real life situations and also has been showed to perform better in order to drive closer to the ideal curvature as well as smoother during the crossing of the curve (Kandil et al., 2009). Since the purpose of the serious game is to transfer something to the drivers in order to achieve better driving behavior in real life, this method seems to be the most appropriate choice for the experiment.

The driver is then moved to the real track in order to start the experiment. At this point he or she is asked to drive as good as possible trying to follow the ideal trajectory in curves while

keeping the speed limits. In order to transfer the theory of ideal trajectories and tangent point method into the game, the driver will receive help in two different ways. In one case there will be the ideal trajectory drawn on the road, and in the other there will be a colored point near the tangent point in order to help the driver to focus the gaze and drive by the use of the tangent point method.

The focus of the study is to evaluate which representation and visualization leads to better driving performances in a car driving simulator with respect to the problem of the ideal trajectories in horizontal curves.

- Does the use of different kinds of feedback to the driver influence the driving behavior?
- Which representation is perceived as best?
- Does the preferred representation correspond to the one that leads to the finest driving performances?

With the purpose of evaluating and comparing the performance of the drivers, their speed and lateral position will be tracked since they are the best indicators for assessing driver behavior on horizontal curves (Stimpson et al., 1977). In order to give real time feedback to the driver, which is very important as shown by Rogers (2007), both the trajectory and the point will change color based on the lateral position of the car in order to give the driver the opportunity to dynamically correct the steering. The data gathered, combined with an opportune questionnaire aimed at receiving participants' feedback, will be subject to further study and evaluation in order to extract results and tendencies from the experiment.

The expectation is that, irrespective of the representation used, both can be perceived as useful in order to help the driver to drive better, but one can lead to better driving performances than the other. One potential practical implication is that the use of the simulator and of the serious game can result in some positive transfer to the participants who can use their new theoretical and practical knowledge somehow in a real life situation, in order to get better habits with respect to the problem of the ideal trajectories in horizontal curves.

The study is naturally divided in 3 principal phases that will be analyzed singularly in the subsequent sections, in order to describe and motivate the research method that will be used:

1. Study of the existent hardware and software infrastructure to evaluate what changes have to be done in order to carry out the experiment.
2. Implementation of the representation methods and of the track used for the experiment.
3. Execution and analysis of the required tests.

3.1 Simulation Hardware and Software

The hardware used for the experiment is the one described in Section 2.4. The use of a real car as simulator gives a considerable feeling of realism and hence is of absolute help in giving seriousness to the experiment.

Unity3D is the cross-platform game engine used for the development of the project. It was published in 2004, by Unity Technologies, and since then its popularity started to grow both in industrial environment and scientific community thanks to its flexibility and ease of use. Three programming languages are supported, C#, Javascript, and Boo. The behavior of each object, developed as a script, can be easily attached to the respective component in the scene since the development environment allows direct graphical editing of the game scenes.

The software utilized is based on the previous work from Franco (2013) and Procaccini (2013), which in turn is based on the CarTutorial demo available on the Asset Store. The CarTutorial project was originally chosen since it offered a solid base to work on. In particular, Franco (2013) and Procaccini (2013) carefully tuned the physics engine in order to get a realistic behavior of the car, that is, a Volvo S80 (Volvo, 2009). They also implemented a networking component absent in the original demo but needed given the client-server architecture of the hardware infrastructure. The result has been a reusable and expandable project fully compatible with the hardware infrastructure available.

Given the reusability as one of the goal for the project, as expressed by Franco (2013), it seemed more natural to extend the project instead of starting from scratch. After an initial period of study of the various components of the project, it has been easy to manipulate every aspect needed for the purpose of the experiment and to add new features where necessary.

3.2 Trajectory and representation of a point near the Tangent Point

Some possible representations have been evaluated and discarded before the decision on what representation use to the comparison. One possible choice, often used in serious games in order to give feedback to the player, is the use of on-screen messages during the various stages of the game. Despite their utility, particularly because one can write detailed information aimed at improving the player behaviour, the principal problem is the position of the message itself. Usually the message appears in the middle of the screen, and this can be somewhat distracting for the driver. To change the position of the message and make it appear near the tangent point seems another poor solution, since the time spent to read the message again can distract the driver during his driving task, especially if the message appears right before the curve, when the driver is engaged in estimating correct parameters in order to face the curve as good as possible.

One can argue that the use of the trajectory on screen can be as distracting as the message, but here the trajectory will serve only as a hint to the driver. In fact, the trajectory will dynamically change colour, and thanks to the peripheral view the driver can always keep his position relative to the ideal trajectory under control.

The use of a dynamically coloured point near the tangent point, instead, will serve not only as a hint in order to judge the position with respect to the ideal trajectory, but also to help the driver concentrate better on focusing his gaze near the tangent point. The change of color of both representations serves as dynamic feedback to the driver, and the importance of such kind of feedback is discussed by Rogers (2007).

The use of such kinds of representations is furthermore motivated by Campbell et al. (2008), who suggests how, in real life scenarios, only direct information presented where drivers are

currently looking or that can be seen using peripheral vision should be used to communicate to the drivers.

3.2.1 Catmull-Rom Splines

In order to represent the trajectory in the game, a reliable and fast piecewise approximation method was needed. Cubic splines, that is, approximating functions obtained by the concatenation of third degree polynomials, are one common choice often utilized in computer graphics given the good approximation at reasonable computation time costs. Beside this, Hermite splines and Catmull-Rom splines, a special kind of Hermite spline, can be defined such that they go through the defined control points (i.e., interpolate the points), as opposed for example with the quadratic Bézier splines.

The polynomial that defines a single Hermite curve is

$$H(t) = (2t^3 - 3t^2 + 1)P_0 + (t^3 - 2t^2 + t)M_0 + (-2t^3 + 3t^2)P_1 + (t^3 - t^2)M_1$$

for $t \in [0, 1]$.

Here P_0 and P_1 are the start and end point, while M_0 and M_1 are the tangent point for P_0 and P_1 , respectively. Hence the curve starts from P_0 in direction of M_0 with $t = 0$ and changes direction to M_1 reaching P_1 with $t = 1$.

Catmull-Rom splines specifies that the tangent vector m_k for the control point p_k is computed as

$$m_k = \frac{p_{k+1} - p_{k-1}}{2}$$

and $m_k = p_{k+1} - p_k$ for the first point and $m_k = p_k - p_{k-1}$ for the last point.

A script that evaluates the given control points with the Catmull-Rom splines function has been implemented and attached to each road piece in order to draw the ideal trajectory in the game. The position of the car, relative to the various control points allow to dynamically change the colour of the line or the points based on the driver performance and this data has been collected for the evaluation of the driver performances.

3.3 Method

An experiment with human drivers has been set up in order to gather the required data for the subsequent study. In this experiment, drivers were asked to drive in a series of horizontal curves in the safest and most comfortable possible way, while the different representation methods try to help the drivers to accomplish the task in a better way. During the test, all the necessary data has been gathered for further analysis and evaluation. Moreover, the subjects were asked for their feedback in a questionnaire in order to supplement the data gathered during the session. The questionnaire has been reported in Appendix A.

As seen by Section 2.6, there are four types of horizontal curves, and some are more difficult to cross than others. Simple curves are the simplest ones to go through. Reverse curves, instead, are the most demanding ones, and it is recommended to avoid their construction whenever possible. Compound curves are necessary on some kind of terrain, and Spiral curves have the purpose of provide a smooth transitioning between two different curves.

Given those observations, the test scenario developed was composed by all the different kinds of curves. Due to time limitations, since this study has been carried out together with other two experiments, Spiral curves sections have not been included in the test. Figure 8 shows an actual screenshot of the prototype developed.

Even if not explicitly designed in different levels, the scenario has the different group of curves in different locations, and the driver goes from one location to another in a level-game fashion. In order to avoid any bias caused by the order, the various sections were presented in a random order during the experiment. In particular, each participant has been asked to complete the test with both representations. Another possibility could have been to divide the participants in two randomly distributed groups, letting one group drive with the use of the drawn trajectory, and the other with the use of the drawn points near the tangent point.

The set of road pieces used contained pieces with different degree of curvature, and one straight line segment. In particular, left and right curves of 15° , 30° and 45° have been used. The duration of the whole test for each participant has been designed in order to be around the 7 minutes mark, since this study has been carried out in conjunction with other two similar experiments, and 20 minutes seems to be the time after which it is more likely to start develop simulation sickness, as observed by (Backlund et al., 2010).

Participants that already took part in the test were asked not to talk with the others waiting for their turn in order to not reveal the exact procedure of the experiment since this could somehow affect these subjects. Also, a document containing the basic information regarding the test procedure has been given to all participants in order to be sure that all had equal information. The transcript of the document has been reported in Appendix B. Other minor instructions were given by voice while the participants were sitting in the car.

Participants were recruited with flyers posted in the University of Skövde, hence a convenience sample emerged. No particular restrictions were applied for the participation.

Data gathered consisted in the lateral position of the car with respect to the ideal trajectory and relative speed for each frame. For the analysis, the Root Mean Square Error (RMS) gives a measure of steering precision. This allows an easy comparison between different driving performances in order to analyse and study the behaviour of the drivers.

To summarize, the experiment has been carried out as follows:

- Some volunteers were recruited with flyers posted in the University of Skövde.
- They gave their written consensus to take part in the test and received written and oral instruction on what the experiment consisted of.
- The experiment consisted in driving through a series of horizontal curves presented in random order, to avoid any bias caused that could affect the data. The various representations tried to help the drivers to accomplish this task in a better way.
- During the experiment, data about the lateral position and speed has been collected in order to be analysed afterward.
- At the end of the experiment, participants have been asked to answer to a questionnaire aimed at evaluating their experience with the simulator and their thought about the representations.



Figure 8 A Reverse curve and the use of points near tangent point and a Compound curve with the drawn trajectory as appeared in the actual prototype, highlighted by a white arrow for clarity.

3.3.1 Ethical Considerations

Given the potential problem with simulator sickness, participants were informed that they could stop the experiment whenever they wanted. Other than that, even if the data collected cannot be classified as sensitive, participants have been informed that all the data was gathered in an anonymous way and used for research purposes only. The participants agreed on the above conditions and gave their written and informed consent signing the document reported in the Appendix C.

3.4 Pilot Test

A brief pilot test has been conducted with three volunteers who gave their impression on the simulator experience. They were asked to perform as if it was the real experiment and a questionnaire was submitted with some specific questions regarding implementation details that have been adjusted and tuned afterwards before the real experiment. Also, an oral interview completed the session to get as much feedback as possible in order to improve the experience. In particular, one of the subjects did not own a driving license so it was interesting also to see how people with no driving experience could perform with the use of the simulator.

Analysis of the questionnaire shows that all the participants enjoyed the experience and did not had any problem in understanding what to do and how to drive the car. This is important, since it means that is easy to get comfortable with the controls and sensibility of the simulator. Even if the session was not logged and analysed afterward, all participants have been seen to perform in a safe manner without any particular error during the driving.

From the questionnaire it emerged that the trajectory drawn on the screen seems to catch the attention of the driver too much, and participants spent a lot of time fixing the gaze on the trajectory. Even if this means that this kind of feedback is working as expected, it should also be noted that looking almost exclusively at the drawn trajectory can be counterproductive since the natural choice for most of the drivers is to drive with the use of the tangent point method. In order to prevent an extensive fixation of the gaze to the drawn trajectory, participants in the real experiment will be explicitly informed that the trajectory drawn on the screen is only a hint and should be considered as such.

From the questionnaire it was found that the absence of G-Forces, which is one of the most important limitations of the available simulator, was not considered so important that it could compromise the feeling of realism and the sensation of being in a real curve too much. One last result from the pilot test was that the environment lacked of typical rural elements lowering the overall sense of realism of the simulation.

Given all the observation above and feedback collected by orally interviewing the participants, the following elements of the prototype have been changed for the real experiment:

- The drawn trajectory has been made narrower and more transparent. This and an explicit note on the instructions of the experiment had the aim of clarifying to the drivers that the drawn trajectory should not completely capture their gaze for the whole experiment, but rather it should be a hint used in order to improve their natural driving style.
- The environment has been enriched with some typical rural elements (principally trees and grass).

4 Results and Analysis

As anticipated in Section 3.3, the experiment has been conducted with the help of human subjects, who have been asked to drive in different sections of a rural road. Six segments and one brief test track in the beginning, aimed at improving the feeling and sensibility of the drivers with the controls of the simulator, composed the entire test. Except for the test track, where the driver was free to drive around without particular restrictions, three sections presented the drawn trajectory on the road, and the same three sections were also designed with the drawn points near the tangent point with the purpose of follow the ideal trajectory through all the experiment. In order to avoid any bias to the data, the various sections were presented in random order for each driver.

In the next section, some results emerging from the feedback obtained via the questionnaire submitted to each participant to the experiment, then the following sections will deal with the detail of each studied features as well as the analysis of the driving data gathered with relative analysis.

4.1 General Consideration

29 subjects were studied, with ages ranging from 19 to 33 (mean 24.7). 23 were male and 6 were female. Subjects are of different nationalities and all except 3 owned a driving license. They were asked to rank general experiences and perceptions with a 1-7 Likert scale. Given the young mean age of participants, a mean of 5.9 years of driving experience and a mean of 1 hour per day of driving emerged. Even if the mean age was young, the participants rated themselves high with regard to their experience in taking curves (mean 4.9). None of the subjects except 3 had ever accidents during curves (e.g. center lane crossing or run off-road). 9 of the subjects had heard about ideal trajectories before, and 6 of them also had some theoretical knowledge about the subject. Regarding the participants without driving license, they were initially included in the experiment in order to see if there could be significant differences between their driving performances and the results of the experiment on them compared to the others. During the experiment, it have been observed that their driving performances were in line with the other participants, hence, as no particular differences could be noticed, they have been included in the analysis with the others as well.

Subjects rated themselves generally high also in the questions regarding their experience in real life driving, driving videogames and driving with the use of a simulator (mean 5 out of 7 for all the three questions). It also emerged that the experience with the simulator was really enjoyable (mean 6.2). In particular, the question regarding participants' experience in driving videogames is based on the work of Backlund et al. (2010), in which a positive correlation between gaming and some skilled oriented aspects of driving emerged. In a way similar to the one followed by Backlund et al. (2010), the idea was to divide participants into two groups based on their own rating regarding driving games. Subjects who rated themselves with 1-2 (out of 7) were considered "non-gamers", while subjects who rated themselves with 6-7 (out of 7) were considered "gamers". The analysis then would have compared the two groups in order to evaluate the presence of significant differences. Unfortunately, only 1 participant rated himself with a rating of 1, while 14 subjects rated themselves with a rating of 6-7. Given the small size of the "non-gamers" sample, the analysis has not been carried out from this point of view.

Table 1 Average ratings for the questions regarding the representations.

Question	Trajectory	Points	P (t-test)
Caught attention too much	5.4	4.6	0,02*
Useful in order to drive better	5.4	4.4	0,04*
Behaviour changed because of the representation	4.7	3.7	0,01*
General usefulness of the representation	5.5	4.9	0,13
Followed the ideal trajectory	5.0	4.7	0,12
Drove in a safe manner (e.g. with respect of speed)	4.0	4.5	0,17

* $p < 0.05$

Even if in general this experiment was not perceived as tiring (mean 2.1) and the sickness level after the experiment was rated low (mean 2.2), it has to be noted that since this study has been carried out in conjunction with two other similar experiments, the combination of all the three sometimes felt a little too much stressing for some of the subjects. In particular, one of the subjects refused to take part in this experiment since he felt particularly sick from the previous one, and sometimes some of the subjects took a longer pause than others between each experiment in order to rest a bit more. No particular problems have emerged, and in any case participants were free to interrupt the experiment whenever they wanted.

4.2 Comparison between the two representations

Some of the questions asked to the participants were aimed at evaluating their perception of the representations utilized to help them in following the ideal trajectory. As stated before in Section 3.2, the ideal trajectory drawn on the screen and the presence of some points near the tangent point were the representations tested. Table 1 summarizes those questions.

The first information that emerges is that the drawn trajectory catches the attention of the drivers more than the drawn points (mean 5.4 and 4.6, respectively). This appeared also from the previous Pilot Test and, while the trajectory has been made more transparent and narrower than it used to be at that time, it still seems to attract the gaze of the drivers too much. Spending a lot of time fixing the gaze on the drawn trajectory, especially in curves, can distract the drivers from fixating their gaze to the tangent point and in this sense this kind of feedback can result counterproductive.

The perceived influence of the drawn trajectory on the driving behavior of the participants is also higher than the one from the drawn points (mean 4.7 and 3.7, respectively). This is in accord to the results of the previous question, since the representation that was most noticed and caught the attention of the participants is also the one that have a major impact on their perceived driving behaviors. This can mean that in order to introduce a different, better behavior in the driver habits, a constant feedback should be always present on the screen. The drawn trajectory, in fact, was constantly rendered, even in the straight sections, while the points appeared only during curves. It was not taken into account that the drawn trajectory could have helped in positioning on straight sections before the curves, but actually that could have helped out the drivers in a certain way.

As an overall result, participants perceived that between the two representations, drawn trajectory is superior in order to help in driving better with a mean of 5.4, whereas the

positive influence of the points has a mean of 4.4. Although not statistically significant under a two-tailed paired t-test ($p < 0.05$), when asked to rate the general usefulness of the two kinds of feedback and representation, drawn trajectory has emerged to be valued higher with a mean of 5.5, while the points obtained a mean of 4.9.

Finally, even if not statistically significant, from the participants' impressions emerged that the trajectory they think they followed thanks to the drawn trajectory is nearer to the ideal one compared to the one followed with the use of the drawn points (mean 5.0 and 4.7, respectively). On the contrary, and again without a statistically significant difference, the perception of the participants regarding the general safeness of driving is in favor of the use of drawn points (mean 4.5 versus 4.0).

4.3 Data Log

As anticipated in section 3, with the purpose of comparing the drivers' performances, their speed and lateral position has been tracked for each frame during the simulation. As noted by Stimpson et al. (1977), those two parameters are the best indicators for assessing driver behavior in horizontal curves. With the lateral position data available, in order to have a measure of steering precision, the Root Mean Square Error (RMS) has been calculated on such data. Even if straight sections data have been recorded, they have been excluded from the analysis.

Figure 9 shows an overall view of the drivers' performances. Simple, Reverse and Compound curves sections are compared with respect to the two representation used, the points and the trajectory.

During the course of the experiment, a general difficulty for the participants in estimating their speed has emerged. This problem was already noticed by previous studies on the same simulator. In particular, Franco (2013) and Procaccini (2013) reported on the difficulties of speed perception in this simulator. Since the perceived speed is lower than the actual one, this resulted in some participants trying to take curves at excessive speed, and this fact generated considerable noise in the data, with the result that the mean average speed resulted very high for some of the subjects.

In order to analyze the impact of the speed on the performances of the drivers and hence on the experiment, participants have been divided in 3 groups based on their mean speed. In particular, the first group has a mean speed of 90 km/h or less, the second group a mean speed between 91 and 110 km/h, and the third group a mean speed above 110 km/h. 9, 11 and 9 subjects composed the three groups, respectively.

Figure 10 shows the data divided by mean speed and averaged across all the sections. This gives a general idea on the impact of the speed on drivers' performances. Finally, the data divided by mean speed and for each section has been reported in Figure 11 in order to evaluate the differences between each section considering the speed.

Difficulties in estimating correct speed emerged also by the questionnaire, where at the question "Do you think you get a good perception of speed during the simulation?" a mean of 3.7 emerged. Among all the factors that influence the speed perception in this simulator, one of the participants pointed out that the presence of manual gears instead of automatic ones

could have contributed in a better speed perception since people are more or less aware of the speed that is achievable with each gear.

Besides this complication, participants did not find particular problems in understanding what to do in the experiment (mean 1.93) and the car was judged to be not so hard to handle during curves (mean 3.1). In general, the experience has been rated with a good grade of realism (mean 4.9), but the absence of G-Forces has impacted the realism (mean 4.9) as well as the previously mentioned low perception of speed.

4.4 Analysis

The first fact that emerges from Figure 9 is that the use of drawn trajectory generally leads to a better driving behavior with respect to the other representation used, the drawn points. In particular, in the Simple curves section, the difference between the two representations is negligible, but in the Reverse and Compound sections the use of a drawn trajectory obtained a performance noticeable closer to the ideal trajectory. It also emerges that the use of drawn points leads to similar performances in the Reverse and Compound sections, while the use of drawn trajectory seems to help out in the Reverse one. Compound section has been the most difficult one with the use of drawn trajectory, while with the drawn points both Reverse and Compound sections have been the most problematic ones.

It has to be noted that the use of the Root Mean Square Error (RMS) does not take into account the direction of the error, that is, if the driving was biased toward the inside or outside of the bend. In order to find out if the behavior of the drivers was more positively biased (oversteer) or more negatively biased (understeer) the Constant Error (CE) has been calculated on the data. In all the cases a positive bias emerged, hence a tendency of the drivers to oversteer. This, as reported by Robertshaw and Wilkie (2008) and Campbell et al. (2008), is in line with the real life situation where drivers usually tend to cut curves. The choice of such cutting curve behavior is usually adopted in order to minimize speed reduction (Felipe & Navin, 1988).

Given the problem with the low speed perception, as expressed in Section 4.3, the available data has been divided according to the average speed. Figure 10 shows how, in accord to previous findings, the drawn ideal trajectory leads to driving closer to the ideal trajectory. As expected, increased speed leads to worse driving performance. Again, the Constant Error (CE) shows a tendency of the drivers to oversteer.

Going deeper into the analysis, as can be seen from Figure 11, the general tendency according to which the use of drawn trajectory leads to better driving performances is respected in all the cases except one. Only in the Simple curves segment with low speed, in fact, the use of drawn points resulted in slightly better driving performances than the use of a drawn trajectory. As an overall result, as already noticed before, a pattern can be observed in which the use of a drawn trajectory is better than the use of drawn points. Data also shows that the Simple, Reverse and Compound sections are increasingly difficult in this order. It is also interesting to notice that the use of a drawn trajectory in the Reverse segments leads to a driving precision comparable to the one obtained by the use of the same representation in the Simple section, and is slightly better than the performance obtained by the use of drawn points in the Simple section. Also, the use of drawn trajectory led to better driving performances in all the Compound sections with respect to the Reverse sections with the use of drawn points and the same speed. The combination of high speed and the use of points led

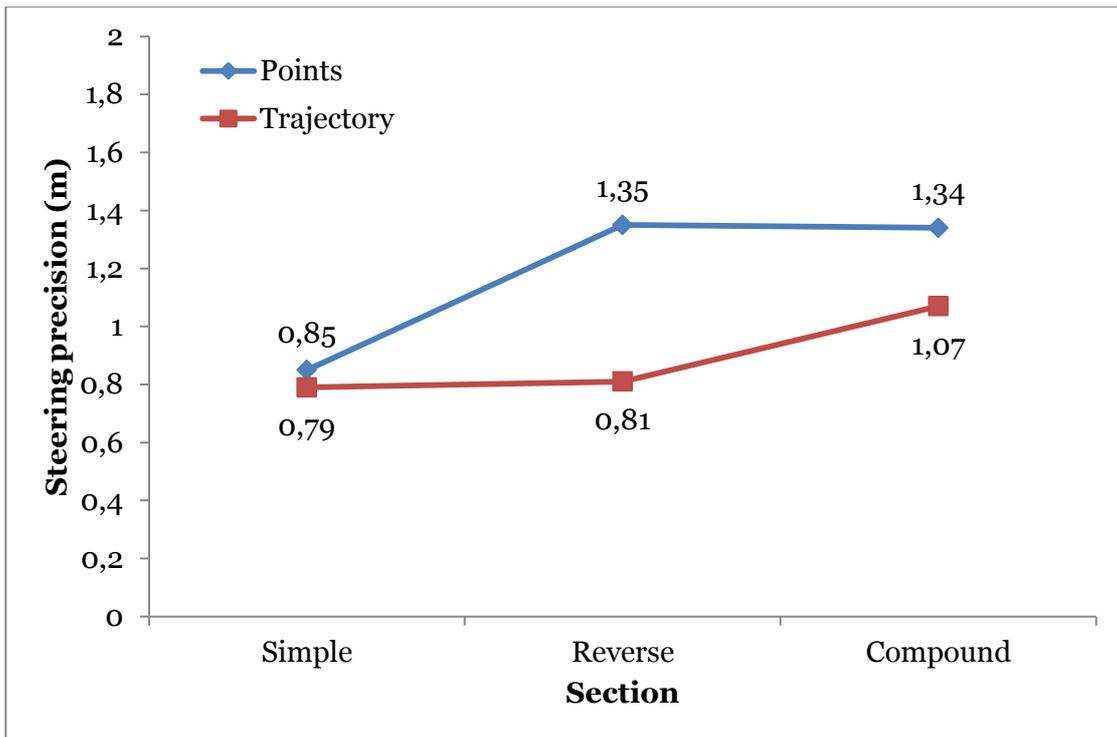


Figure 9 Steering precision by the use of the Root Mean Square Error (RMS), divided by the various horizontal curves sections.

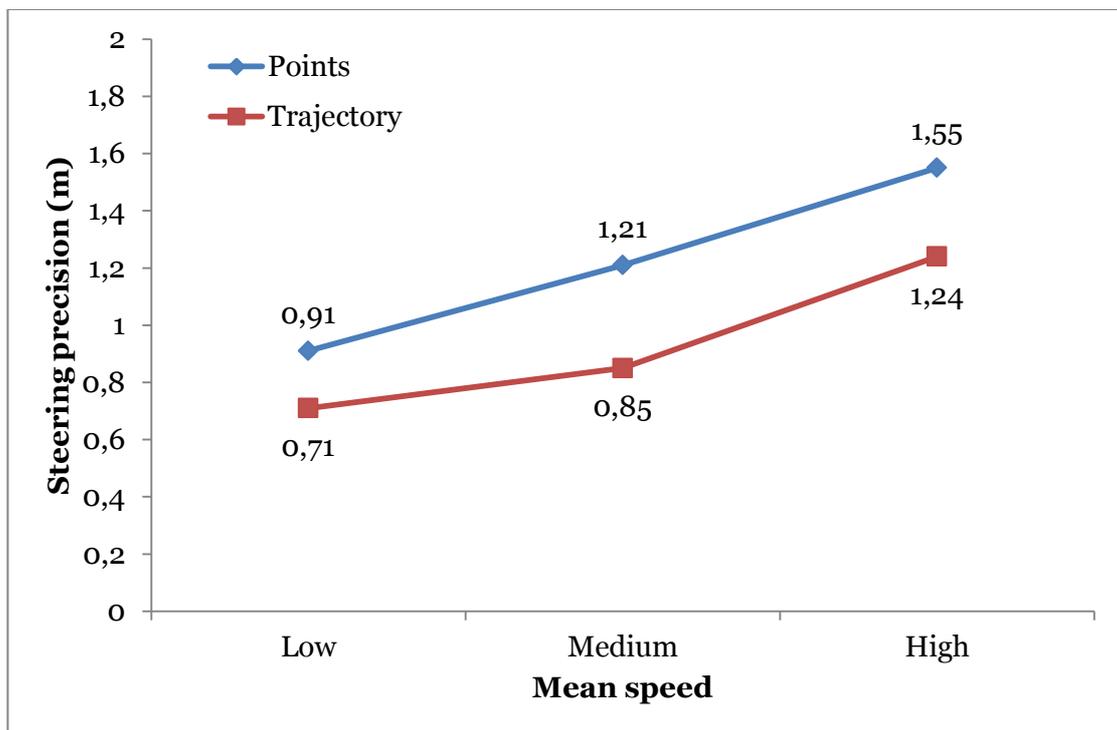


Figure 10 Steering precision by the use of the Root Mean Square Error (RMS), divided by mean speed of the participants. The data has been averaged across all sections.

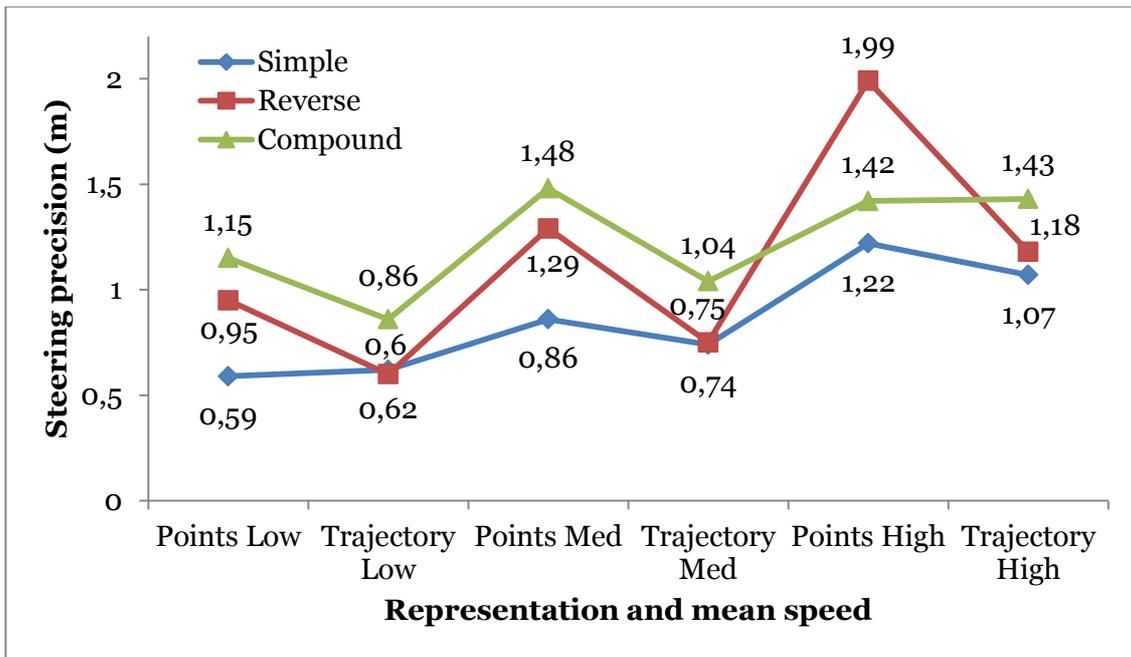


Figure 11 Steering precision by the use of the Root Mean Square Error (RMS), divided by mean speed of the participants. Each segment and relative representation utilized has been reported.

to a particularly bad performance in the Reverse section but no particular evidence can be observed from the data in order to explain the results on the use of drawn points with high speed in the Reverse section.

Even if the data gathered has been constantly affected by a low speed perception and hence drivers often tended to drive with excessive speed, causing some bias in the data resulting in oversteering over the natural tendency, a clear pattern can be found in which the use of drawn trajectory helped out the drivers in keeping a lower distance from the center line. The approach speed while taking curves has obviously a great impact on how the driver behave in the subsequent segments of the curve, but in this case the high speed affected the use of both representation and hence the error was present in both the representations evaluated. To conclude this section, it can be noted how some of the participants thought that they learned something relevant to driving from this experiment, while other did not perceived the same (mean 4.1).

5 Conclusions

In this section a summary of the obtained results will be presented, as well as a discussion on the knowledge contribution of this study. Some proposal for future works related to this one and future areas to be analysed are also presented.

5.1 Summary

The purpose of this work was to evaluate the differences in perception and performance of two kinds of feedback in a driving simulator aimed at improving driving behaviour with respect to following a trajectory close to the ideal one. The representations used were the drawn ideal trajectory and the use of some points near the tangent point.

29 volunteer subjects took part in the experiment for the evaluation which consisted in driving in a rural road through various sections which presented various types of horizontal curves. In particular, three sections with Simple, Reverse and Compound curves were tested. At the end of the session, each participant has been asked to leave his feedback on an opportune questionnaire aimed at evaluate the subject perception of the two representations, as well as a general opinion on the experience as a whole. This, combined with the driving data gathered during the experiment, has been subject to evaluation in order to compare the two representations used.

Objective of the work was to find out if the use of such kind of representations can influence the driving behaviour and if one of the two is perceived as best by the participants. The questionnaire was aimed at answering those two questions. Furthermore, drivers' performances have been evaluated in order to analyse if the representation that is best perceived is also the one who led to better driving performances.

Analysis of the data, even if biased by a mean high speed caused by a general low speed perception, shows a clear pattern in which the use of drawn trajectory leads to performances closer to the ideal trajectory. This representation has also been valuated as better in the questionnaire, and hence from the available data it seems possible to say that this kind of feedback is better perceived and leads to better performances compared to the other one.

5.2 Discussion

The work is based on some solid foundations in which previous evaluations of learning effects in the same game-based driving simulator led to positive results (Backlund et al., 2010). Even if this work has not the presumption of being considered a complete serious game, some of the aspects typical of such category of games can be identified and others can be added in order to develop a more complete experience, as for example the use of a game task in order to enhance learning.

From a traffic safety point of view, the results show that something can be done in order to improve driving behaviour. In particular, more theoretical and practical knowledge about the subject of ideal trajectories in horizontal curves can result in a general improvement in drivers driving habits which can lead to a decrease in horizontal curves accidents and a better understanding of the dynamics involved during the negotiation of a curve. In fact, there are many theoretical studies about the subject, as for example the extensive report

from Campbell et al., (2008), but none of them has a practical implication aimed at improving driving behaviour.

The knowledge shown in this work about the fact that the presence of some kind of feedback can improve driver behaviours in a complex task such as curve negotiation can lay the foundations on which other similar works based on this one or with different kind of feedback and representation can be carried out in order to have a clearer prospective on the subject.

5.3 Methodological considerations and limitations

The design, implementation, testing and evaluation of complex driving scenarios are difficult and many can be the possible sources of noise. For the purpose of this work, the principal source of bias has been a low speed perception of the simulator that mined the experience of some participants. This, combined to a “gaming factor” in which some of the testers may have been acted more like they would have done in a computer game rather than in a real life situation, even if clearly stated to drive as in the latter situation, could have contributed the most to add noise to the data. In order to address the problem of the low speed perception, one possible solution could have been to let the car accelerate automatically, until a certain appropriate speed, in the various sections, leaving at the participants the task to only brake and turn. This possibility has been taken in account during the design of the experiment but has been discarded since it seemed really limiting in terms of realism of the experience for participants.

The objective of the drawn trajectory is to keep track of the lateral position using the peripheral vision. It would have been interesting to have the possibility to track the gaze of the participants in order to calculate the exact percentage of fixation of the gaze for each zone of the road, especially on curve segments. The possibility to track participants’ eyes movements with a camera and to analyze the recordings afterward has been taken into account, but has been excluded due to time limitations, and no other eye movements tracking system was available. This is one of the major limitations of this study.

5.4 Future Work

As it is, the work is far from being considered complete, and much can be done in order to add more seriousness to the experiment. On a small scale, many details can be implemented aimed at facing the problem of low speed perception of the simulator. For example, the use of some game elements such as sounds when exceeding in speed or when invading the other lane. The use of audio elements can also be added in order to give voice instructions to the drivers, in a way similar to a GPS device. Another possible improvement is to change the colours of the feedback not only based on the position with respect to the ideal trajectory, but also based on the speed of the car. These suggestions, even if aimed at alleviating the problem of speed perception of the particular simulator used, can also have a general positive impact on the perception of the feedback. The use of some sort of eye-tracking system is also suggested in order to have more clear and reliable data on the precise gaze fixation used during the experiment. Another possibility is to add other vehicles in the scenario in the opposite lane. This can be useful in order to reduce the high sense of comfort that some of the participants could have experienced when they realized that no other vehicle was present in the environment, and that could have influenced their driving



Figure 12 The use of a Head-Up Display in order to highlight the side of the road in presence of fog. HUD system photo: General Motors. Taken from <http://www.wired.com/2010/03/gm-next-gen-heads-up-display/>



Figure 13 The application Hudway (<http://www.hudwayapp.com/>) shows how is possible to use the augmented reality to show information on the windshield of a car.

performance. Finally, as stated before, the addition of one or more game tasks can be considered in order to enhance learning.

A sample with a sufficient amount of subjects which can be divided between “gamers” and “non-gamers”, as discussed in Section 4.1, can be studied in order to carry out an analysis on those two categories of subjects. As shown by Backlund et al. (2010), significant differences can emerge between those two groups. In this case, it would be interesting to study if the impact of the representations is the same, and if there are differences in driving improvement aspects between the two categories.

A different route in which the representations are refined based on the Gibson’s affordance theory (Gibson, 1986) can be explored. In that case, a further investigation on how the study can be conducted in accord to Gibson’s theory could be needed.

On a big scale, the current work can be one of the elements of a bigger project aimed at improving and teaching rules about traffic safety to young drivers. One possible idea could

be the presence of a driving simulator aimed at improving the driving behaviours in a driving school. Hence, when people are not yet allowed to drive real cars, the use of the simulator can give a general view of what to expect from real driving. Of particular interest, typical of the serious games, would be the possibility to repeat particular situations in dangerous scenarios such as environments with the presence of heavy rain, fog or snow. In this case, the presence of a feedback aimed at improving the lateral position of the car in the lane would be only one of the possible suggestions to the driver which would have been involved in a more complex scenario with other aspects to learn.

Another idea, this time aimed at carrying out the same experiment in a real life setting with the use of feedback is about the use of a windshield as a Head-Up Display. Figure 12, for example, shows how is possible to use a Head-Up Display in order to highlight important elements of the road. The same possibility could be reached using a smartphone and an augmented reality application in order to accomplish the same purpose. Figure 13 shows how it is possible to display information on the windshield of the cars.

References

- Alexander, J., Barham, P., & Black, I. (2002). Factors influencing the probability of an incident at a junction: results from an interactive driving simulator. *Accident Analysis & Prevention*, 34(6), 779-792.
- Alluisi, E. A. (1991). The development of technology for collective training: SIMNET, a case history. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, 33(3), 343-362.
- Asplundh Environmental Services., Holewinski, D. E., Zeigler, A. J., Michigan., & United States. (1979). *Guidelines for removing hazardous trees from highway rights-of-way: A management manual*.
- Backlund, P., Engström, H., & Johannesson, M. (2006). Computer gaming and driving education. In *Proceedings of the workshop Pedagogical Design of Educational Games affiliated to the 14th International Conference on Computers in Education (ICCE 2006)*, 9-16.
- Backlund, P., Engström, H., Johannesson, M., & Lebram, M. (2010). Games for traffic education: An experimental study of a game-based driving simulator. *Simulation & Gaming*, 41(2), 145-169.
- Breuer, J. S., & Bente, G. (2010). Why so serious? On the relation of serious games and learning. *Eludamos. Journal for Computer Game Culture*, 4(1), 7-24.
- Campbell, J. L., Richard, C. M., & Graham, J. (2008). NCHRP Report 600 B: Human Factors Guidelines for Road Systems, *Transportation Research Board*, Washington, DC.
- CarTutorial. [Online]. Available at <http://u3d.as/content/unity-technologies/car-tutorial/1qU>. [4 April 2014].
- Doherty, M. E., & Balzer, W. K. (1988). Cognitive feedback. *Human judgment: The SJT view*, 54, 163-197.
- Dutta, A., Fisher, D. L., & Noyce, D. A. (2004). Use of a driving simulator to evaluate and optimize factors affecting understandability of variable message signs. *Transportation Research Part F: Traffic Psychology and Behaviour*, 7(4), 209-227.
- Eddowes, E. E., & Waag, W. L. (1980). *The use of simulators for training in-flight and emergency procedures* (No. AGARD-AG-248). Advisory Group for Aerospace research and Development, Neuilly Sur Seine, (France).
- Ekanayake, H., Backlund, P., Ziemke, T., Ramberg, R., & Hewagamage, K. (2011). Assessing performance competence in training games. In *Affective Computing and Intelligent Interaction* (pp. 518-527). Springer Berlin Heidelberg.
- Enochsson, L., M. D., Bengt Isaksson, M. D., Tour, R., Kjellin, A., Hedman, L., Torsten Wredmark, M. D., & Tsai-Felländer, L. (2004). Visuospatial skills and computer game experience influence the performance of virtual endoscopy. *Journal of gastrointestinal surgery*, 8(7), 874-880.

- Evans, L. Traffic Safety. Bloomfield Hills, MI; *Science Serving Society*; 2004.
- Felipe, E., & Navin, F. (1998). Automobiles on horizontal curves: experiments and observations. *Transportation Research Record: Journal of the Transportation Research Board*, 1628(1), 50-56.
- Fitzsimmons, E. J. (2011). *Development and analysis of vehicle trajectories and speed profiles along horizontal curves*. PhD thesis, Iowa State University, Ames, IA.
- Franco, G. (2013). *Effects of AI on driving experience*. Master thesis, University of Skövde.
- Gawron, V. J., & Ranney, T. A. (1990). Curve negotiation performance in a driving simulator as a function of curve geometry. *Applied ergonomics*, 21(1), 33-38.
- Gibson, J. G. (1986). *The ecological approach to visual perception*. Hillsdale, N.J: Lawrence Erlbaum.
- Gunay, B., & Woodward, D. (2007). Lateral position of traffic negotiating horizontal bends. *Proceedings of the ICE-Transport*, 160(1), 1-11.
- Horberry, T., Anderson, J., & Regan, M. A. (2006). The possible safety benefits of enhanced road markings: A driving simulator evaluation. *Transportation Research Part F: Traffic Psychology and Behaviour*, 9(1), 77-87.
- Jenkins, J. M., & Rilett, L. R. (2005). Classifying passing maneuvers: a behavioral approach. *Transportation Research Record: Journal of the Transportation Research Board*, 1937(1), 14-21.
- Kandil, F. I., Rotter, A., & Lappe, M. (2009). Driving is smoother and more stable when using the tangent point. *Journal of Vision*, 9(1), 1-11.
- Kandil, F. I., Rotter, A., & Lappe, M. (2010). Car drivers attend to different gaze targets when negotiating closed vs. open bends. *Journal of vision*, 10(4), 24.
- Lager, A., & Bremberg, S. (2005). Hälsoeffekter av tv-och datorspelande: en systematisk genomgång av vetenskapliga studier [Health effects from computer games: A systematic survey of scientific studies]. *Swedish National Institute of Public Health*.
- Land, M., & Horwood, J. (1995). Which parts of the road guide steering?. *Nature*, 377(6547), 339-340.
- Land, M. F., & Lee, D. N. (1994). Where do we look when we steer. *Nature*. 369, 742-744.
- Land, M. F. (1998). The visual control of steering. *Vision and action*, 163-180.
- Land, M. F., & Tatler, B. W. (2001). Steering with the head: The visual strategy of a racing driver. *Current Biology*, 11(15), 1215-1220.
- Lebram, M., Engström, H., & Gustavsson, H. (2006). A driving simulator based on video game technology. *11th International Conference Information Visualization (IV'07)*, 908-916.

- Leitão, J. M., Moreira, A., Santos, J. A., Sousa, A. A., & Ferreira, F. N. (1999). Evaluation of Driving Education Methods in a Driving Simulator. *In proceedings of GVE 1999*, 159-164.
- Mitchell, A., & Savill-Smith, C. (2004). *The use of computer and video games for learning: A review of the literature*. Learning and Skills Development Agency.
- Orlansky, J., & String, J. (1979). Cost-effectiveness of flight simulators for military training. In *The Interservice/Industry Training, Simulation & Education Conference (I/ITSEC)* (Vol. 1979, No. 1). National Training Systems Association.
- Perkins, D. N., & Salomon, G. (1992). Transfer of learning. *International encyclopedia of education*, 2.
- Prensky, M. (2003). Digital game-based learning. *Computers in Entertainment (CIE)*, 1(1), 21-21.
- Procaccini, M. (2013). *Evaluation of the perceived sense of speed in a driving simulator*. Master thesis, University of Skövde
- Rakauskas, M. E., Gugerty, L. J., & Ward, N. J. (2004). Effects of naturalistic cell phone conversations on driving performance. *Journal of safety research*, 35(4), 453-464.
- Riemersma, J. B. J. (1981). Visual control during straight road driving. *Acta Psychologica*, 48(1), 215-225.
- Ritterfeld, U., & Weber, R. (2006). Video games for entertainment and education. *Playing Video Games-Motives, Responses, and Consequences*, 399-413.
- Robertshaw, K. D., & Wilkie, R. M. (2008). Does gaze influence steering around a bend?. *Journal of Vision*, 8(4), 18, 1-13.
- Rogers, J. *Adults Learning* (5th Edition). Buckingham, GBR: Open University Press, 2007. Copyright © 2007. Open University Press.
- Smith, D. L., Najm, W. G., & Glassco, R. A. (2002). Feasibility of driver judgment as basis for a crash avoidance database. *Transportation Research Record: Journal of the Transportation Research Board*, 1784(1), 9-16.
- Spacek, P. Fahrverhaltenun Unfallgeschehen in Kurven, Fahrverhalten in Kurvenbereichen. Institut für Verkehrsplanung, Transport Technik, Strassen-un Eisenbahnbaur, ETH Zürich, 1998.
- Staplin, L., Lococo, K., Byington, S., & Harkey, D. (2001). *Guidelines and recommendations to accommodate older drivers and pedestrians* (No. FHWA-RD-01-051,).
- Stimpson, W. A., McGee, H. W., Kittleson, W. K., & Ruddy, R. H. (1977). Field evaluation of selected delineation treatments on two lane rural highways. Report *FHWA-RD-77-118*, FHWA, U.S. Department of Transportation.
- Susi, T., Johannesson, M., & Backlund, P. (2007). Serious games: An overview. IKI Technical Reports; *HS- IKI -TR-07-001*. University of Skövde.

- Torbic, D. J., Harwood, D. W., Gilmore, D. K., Pfefer, R., Neuman, T. R., Slack, K. L., & Hardy, K. K. (2004). *Guidance for Implementation of the AASHTO Strategic Highway Safety Plan. Volume 7: A Guide for Reducing Collisions on Horizontal Curves* (No. Project G17-18 (3) FY'00).
- Unity3D. [Online]. Available at <http://unity3d.com/>. [4 Apr 2014].
- Volvo S80-Specs. *Volvo S80 technical specifications*. [Online]. Available at http://www.volvoclub.org.uk/pdf/s80/S80_2009_techsspecs.pdf. [4 Apr 2014].
- Yan, X., Abdel-Aty, M., Radwan, E., Wang, X., & Chilakapati, P. (2008). Validating a driving simulator using surrogate safety measures. *Accident Analysis & Prevention*, *40*(1), 274-288.
- Walker, T. M. (2006). NASCAR teen uses video games to become racer. USA Today. http://usatoday30.usatoday.com/tech/gaming/2006-06-14-nascar-teen-racer_x.htm. [4 Apr 2014].
- Wann, J., & Land, M. (2000). Steering with or without the flow: is the retrieval of heading necessary?. *Trends in Cognitive Sciences*, *4*(8), 319-324.
- Wann, J. P., & Swapp, D. K. (2000). Why you should look where you are going. *Nature neuroscience*, *3*(7), 647-648.
- Weinberg, G., & Harsham, B. (2009). Developing a low-cost driving simulator for the evaluation of in-vehicle technologies. In *Proceedings of the 1st International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (pp. 51-54). ACM.
- Wilkie, R., & Wann, J. (2003). Controlling steering and judging heading: retinal flow, visual direction, and extraretinal information. *Journal of Experimental Psychology: Human Perception and Performance*, *29*(2), 363.
- Wilkie, R. M., & Wann, J. P. (2003). Eye-movements aid the control of locomotion. *Journal of Vision*, *3*(11), 3.
- World Health Organization. (2010). *Global status report on road safety: time for action*. 2009. World Health Organization: Geneva, Switzerland: WHO Press.

Appendix A - User Questionnaire

1. General questions

- a. How old are you?
- b. What is your sex?
- c. How many years of driving experience?
- d. How many hours of driving per day on average?
- e. How would rate your gaming driving experience? (1 to 7, 7 being the best)
- f. How would rate your simulator driving experience? (1 to 7, 7 being the best)
- g. How would rate your real life driving experience? (1 to 7, 7 being the best)
- h. Have you ever heard about ideal trajectories in curves before? (Yes or No)
 - i. If yes, have you some theoretical knowledge about the subject? (Yes or No)
- i. How would you rate your experience in taking curves? (1 to 7, 7 being the best)
- j. Have you ever had accidents during curves (e.g. center lane crossing or run off road)? (Yes or No)

2. Post-session questions (regarding the drawn trajectory)

- a. Do you think the drawn trajectory caught your attention too much? (1 to 7, 7 you looked almost only at the drawn trajectory)
- b. Do you think the trajectory you followed (not the drawn one) was near the ideal one? (1 to 7, 7 being the ideal one)
- c. Do you think the drawn trajectory was useful in order to drive better? (1 to 7, 7 very useful)
- d. Do you think you drove in a safe manner (with respect to speed) with the trajectory drawn on the screen? (1 to 7, 7 very safe)
- e. Do you think your driving behaviour changed during the test because of the drawn trajectory? (1 to 7, 7 your behaviour changed a lot)
- f. How would you rate the usefulness of this kind of feedback (1 to 7, 7 very useful)

3. Post-session questions (regarding drawn points on the side of the road)

- a. Do you think these points caught your attention too much? (1 to 7, 7 you looked almost only at the points)
- b. Do you think the trajectory you followed was near the ideal one? (1 to 7, 7 being the ideal one)
- c. Do you think the drawn points were useful in order to drive better? (1 to 7, 7 very useful)
- d. Do you think you drove in a safe manner (with respect to speed) with the points drawn on the screen? (1 to 7, 7 very safe)
- e. Do you think your driving behaviour changed during the test because of the drawn points? (1 to 7, 7 if your behaviour changed a lot)

- f. How would you rate the usefulness of this kind of feedback (1 to 7, 7 being very useful)

4. Post-session questions (generals)

- a. Did you enjoy driving with the simulator? (1 to 7, 7 being the best)
- b. Did you have any sense of discomfort/sickness during the experiment? (1 to 7, 7 being very uncomfortable and sick)
- c. Did you have any sense of tiredness during the experiment? (1 to 7, 7 being very tired)
 - i. If you rated 4 or more in the previous question, in which point of the experiment did you start feeling tired? (beginning/middle/end)
- d. There were problems in understanding what to do? (1 to 7, 7 there were problems in understanding what to do)
- e. Was the car difficult to handle during curves? (1 to 7, 7 very difficult)
- f. Was that in general a realistic experience? (1 to 7, 7 very realistic)
- g. Do you think you have learned something relevant to real driving from this experiment? (1 to 7, 7 you think you learned something relevant)
- h. Do you think you get a good perception of speed during the simulation? (1 to 7, 7 if the perception seems good)
- i. Does the absence of G-Forces (e.g. lateral forces) impact too much on the realism of the experience? (1 to 7, 7 if the impact is very strong)

Any suggestion aimed at improving any of the previous points or the quality/perception of the game in general is welcome and can be left on this paper or you can talk directly with the experiment conductor.

Thanks for your collaboration!

Appendix B - Instructions for the Experiment

In this particular experiment, you will drive in various segments of road in a rural environment. Objective of the experiment is to evaluate two different kind of feedback aimed at helping the driver in the task of following the ideal trajectory in curves.

What is ideal trajectory? **Ideal trajectory is exactly the center-line of the road in every point of the curve.** Try to follow the ideal trajectory through all the experiment!

Initially, you will be placed in a test track. Feel free to drive around without particular restrictions. During this time is important that you gain sensibility with simulator controls while having fun around. At the end of the test track the real experiment will start. From now on, we kindly ask you to handle the various situations in the way that is more natural to you. Remember that the feedback you will receive is only supposed to help you in your natural driving style.

During all the session, some data about the way you drive will be gathered, and at the end of the experiment we are going to ask you some questions about the experience via a questionnaire.

Both the data gathered and the answers to the questionnaire will be anonymous and will be used by the research team for research purposes only.

Remember that you can stop the test whenever you want. In this case, please let us know why.



HÖGSKOLAN
I SKÖVDE

Appendix C - Informed Consent

We kindly ask you to participate in a test aimed at evaluating two simulators.

Participation is voluntary, and you can stop the test whenever you want. If that happens, we just ask you to tell us why.

Keep in mind that some people can experience simulation sickness, that is, some heavy discomfort when using the simulator for too long time. If this happens to you, let us know and we will stop the test.

Also, if you are affected or you think you can be affected by amaxofobia, that is, the fear of driving, you are discouraged to take part in the experiment.

The test consists in a series of driving sessions across different situations, which you are supposed to handle in the way that is more natural to you. During each session, some data about the way you drive will be gathered, and we are going to ask you some questions about your impressions.

The collected information will be used by the research team for research purposes only and the published results will be anonymous, with no possibility to trace it back to single individuals.

By signing this consent, you accept to take part in the test, and allow us to use the gathered information in the ways described above.

Date:

Test Subject:

Test Conductors:
