Low-cost Driving Simulator for Driver Behavior Research

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Abstract - *Driving simulator is an important tool for driving behavior studies. It offers a safe and replicable virtual driving environment where it is possible to create scenarios that are ethically, logistically and monetarily impossible to carry out in real environment. The development of simulator technology and especially the reduction of prices in certain key areas have made it possible to create low-cost driving simulators with the features that are usually found only in very expensive high-fidelity driving simulators. In this article a low cost driving simulator (pricing below € 20.000) for the research of the drivers' behavior is presented.*

Keywords: Low-cost, driving simulator, driver's behavior, motion-base, stereoscopic view, curved screen

1 Introduction

There are some commonly recognized reasons why simulation is used in driving performance or behavior studies. First, repeatability provides the researcher with the ability to study the phenomena numerous times, which in the real world would be hard to accomplish [1]. Second, safety plays a critical role when studying, for example, unexpected driving conditions or driving under the influence of alcohol. Third, tracking of the most operations of the driver becomes possible in a simulator [2], and fourth, a simulator enables the use of versatile research equipment, thus providing a comprehensive recording of multivariate data for detailed analysis. This was also the basis for the development of the present low-cost driving simulator.

Although simulation provides several benefits for research, it also generates a new problem known as simulator sickness. Simulator sickness has been reported to be less frequent in a motion based driving simulator compared with a fixed-based one [3], [4]. Slob [5] argues that the main reason why a motion system is important is the prevention of simulator sickness. Thus, one of the requirements for the development of the present driving simulator was that at least a moderate motion platform should be included.

There are impressive, high-fidelity driving simulators that mimic the real environment rather closely, such as NADS-I at the University of Iowa [6], Toyota's driving simulator [7], Daimler AG driving simulator [8], Swedish National Road and Transport Research Institute (VTI) simulators [9] and a recently developed simulator at the University of Tongji in Shanghai [10]. These simulators are also in the high-end of the budget. In the low-end of the budget, a simulator can simply be an off-the-shelf computer game with a steering wheel and pedals. Then again, there can be thousands of variations depending on the quality and price.

It is impossible to create a simulator that would in all aspects equal a real driving situation. No matter how realistically the simulation environment is created, the subject still knows that s/he is sitting in a simulator. All that can be done is to try to create as realistic a simulation environment as possible, in which the actions of the driver mimic those in the real driving situation. The main goal of the present project was to implement, as far as possible, features to the simulator that can usually be found in simulators belonging to the high-end of the budget. In this article, a technical description of a low-cost simulator solution which fits this description is presented.

2 Simulator hardware

A single custom-built high-performance desktop computer was used for running the simulator environment. The computer has an Intel 3.07 GHz i7 950 quad core with 12 GB of DDR3 RAM memory and Windows 7 operating system. Three nVidia GTX 470 graphic adapters were used for the video output. Two of these cards provide the 3D view for three 3D projectors (Optoma GT720) in Scalable link interface (SLI) parallel processing mode. Third graphic adapter was dedicated for calculating PhysX and providing video input for a LCD screen containing driving telemetry.

While the driving simulator environment was being developed, different display solutions were experimented. It became clear that for successful navigation and driving performance, a side view is imperative. Particularly, turning at the crossroads and detecting incoming traffic at intersections becomes increasingly difficult when the scene is limited to the front view only. An in-house designed 220 degree curved display with radius of 2.5 meters (8.2 feet) was constructed. The resolution for the projected image is 3840x720 and the actual size of the image in the curved screen is 10 x 1.9 meters (32.8 x 6.2 feet). For combining the image from three different projectors and making the view look seamless, a program called Nthusim is used.

nVidia's 3D Vision Home kit [11] with shutter glass technique was selected for the presentation of stereoscopic 3D view. It was expected that the stereoscopic view makes estimating distances easier and increases the feeling of realism by adding depth to the view. No driving simulator studies where stereoscopic shutter glass view was used were found. In a flight simulator research [12] stereoscopic 3D view was considered valuable in situations in which the aircraft is very close to the ground or to another airplane in taxiing, formation flying or air to air refueling, for example.

Some details of the real car were added to the simulator in order to increase the realistic driving feeling. These include a middle console with the gear shifter and hand brake from a Volvo S60, blinkers attached to the back of the seat and a high impact speaker installed inside the driver's seat in order to add a feeling of vibration while driving. Logitech Z-5500 high quality 5.1 Speaker system is used for creating realistic driving sounds. A small display including gages for speed, RPM, fuel level and engine temperature was added behind the steering wheel in order to create an illusion of real car indicators.

Figure 1. The driving scene of the low-cost driving simulator

The base for the motion platform and driving control system is manufactured by Frex GP (Osaka, Japan). This system was modified for more realism, including three degrees of freedom (3 DOF) motion platform, high quality steering wheel, pedals and gear shifter. The original linear actuators from Frex GP, which were only capable for moving 10 kg each, were replaced by actuators capable of moving 50 kg each. One of the actuators from the Frex GP system was used to create the rear sliding effect.

Controllers were connected to the simulator computer via USB. Linear actuators for the motion control were fastened into a car seat manufactured by Volvo, and the weight distribution of this "vehicle" is in the middle of the driver's seat. While driving in the simulator, traffic rules and speed limits (40–80 km/h; 25–50 mph) are to be followed. While driving under these rules the feeling of motion created by this light motion platform is adequate. For situations that contain a lot of fast movements, like off-road racing, the limitations of the movement platform become evident.

3 Simulator Software

rFactor, a commercial game developed by Image Space Inc., was used as the platform for the driving simulator. The game runs on an engine called gMotor-engine2. There are several substantial advantages on running the simulator using a commercial game. The price of the game is about 40 euros (55 dollars), which makes it a very cheap solution compared to the normal simulator software pricing in the tens of thousands of euro. The game developers have offered the users many tools for controlling the game environment, which makes the simulator environment highly modifiable.

There were also other reasons why rFactor was selected as the main software for the driving simulator. The game physics are generally considered to be realistic. No research data on the accuracy of the game physics were found, although the subjective feeling of the driving is quite realistic. For the present research project the feeling of realism is more important than the accuracy of the mechanics of the simulator.

Getting reliable telemetry data (recording of different mechanical aspects of driving) is imperative for research purposes. When using rFactor this is quite easily accomplished with an in-house programmed plugin. Another plugin is used for real-time telemetry monitoring of driving. The telemetry data includes large variety of variables which are important for our research purposes, such as steering, braking, accelerating, and even tire temperature or wheel rotation speed.

One of the most important factors in the selection of the simulation software was the ability to create custom-made driving scenarios. For the needs of varying research themes, it was essential that the simulation environment could be built from scratch without limitations. Bob's track builder (BTB) offers this option. BTB has a very accurate and easy-to-use interface for building roads and landscape. GPS location data can be imported and road maps can be created based on those coordinates. If the GPS data includes height data, this can be transferred directly to BTB. The road network can also simply be drawn and the height can be adjusted manually.

When the road network has been designed or imported, the road can be modified in varying ways. The width and the camber of the road can be changed and bumps and shapes can be added to the surface. The appearance of the road can be modified by importing road textures and more details can be added by including specular and bump maps to the road. These maps make the surface look more uneven or change the lighting and reflection settings of the texture. The friction properties of the road can be altered, thus creating for example black ice for unexpected slippery conditions. After the road network design is finished, a landscape can be added around the roads. The height, texture or the driving feel of the landscape can be modified.

One of the main goals for the simulator was to create driving scenarios which include elements from the Finnish traffic environment, such as buildings, trees and traffic signs. For the modeling, several different programs were used. Most of the 3D modeling was done using Google SketchUp because of its good compatibility with Bob's Track Builder. Autodesk 3Ds Max and 3Dsimed were used for the more detailed graphics and animated textures. 3ds Max road object set was purchased and used in order to improve the outlook of roads. The package includes high quality roads with realistic sidewalks and street lights.

The main challenge with the designing of 3D objects is to make the objects look realistic, but still keep the structure of the models simple enough to ensure the smooth rendering of the world. This requires reducing some graphical improvements, such as transparent windows on distant houses and 3D model trees in the distance. Detailed models were used near the driving lane, whereas low detail objects were used in the background. The model's level of detail is also altered depending on the drivers distance from the object.

The default control program for the actuators provided by Frex GP was replaced by a program called X-Sim. It offers a more profound control over the movement of the actuators. X-Sim program runs on a separate computer, and it receives motion data from the game engine. This data is transformed into movement based on set multipliers, which define the intensity of the movement that the actuators perform. The data is then sent to the motion platform via Ethernet cable. Because the drivers have to follow moderate speed limits and traffic rules, the G forces do not rise very high. Therefore the G force data received from the game was dampened, and most of the movement of the motion platform was based on the values of pitch, roll and yaw.

4 Research equipment

For the successful research on human driving behavior, measurements of physical actions of simulator are required (telemetry data) synchronized with different kinds of recorded data from the driver. The motion control software X-Sim provides an option to create a trigger signal for outside measuring devices. A data channel with no value for the researcher (tire temperature) was selected for the synchronizing purposes (triggering). Once the driving situation starts the data is automatically sent to the X-Sim program, which transforms it to a start signal for the NeurOne EEG / EMG device [13], EyeLink II eye movement device [14] and Basler high speed cameras with Vicon motion analysis software [15][16]. NeurOne is used for most of the physiological measurements, including the measurements of EEG, EMG, GSR and heart rate. These physiological measurements offer a comprehensive outlook on the neurophysiological aspects of driver's behavior during tasks in the simulator.

5 Data Analysis

In the driving situation a set of multimodal and time-stamped synchronized data is collected. These consist of 1) experiential data (subjective reports), 2) behavioral data (observable changes in the subject's behavior), 3) electrophysiological recordings (EEG, EMG GSR, heart rate), 4) eye movement recordings, 5) mechanical data from the vehicle, including the use of different control parts (steering wheel, brake, throttle), and more continuous events, such as use of gas, and 6) environmental situation (video recording of the road and driving environment, other vehicles, pedestrians, traffic signs, weather conditions).

The setup offers the possibility for the integrated analysis of the factors important in driving. Thus, we develop methods that make comprehensive use of all the multimodal data. The aim is to sort out from the wealth of data factors that explain, e.g., successful driving or driving accidents. This kind of knowledge may then be applied to the planning of the traffic environment or to the teaching of driving.

6 Discussion

The price of the present simulator does not exceed € 20.000 ($ 28.500). However, with such a low price, there are some limitations especially with the software that restricts the type of research that can be carried out with the simulator. Lack of an intelligent triggering mechanism prevents the research on more complicated driving situations. The traffic in the environment cannot be controlled, and other vehicles follow a pre-programmed route responding accordingly to objects in the driving environment. They may brake, for example, if there is another car or an object on the road, but they do not react to the objects themselves (e.g., to the meaning of the traffic light, or rail road crossing beams). Such limitations make it necessary to upgrade the simulation software in the future if more complex traffic situations will be studied.

Research on the advantages of 3D stereoscopic view while driving would be very important. At the moment, 3D view is used because it is expected to have a positive effect on the estimation of distances and making correct turning in the intersections of the road easier. In addition, it is not known whether 3D scene is more susceptible to simulation sickness. In this respect more research is needed.

The present simulator provides an excellent tool for performing physiological (EEG, EMG) and eye movement measurements (for the latter especially the large driving scene is important). EEG and EMG measurements are very sensitive to mechanical and electrical disturbances. However, the motion platform, despite of being rather moderate, has its advantages, as it does not cause too much mechanical or electrical ambient noise. With good grounding no problems have been encountered in the recording of electrophysiological data.

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7 References

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