Driving simulators for driver training: state of the art

Dr. Bart Kappé
TNO Defence, security and safety
Kampweg 5, 3769 DE
Soesterberg.
Kappe@tm.tno.nl

Abstract

Driving simulators are built from five principal components: vehicle model, visuals, motion, traffic model and scenarios and instruction. For each of these components, I will briefly comment on the state of the art. Bottom line is that current driving simulators cannot present all the relevant information to the driver. In a driving simulator we are confronted with a relatively simple environment, inhabited by traffic that sometimes behaves oddly. This is not an ideal environment for training experts, but is suitable for novices. In the Netherlands, about 70 cost-effective driving simulators for novice driver training are in use at the schools. With a focus on didactics, these machines are great tools for driver training. The simulators are used in two ways: integrated or prior to the normal driver training, and I will briefly discuss the implications.

Introduction

Driving simulators have been around for decades. Initially, they primarily served research purposes. Later, they were also used for driver training. This paper presents an overview of the state of the art in driving simulation, ending with the use of driving simulators for initial driver training in the Netherlands. We will focus on five principal components of a driving simulator: vehicle model, visuals, motion, traffic and scenarios & instruction.

Vehicle model

Initially, driving simulators used relatively simple, special purpose vehicle models. Such models allowed steering behaviour of a car to be modelled in real time, given the limited computing power available. Today, vehicle models approach perfection, and simulators can basically use the same models, programming languages, and software tools that car engineers use in the design of their vehicles. This allows the handling characteristics and driving comfort of a vehicle to be evaluated very early in the design phase. There are several car manufacturers using driving simulators this way (e.g. Daimler-Dasa, Renault, Ford). While the vehicle is typically well modeled, I will show that evaluating handling characteristics is a major challenge even with the current generation of high-end driving simulators.

Visuals

Driving is a visually dominant task, and presenting visual information is an important issue in driving simulators. The first driving simulators used a camera monitor system hovering over a conveyor belt or maquette, see Figure 1. This allowed rich, textured visual environments to be presented in the simulator, be it at a relatively low (video) resolution.

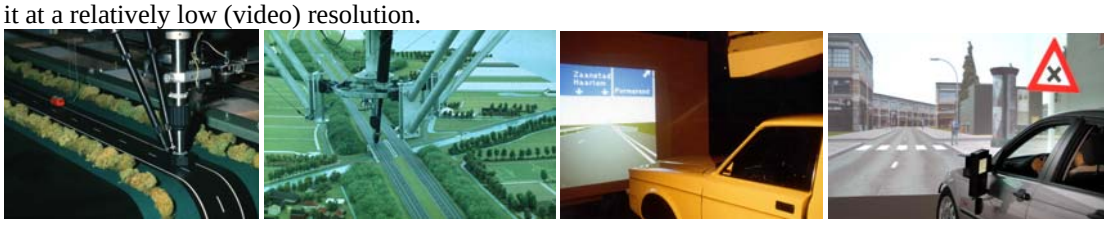

Figure 1, the four generations of driving simulators at TNO Human Factors

The first CGI's were a setback in terms of image quality. They were very expensive, had no texturing or shading and with a relatively low resolution and update rate. With the emergence of PC-based computer graphics it is now possible to present complex virtual environments at resolutions of 1024 x 768 pixels or more per channel and update-rates in excess of 30 Hz. Multiple rendering PC's can be clustered and synchronized to present a wide, multi channel view of the virtual environment.
Graphical modeling advances rapidly. In this respect, computer games are often leading the way by pushing hardware and software developments. The current generation of games shows more realistic, dirty environments, with objects and people that behave quite realistically see Figure 2. Such games also may use 'procedural geometry' which allows a natural, detailed environment to be generated on-the-fly, without planting each individual object in advance. In time, these developments will find their way in driving simulators.

Figure 2, Halflife 2® shows realistic environments, in which objects may have physical properties. Blueberry3D® allows natural environments to be modeled rapidly with almost infinite detail using fractal calculations.

Even though computer graphics have shown a remarkable progress, they only present a fraction of the visual information that is normally available to the driver, see Figure 3. Apart from fundamental problems with distance and speed perception (Kemeny & Panerai, 2003), virtual environments generally lack many of the intricate cues drivers use when driving. The small pellets of gravel in a curve, that shiny icy patch on the bridge, or having eye contact with another person are examples of the many aspects that are not (yet) adequately represented. Virtual environments are generally built from 'facades', merely presenting a view of an environment, without representing the underlying physical, biological and/or cognitive properties. For instance, realistic, fully interactive cyclists and pedestrians are very difficult to model, and as of yet, no driving simulator is capable of simulating large numbers of them. It is very difficult to realistically model the physical, motion and/or decision making properties of the objects and participants you observe. And, even if we could model these aspects, we do not seem to know all the visual cues an experienced drivers may use when driving.


Figure 3, computer generated environments may look nice, but are relatively simple to the complexity of the normal driving environment, especially the behavior of traffic participants.

Motion

While visual perception is dominant in most driving tasks, vestibular perception plays an important role in vehicle control. Cars can move vigorously, and may exhibit large linear accelerations while accelerating, braking and in curves. The current generation of hexapod motion platforms does not allow such large linear accelerations to be simulated accurately. To provide these cues to some extent, several driving simulators rely on large X, Y, X/Y or rotatory motion platforms, see Figure 4. Even with these large motion platforms, however, simulating realistic motion cues in driving simulators will remain a challenge for a while. This obviously poses a problem when driving simulators are used to evaluate driving characteristics of vehicles still under development. Even with a 100% correct vehicle model, vestibular cues cannot be correctly presented to the driver. This not only holds for driving in extreme conditions, but is a fundamental problem in everyday 90deg turns as well. We have found that experienced drivers tend to be especially sensitive to such flaws in driving simulators, resulting in high numbers of simulator sickness.

Figure 4, different high-end motion platforms in research driving simulators (NADS, VTI, Daimler-Dasa, TNO Human Factors)

Traffic model

We do not drive in splendid isolation. Traffic is all around us, in large numbers and may occur in complex situations. To be acceptable, computer generated traffic has to accurately reproduce driving behaviour at the control, the manoeuvring and the strategic level. This implies that each simulated car has its own vehicle model, perception and control model, and decision logic. There are many different traffic models currently in use. Some merely present a car moving over a track, with hardly any interaction. Others are fully interactive and scriptable, and can handle complex situations on multi-lane intersections and roundabouts. At close observation, however, flaws exist in these models: physical behaviour is not correct, vehicles are not steered the way a driver normally would, manoeuvres are initiated inappropriately, and decision making is not very ‘intelligent’. Such erratic behaviour is often observed in traffic situations that can not handled by obeying the rules of traffic, such as when four vehicles arrive at the same time at an intersection.

Scenarios & instruction

One of the most apparent advantages of simulators is that you can make things happen at the moment you want them to happen. Most driving simulators allow the traffic to be controlled in such a way that a specific situation will occur when desired. Thus, a simulator lesson can offer as many instructive traffic situations as possible, tailoring the content to the student's learning needs.

Virtual instruction is an important aspect in driving simulators. If students can learn more or less by them selves, a single simulator instructor can operate several simulators at the same time. However, programming virtual instruction is a challenge. Simple instructional tasks can be managed, like giving route instructions, standard explanations of things to come and feedback on errors. More complex instructional tasks are currently almost impossible for a computer: assessing mental workload of the student, finding the underlying process why errors are made, or determining if a student has a correct situational awareness. Such aspects can only be dealt with by a driving instructor.

Implications for driver training

Driving simulators are not perfect. Like any simulation they are a mere abstraction of reality. They cannot present all the information a driver normally uses. Adequate simulation of human behaviour (motion, decision making and instruction) is very difficult. Experienced drivers will likely notice that the simulated vehicle steers a bit weird and that they are driving in a simplified environment inhabited by traffic participants that sometimes behave oddly. Given these conditions, it is difficult to use state of the art driving simulators effectively in the training of expert drivers. Of course, in the future, simulator with more sophisticated graphics, motion, traffic and scenarios will emerge. It will take some time though, before all these aspects of driving are adequately modelled.

Figure 5, different driving simulators used for initial driver training in the Netherlands. Greendino (left) and VVCR (right)

State of the art driving simulators in the Netherlands

In the past few years, driving simulators have been widely introduced in Dutch driving schools. When the largest driving school in the Netherlands, ANWB rijopleiding, introduced VVCR driving simulators in their driving course, other driving schools followed with driving simulators manufactured by Green Dino. Currently, more than 70 driving simulators are operational at the schools. These simulators are based on PC clusters, and have wide three channel visual displays based on standard LCD projectors, see Figure 5. They present traffic on different types of roads, intersections and roundabouts with typical Dutch delineation, signs and infrastructure. These relatively simple simulators teach novice students the basics of driving a car: vehicle operation, traffic procedures and interaction with other road users. More complex skills and even the more complex aspects of the basic skills are trained during the regular driving lessons: in a car, on the road, with an instructor.

It might be surprising, but in my view the 'art' in these driving simulators is not in the simulator itself. The art is to fully use the simulator's potential, by using the system for what it does best, as efficiently and effectively as possible. We do not regard the simulator in isolation, but as an integral part of the driver training. We focus on simulator didactics, as they contribute most to its effectiveness.
At ANWB rijopleiding, the simulator is fully integrated in the two week training course. In this course, students learn how to drive in a structured way, with a focus on a specific set of tasks each day.
Each set of tasks is first trained in the simulator, where the aim is to automate these tasks as much as possible. In total, the students have 18 driving simulator lessons of 20 minutes each, see Table 1. In total, these lessons contain about 500 predefined situations, developed in cooperation with the driving instructors of the school. The simulator gives basic instruction and feedback to the student. After their lesson in the simulator, students practice the same tasks in a car on the road. This secures a high transfer of skills between simulator and practical driving lessons, and minimizes negative learning effects.

Table 1, the simulator lessons, the tasks that are trained, and the number of predefined scenarios

Lesson	Tasks	Scen.
1	Starting, driving-off, turning off, gears 1-2, braking	6
2	Gears 1-2-3, Gears 3-2, braking at higher speed	4
3	Scanning at intersections	19
4	Lane choice, driving curves	26
5	Single lane intersections	50
6	Multiple lane intersections	22
7	Single and multiple intersections, lane choice	43
8	Mini roundabouts	15
9	Lane technique, signs	44
10	Driving independently	52
11	Roundabouts	17
12	Driving outside the built-up area	19
13	Merging, exiting, weaving, following, overtaking on highways	10
14	Driving outside the built-up area	9
15	Merging, exiting, weaving, following, overtaking on highways	12
16	Single & multi-lane intersections, (mini) roundabouts, lane techn.	50
17	Roundabouts	49
18	Lane technique, multi-lane intersections	27
19	(Busy)highways, sudden traffic jams	18
	Total	**492**

In an evaluation study, instructors commented that simulator students had mastered the basic drills and scanning strategies in the simulator. This gave the instructors more time to refine a student's skills, and pay more attention to higher-order, cognitive aspects. The instructors estimate a simulator lesson of 20 minutes to be equally effective as a 1 hour practical driving lesson

Some Dutch driving schools use a different concept. In the Netherlands, 17 year olds are not allowed to drive a car nor receive practical driver training. These schools use the simulator to train their students prior to the practical driving lessons. The students can take these simulator lessons at reduced cost compared to normal driving lessons. They practice the same tasks as the ANWB driving simulator, in less complex

‘random’ situations (i.e. without encountering predefined situations). Although such a setup may be commercially interesting, the learning value of this approach is difficult to determine. There is a relatively long period between a simulator and practical driving lessons, decreasing transfer of learning. This period allows incorrectly learned skills, such as scanning and traffic procedures, to be fully automated before they are corrected in practical driving. It may take some time to reprogram these incorrect practices to the desired behavior. However, again driving instructors are again positive on the skills of their simulator students. They spend less time explaining basics, leaving more room for high-order skills and refinement.

Conclusions

Driving is a task that is performed in a complex environment. Controlling a vehicle in busy traffic or under extreme driving conditions is a skill that can only be mastered with a substantial amount of practice. When driving, we process massive amounts of information. Driving simulators cannot provide all this information. Virtual environments do not allow proper 3D perception, are relatively empty, are built from simple facades and are inhabited by ‘dumb’ traffic participants. This is not the ideal environment for training experts.

In the Netherlands, driving simulators are successfully used for initial driver training. That is where, in our view, is where driving simulators currently suit best. Novice drivers need to learn basic skills, like vehicle operation, steering, maneuvering and interaction with other traffic. They do not need all the complexity of the normal driving environment, but can learn well in a virtual world. The current generation of low-cost driving simulators can offer such an environment, with traffic in a detailed road environment, providing virtual instruction and feedback on errors. These simulators focus on the didactical aspects of the simulator, and are integrated with the normal driver training. Thus, we use relatively simple simulators for basic driving tasks, but we do so very effectively.

Reference

Kemeny, A., Panerai, F. (2003) **Evaluation perception in driving simulation experiments** Trends in Cognitive Sciences, 7(1):31-376.