A Driving Simulator Based on Video Game Technology

Mikael Lebram*
University of Skövde

Henrik Engström†
University of Skövde

Henrik Gustavsson‡
University of Skövde

Abstract

This paper presents the design and architecture of a mid-range driving simulator developed at the University of Skövde. The aim is to use the simulator as a platform for studies of serious games. The usage of video game technology and software has been a central design principle. The core of the simulator is a complete car surrounded by seven screens. Each screen is handled by a standard PC, typically used for computer games, and the projection on the screens is handled by budget LCD-projectors. The use of consumer electronics, standard game technology and limited motion feedback makes this simulator relatively inexpensive. In addition, the architecture is scalable and allows for using commercial video games in the simulator.

Observations from a set of experiments conducted in the simulator are presented in this paper. In these experiments driving school students were instructed to freely explore a driving game specifically designed for the simulator platform. The result shows that the level of realism is sufficient and that the entertainment value was considered to be high. This opens the possibilities to employ and use driving simulators for a wider set of applications. Our current research focuses on its use with serious games for traffic education.

CR Categories: I.3.2 [Computing Methodologies]: Computer Graphics—Graphics Systems; I.6.3 [Computing Methodologies]: Simulation and Modeling—Applications

Keywords: driving simulator, virtual reality, computer games, serious games

1 Introduction

The use of simulators for training is an old and well accepted method used in situations where training in real environments is difficult, dangerous and/or expensive. In particular, simulators for civil and military air pilot training are well established [Rolfe and Staples 1988]. Computer based flight simulators have been used since the 1960's. In the light of this, the usage of car driving simulators is less common. There exists advanced simulators for traffic safety research [Kuhl et al. 1995; ITS 2006; Östlund et al. 2006] and there are some examples of simulators for driving education [INRETS 2006], but for the vast majority of drivers the training is solely conducted in real traffic environments. The potential advantage of using driving simulators in, for example, traffic education is that it enables generation of extreme situations or traffic environments not available in the student's surroundings.

Using simulators for drivers' education is different from pilot education in many ways. The volume of students involved in driving education is larger than that of pilot training. The cost associated with a driving training program is also much lower. This implies that simulators for drivers' education need to be less expensive in order to be widely adopted.

In the video game area, driving and racing has been a central theme for a long time. Since Night Driver (1976) [Atari 2006], the original first-person racing game, hundreds of racing titles have been released. In addition, car driving is a central activity in games of other genres as well. Over the last 30 years driving games has gone from relatively simple simulations in arcade-machines to highly realistic rally simulations that runs on an off-the-shelf personal computer (Figure 1).

Figure 1: 30 years of racing games. Night Driver [Atari 2006] (left) from 1976 and GTR II [SimBin 2006] (right) from 2006

Over the years the graphical quality of computer games has increased exponentially, the current level of detail of graphical models is sufficient for most training simulator purposes. In addition, video game developers have high skills in producing entertaining, immersive products that motivate their users to spend many hours a week [ESA 2005]. The games are sold as consumer products in large volumes which implies that the price is only a fraction of the price of a specialised simulator product.

The goal for the simulator presented in this paper is to utilize the developments in the video game area to create an advanced driving simulator using video game technology. This includes the use of standard of-the shelf soft- and hardware infrastructure as well as adaptation of commercial-of-the-shelf (COTS) games. The simulator is currently used to explore how serious games [LoPiccolo 2004; Zyda 2005; Blackman 2005] can be developed and used in traffic education.

This paper is organized as follows: In Section 2 we give a background presentation of driving simulator technology. In Section 3 we present the architecture and design of our driving simulator followed by Section 4 where we report experiences from using the simulator in a set of experiments. In Section 5 we draw conclusions and elaborate on the implications of our approach.

*e-mail: mikael.lebram@his.se
†e-mail: henrik.engstrom@his.se
‡e-mail: henrik.gustavsson@his.se

2 Background

Driving simulators are developed and used for research purposes mainly within the traffic safety context. The French national institute for transport and safety research presents a survey of simulators [INRETS 2006] including 50 simulators for research purposes, a handful for corporate purposes (e.g. car industry) and 20 driving training simulators. The research simulators are generally in the high-end with large budgets while the training simulators are typically low-range products targeted at driving schools.

A driving simulator is composed of a number of components, illustrated in Figure 2.

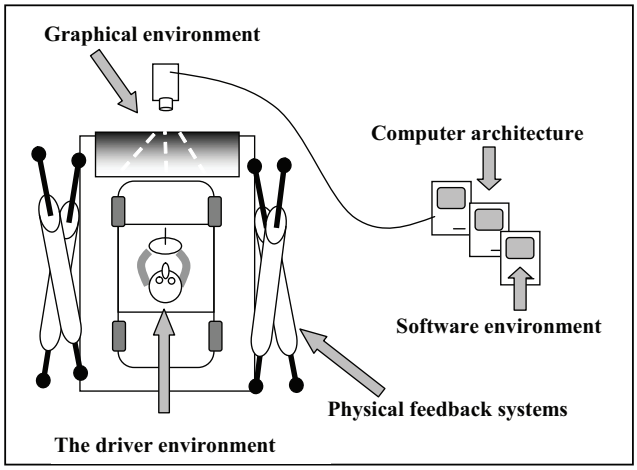

Figure 2: Components of a driving simulator

The driver environment may be more or less realistic ranging from an authentic complete car to a steering wheel (or even mouse and keyboard). The graphical environment renders the simulated world to the driver. It may differ in graphical quality, the size and range of the projection as well as the technology used to generate the view (CRT displays, 2D projection, 3D shutter-glasses etc.). The physical feedback system is responsible for generating other inputs to the driver, such as sound, motion and other haptic feedback. The computer architecture ties the various systems together and constitutes the platform for generating and monitoring the simulation by the software. The software available for a simulator is governed by the nature of the underlying systems. Specialised software may be needed if the underlying hardware is tailor made.

The most notable difference between high-end and low-end simulators is the physical feedback systems. The research simulators have large mechanical systems that generates g-forces in different directions. As an example, the *Leeds Advanced Driving Simulator* [ITS 2006] is a 4 million Euro project with a spherical projection dome. The driver environment and the dome are appended to a motion base that has 8 degrees of freedom. The simulator is hosted in a 14x12x7 meter hall. As a contrast *S-4150*, a basic training simulator from Simulator Systems International [SSI 2006], consists of a steering wheel and a CRT display in front of the driver. The simulator has clutch and brake and no physical feedback system. The cost of S-4150 is approximately 5 000 Euro.

In addition to the simulators mentioned above there exists a large number of ”driving simulators” in the shape of video games. We refer to these as gaming simulators. A gaming simulator may be an arcade machine designed to give an entertaining experience and not necessarily a realistic one. There however exists gaming simulators that are designed to produce a realistic driving experience. As an example, the GTR racing game has been developed by a racing team [SimBin 2006] with a goal to produce a highly realistic racing experience. For example, the simulation is so good that it is used by racing drivers to memorize courses [Björklund 2006]. The cost of a driving simulator composed of a PC, some CRT:s, a racing wheel and a game is typically less than 1 000 Euro.

3 The Driving Simulator

The goal of the driving simulator developed at the University of Skövde is to utilize the cost-effective and entertaining aspects from gaming simulators. The system is composed of 8 standard game PCs - 7 clients and a server. Each client is connected to a budget LCD-projector projecting on screens surrounding a real car. As the simulator is intended to be used for video games, the requirements on realism are somewhat different compared to high-end simulators used for traffic safety research. For games there is always an entertainment requirement that has to be considered. By using of-the-shelf hardware components it is possible to utilize game software and technology. We have successfully modified a number of COTS games to run on the simulator platform. In this section we present the architecture and design of the simulator.

3.1 The driver environment

The driver environment is a complete Volvo S80 with authentic controls and instrumentation. Figure 3 shows the driver environment.

Figure 3: The driver environment

The use of a real car provides a great deal of realism to the simulator. Users of the system have no problems in understanding the functionality of the interface to the simulator. In addition the feeling of being inside a car is a familiar situation which, for most people, is associated with a responsibility for the car and fellow road users. This brings a sense of seriousness to the driving.

3.2 Graphical environment

The graphics generated in the simulator is projected on seven flat screens as illustrated in Figure 4. These screens cover the whole field-of-view for the driver and the parts covered by the rear view mirrors. In the design phase an alternative solution, to back-project the graphics directly on the windshield, was rejected for a number

of reasons: Firstly this solution gives a very closed and flat projection where the external parts of the car are not visible. It is also not possible for the driver or passengers to move their heads to get a different perspective on the surroundings (e.g. if the windshield post is covering some part of the view). Another aspect to consider is the distance from the observer to the projected screen. The simulations are generated using window-projection [Cruz-Neira et al. 1992] that is computed from the perspective of the driver which means the passengers will experience a distortion. With the chosen solution the distance to the screens is greater and the distortion for passengers is acceptable. An additional advantage by using screens outside the car is that it enables the original rear mirrors to be used and it is possible for the driver to turn his head and look in the rear window. The latter is not possible when, for example, LCD-displays are used as rear mirrors.

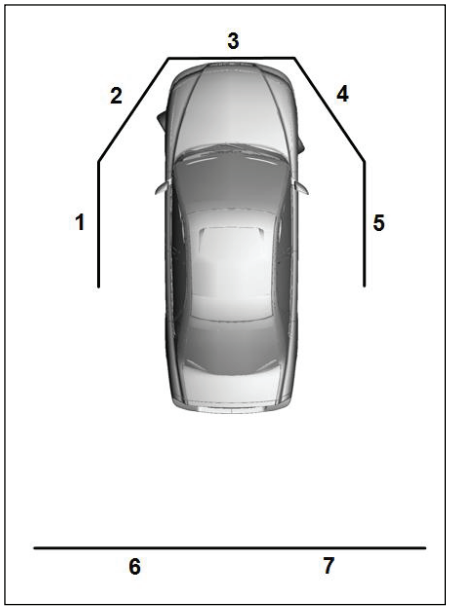

Figure 4: The simulator car surrounded by screens (1-7)

The projection on the screens is similar to that used in a Cave [Cruz-Neira et al. 1992]. The choice of rectilinear projection instead of cylindrical or spherical is mainly economical. Each screen is handled by a budget LCD-projector and as the screens are not projected seamlessly there are low requirements on the calibration. This also makes it possible to use a large number of screens and hence cover a larger fraction of the field-of-view, than is common in mid-range simulators. The forward visual field-of-view is 220 by 30 degrees, and 60 by 30 degrees in the rear direction. As a comparison, the high-end simulator used in [Peters and Östlund 2005] has a forward visual field-of-view of 120 by 30.

3.3 Physical feedback systems

The generation of physical feedback in a driving simulator may be extremely complex. The simulator at the university of Skövde adopts a fixed-based approach which means that no g-forces are generated. This is in total contrast with the mid-range simulator presented by Huang and Chen [Huang and Chihsiuh 2003] which emphasises on the motion system in favour of the graphical system and the driver environment.

The illusion of movement in our simulator is generated by the use of sound, vibrations and the car's fan. The sound is generated in the internal surround system of the car. In addition a "ButtKicker" [Guitammer 2005] is used to generate vibrations in the body of the car which are propagated to the whole car including the steering wheel. One important property relating to physical feedback in a driving simulator is the haptics of the steering wheel. In a car with servo-steering there is not as much movements as when there is a direct connection between the steering wheel and the tyres. The most important remaining physical property is that the wheels should strive to return to their original position. In the simulator this has been achieved by placing each front wheel on an axial ball bearing. Due to the steering axis inclination there will be a strive to return the wheels to a parallel position. In addition, the movements of the front wheels gives a notable movement of the car that can be considered to be a form of passive physical feedback.

The physical feedback component that possibly contributes most to the perception of speed in the simulator is the internal fan. It is controlled by the simulation and the force of the fan is linear to the speed of the car [Carraro et al. 1998]. When the driver is reaching a high speed the wind and the substantial noise from the fan contributes to create a high speed perception. It is well known that it is difficult to get a good perception of speed in computer generated simulations [Godley and Fildes ; Östlund et al. 2006]. The use of a fan is a simple but effective way to increase the perceived speed.

3.4 Computer Architecture

The computer architecture in the simulator consists of 8 standard gaming PCs equipped with a mid-range graphics card. One computer is acting as server while the other are clients each responsible for one screen. The clients and server are typically running identical simulations with the only difference that the server is sending synchronize messages to the clients. The clients differ only in the camera position used when rendering. The computers are connected in an Ethernet LAN. All hardware components are standard consumer products. The only tailored component of the simulator is the interface with the car [Mine 1995]. The movements of the steering wheel and other controls are monitored by microcontrollers that communicate with the server via a USB game control protocol. In this way the car can be seen as a highly specialised joystick. The advantage with this approach is that the simulator can be used with any computer game that supports joysticks.

3.5 Software Environment

As mentioned above, almost any computer game can be played on the simulator platform. In most situations it will however be limited to use only one screen. To utilize all 7 screens the software has to support multiple clients with adjustable camera positioning. The extensions required are hence very small and we have successfully managed to adjust several commercial games to be used in the simulator using multiple screens. In addition to using COTS games we have also developed an infrastructure based on an open source game engine. This allows for custom made simulation application and games.

4 Experiments

The simulator has been used in an experimental study with 24 driving school students as subjects. The gaming background of the students varied from inexperienced (13) to experienced players (5). The experimental setup was such that the subjects were offered as

much time they wanted (up to a maximum of 30 minutes) playing and exploring a game. This was followed by a number of evaluative tests where they were instructed to perform certain tasks, followed by a questionnaire. All simulations were monitored and logged.

The game used in these experiments is relatively simple. The player is driving on a five-lane motorway following an ambulance. The difficulty of the game increases by the intensity of the traffic and the behaviour of fellow road users. Although we had other main goals with these experiments, they have also provided some feedback on the performance of the simulation environment.

First of all, the subjects where extremely positive concerning the entertainment value of the simulator. In the questionnaire subjects were asked to specify how they agreed to the statement ”it was fun to drive”, on a 5-graded Likert scale where 1=fully disagree and 5=fully agree. The average for all subjects where 4.6 which is a very high result considering the relative simplicity of the game. This result may also be derived from the amount of time the subjects spent in the simulator. They were explicitly instructed to decide themselves when to stop driving. The result was that experienced gamers spent on average 29 minutes playing the game compared to 23 minutes for inexperience players. This is a statistically significant difference which is interesting as one may suspect that experienced gamers would not appreciate a game that is far from a state-of-the-art racing game. One possible interpretation is that the simulator platform itself contributed to the positive experience, in particular for gamers.

Concerning the realism of the game and simulator the average of the subjects was 3.6 for the statement ”the driving was realistic” (using a 5-gradet Likert scale). This is clearly above average which indicates that the simulator is efficient. Some users commented on initial problems with the control of the car. These initial problems do not seem to have had any negative impact on the overall experience and performance of the drivers. This can be confirmed from analysis of how the drivers managed to position their car in the lane (lateral position). Lateral position is commonly used for validation of driving simulators [Green 2005; de Waard et al. 2005]. Figure 5, illustrates the relative lateral position of the car during all experiments.

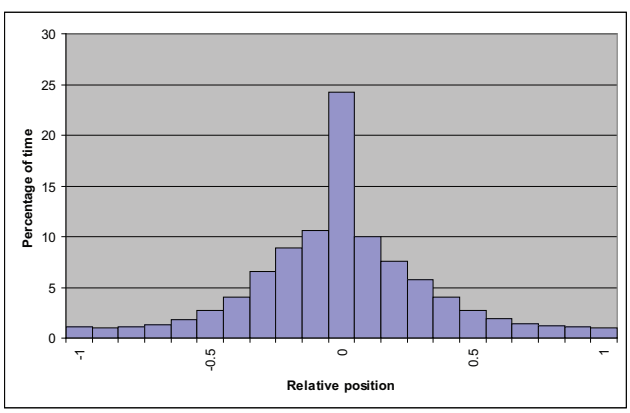

Figure 5: Histogram of the relative lateral position of the car

The total driving time for all subjects was almost 12 hours. The position of the car was sampled at 10Hz. The histogram in Figure 5 is based on all logs from all experiments (413 973 samples). The relative position of the car in the lane was divided into 21 discrete intervals. The histogram was created by summarizing the number of times the car was positioned in respective interval and then divide it with the total number of samples. Note that the recorded information only considers the relative position within the lane (irrespective of what lane the car was in). The tails in the histogram are due to lane changes and the gameplay is such that frequent lane-changes are required to succeed. In fact, the drivers changed lane on average every 15 seconds. The most notable property of the histogram is the large bar in the middle. Despite the frequent lane changes the drivers spent almost 25% of the time exactly centred in the middle of the lane. The central bar is moreover more than double the size of the surrounding bars. We interpret this as the drivers have intuitively managed to position the car very close to the centre of the lane. This implies that the visual representation gives a realistic impression of the position of the car. The rectilinear projection hence seems to work very well.

The use of original rear view mirrors also seems to be efficient. The subjects' use of the mirrors was monitored during experiments and the result shows that they used both the internal as well as the external mirrors frequently. In fact, the use of mirrors was more frequent than the lane-changing. On average the subjects used the mirrors every 10 seconds compared to 15 seconds for lane changes.

Simulator sickness (also termed cybersickness) is a well known problem in simulators and is related to motion sickness [Harm 2002; AGARD 1988]. As much as 30% of the users of simulators may experience symptoms severe enough to discontinue use [Harm 2002]. Simulator sickness is believed to be caused by confusion between the perceived motion and the actual motion [Bertin et al. 2004]. The problem seems to be difficult to totally eliminate, even for high-end simulators [Peters and Östlund 2005].

Since the simulator presented in this paper is a fixed-based system, problems with simulator sickness was not unexpected. These problems were however minor in the experiments. Four subjects (17%) reported sickness as one of the reasons they decided to stop playing the game. The average playing time of these four subjects was 21 minutes compared to 25 minutes for those that did not report any sickness problems. The relatively small difference in time makes us believe these subjects did not experience severe problems with simulator sickness.

5 Discussion

In this paper we have presented a driving simulator based on video game technology. Our approach has been to use relatively inexpensive hardware components to create a graphical system that surrounds a real car whose instrumentation has been adopted to be used as a game control. A main difference to high-end simulators is the modest physical feedback system. The presented simulator uses a fan, vibrations and sound in addition to the graphical feedback. The driving simulator has successfully been used in an experimental study. Observations from this study indicate that the simulator is efficient in that it creates a realistic and entertaining experience to the users. The absence of physical feedback does not seem to incur serious problems with simulator sickness. In addition the rectilinear projection gives a realistic perception of the simulated environment. This has been shown by analysing the lateral positioning of the car.

When developing a simulator one goal is to create a realistic experience. Realism comes to a price and with a limited budget the benefit has to be balanced with its price. In our approach we have decided to sacrifice the physical movement realism in favour of the realism of having a real car as the driver environment. We believe that the use of a real car is one of the key benefits of the presented simulator. The smell and touch of a car gets the driver in the mind-set of driving. In addition, our simulator allows for passengers, which is

a typical driving property which is neglected in many other simulators. The driving task is, for example, much harder to handle when there are two fighting children in the backseat.

The simulator architecture presented in this paper is flexible and scalable. For example, the number of screens used can easily be extended by adding a projector and a PC for each screen. The server can broadcast messages to all involved clients which mean that the total load of the system is in practice independent of the number of screens. Each PC handles the rendering of one screen which differs only in their camera positioning. The flexibility of the architecture is illustrated by the fact that we have successfully modified several COTS games to be playable on the simulator platform. The ability to adopt and use commercial software is important as the cost of software development may be huge. In future studies we plan to use COTS racing games whose graphical quality require budgets way beyond that of the simulator hardware.

To summarize, the contribution of the presented work is that we have combined the quality and cost-effectiveness of the gaming technology with the extensiveness of the mid-range to high-end simulators. We estimate that the hardware cost of the presented simulator is less than 20 000 Euro excluding the cost of the car.

In our ongoing and future research we will use the simulator to explore the potential benefit of using computer games in traffic education. We will test whether a serious driving game designed with the specific purpose of enhancing certain traffic safety variables is effective. The general idea is to combine the strengths of traditional simulators with the fun of games.

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