Developing a Low-Cost Driving Simulator for the Evaluation of In-Vehicle Technologies

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ABSTRACT

We present a case study concerning the development of a driving simulator at Mitsubishi Electric Research Labs. By relying largely on off-the-shelf components, we have kept the total system cost under USD 60,000, yet attained a level of fidelity comparable with more expensive, custom-built research simulators.

Categories and Subject Descriptors

H.5.2 [INFORMATION INTERFACES AND PRESENTATION] User Interfaces – Benchmarking, Evaluation/methodology, Prototyping

General Terms

Design, Experimentation, Human Factors, Economics

Keywords

Driving simulation, automotive user interfaces, human-machine interfaces.

1. INTRODUCTION

In theory, it is preferable to conduct automotive human-computer interaction research in moving vehicles on real roads or test tracks, as is often done in transportation engineering studies. Practically speaking, however, HCI studies in real vehicles are rare. This may be due to the safety and liability issues inherent in testing unproven technology not specifically related to core vehicle operation. But beyond safety advantages, driving simulators offer HCI researchers distinct advantages over real vehicles in terms of repeatability. By keeping the simulation scenario exactly the same from trial to trial or subject to subject, one can highlight the differences between in-car devices or interfaces with fewer complications and confounds.

We believe it is for this latter reason that driving simulators have emerged in the past several years as vital tools for the evaluation of new in-vehicle technologies. Whereas in the past automotive OEMs and aftermarket device manufacturers might have considered their interfaces' visual and psychomotor demand at design time and then brought products to the market with "fingers crossed," today there is more emphasis on empirically verifying this demand in simulated driving situations [2],[9],[17].

Exactly what a "simulated driving situation" entails, however, varies widely from institution to institution and study to study. At the low-fidelity, low-cost end of the spectrum are studies that involve counting the number of vehicle crashes in a video game session [13] or having subjects carry out abstract steering-like tasks such as tracking a shape's horizontal movement using a wheel [6]. At the high-fidelity, high-cost end of the spectrum are the multi-million-dollar, full-motion platforms that occupy entire hangar-sized buildings [11]. Somewhere in the middle are hundred-thousand-dollar research simulators (e.g. [14]) that offer unparalleled flexibility in terms of scenario creation and playback. However they require an enormous investment of time for object modeling and scripting, and their cost generally does not include equipment (computers, displays, and driving chairs/vehicle cabs).

This paper discusses the construction of a simulator with a degree of realism and flexibility similar to that of mid-level research simulators, but at a far lower cost. It is not the aim of the present work to compare our simulator with other setups on a point-by-point basis. Rather we offer a practical case study in hopes that our techniques and experiences can be valuable as other institutions weigh their options.

In the following sections, the simulator's hardware and software components will be discussed, some supporting tools will be mentioned, and then we will briefly discuss the current limitations of the setup and our plans for addressing these limitations in the future.

2. SIMULATOR HARDWARE

2.1 Computer

A single high-end desktop PC is the basis for our simulator. The CPU is a 3.0 GHz Intel Core 2 Extreme, with 4.0 GB of 2000MHz DDR3 RAM. Two NVidia GeForce 8800 Ultra graphics cards are used for video output, either in standard or parallel-processing (SLI) mode depending on display configuration (see below). We chose Windows XP as the operating system because of driver support and its compatibility with a wide array of gaming and simulation software. The total cost of all computer components was under $2500.

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2.2 Input/Output devices

The most important input/output device is a D-Box GP Pro-200 RC gaming chair [5]. This cockpit-style chair (see Figure 1) rests on three hydraulic actuators that move in response to events in the driving simulation. These movements consist of vibration and tilt with two degrees of freedom. The vibration is synchronized with simulated engine RPM and greatly improves the perception of the virtual vehicle's speed. The tilt corresponds to in-game acceleration, braking, and steering/cornering. We find that the vestibular stimulation offered by this tilt feature helps to counteract the "simulator sickness" effect that is the bane of fixed-base, motionless simulators.

A Logitech G25 force-feedback wheel bolted to the D-Box chair affords primary steering input. This is one of the largest and most solidly built game controllers on the market, and comes with a weighted throttle, brake, and clutch pedal assembly as well as a shifter knob. Engine noise and sounds/music generated by in-vehicle interfaces are played through a Creative Inspire 5.1 speaker system. The D-Box chair includes the Logitech G25 and the speaker system, and retailed for $15,000 in 2008.

2.3 Displays

We have experimented with two different display configurations. The first was a Samsung SyncMaster 305T LCD measuring 76 cm diagonally and offering 2560 x 1600 native resolution (SLI-mode video was necessary for smooth rendering at this resolution). This display was placed on a shelf approximately 147 cm off the floor (as shown in Figure 1). This configuration offered a horizontal viewing angle of 42.7° and a vertical viewing angle of 27.7° in the worst case (the adjustable seat slid as far back as it will go, resulting in a viewing distance of 81.8 cm). At this screen distance and position, the most natural in-game camera perspective superimposes some of the vehicle interior (dashboard and forward left pillar) over top of the roads and terrain. We purchased the Samsung display for $1245.

Figure 1: First configuration

We were quite satisfied with the level of textural detail and realism afforded by this high-resolution display configuration (about 60 pixels per horizontal degree). However, we wanted to experiment with larger, potentially more immersive displays. To this end we re-purposed three DLP-based Mitsubishi MegaView displays [10] that had been used for a previous project in the lab and were sitting idle. Each display measures 127 cm diagonally and supports 1024 x 768 resolution. We arranged them in a coplanar 3x1 layout and combined their inputs using a Matrox TripleHead2Go device. This allows them to appear to the Windows display driver as one large, combined 3072 x 768 display rather than three individual displays. In order to bring the subject's eye level in line with the vertical center of the displays (approx. 127 cm off the floor), we placed the D-Box chair on a sturdy wooden platform rather than building expensive custom mounts for the displays. At a viewing distance of 186 cm, again in the worst case, the horizontal viewing angle is 78.6° and the vertical angle is 23.1°. Despite the lower resolution in this case (about 39 pixels per horizontal degree), the driving experience is qualitatively more immersive and realistic in this configuration because of the larger screen size. As shown in Figure 2, the most natural in-game camera perspective for this physical layout is the "hood view."

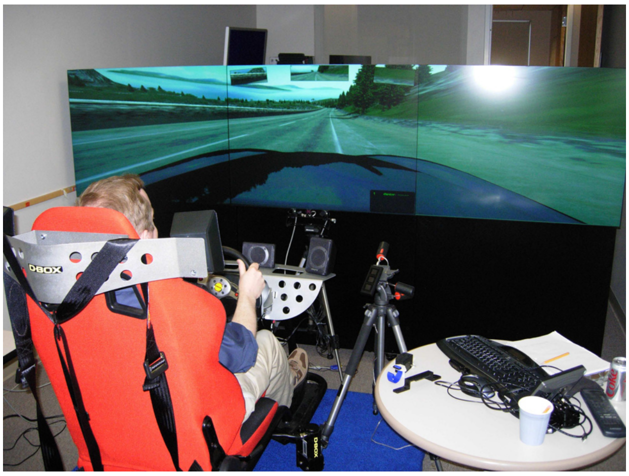

Figure 2: Second configuration

While it could be argued that using $20,000 commercial-grade displays such as the Mitsubishi MegaViews invalidates the positioning of our simulator as a low-cost alternative, it should be pointed out that a very similar setup could be achieved using consumer-grade equipment. DLP or LCD projectors at 1024 x 768 resolution can be had for under $1000 apiece.

3. SIMULATOR SOFTWARE

After evaluating several open-source and commercial alternatives, the commercial driving game rFactor [8] was chosen as the software platform for our driving simulator. It offers a convincing, realistic driving experience thanks to richly detailed graphics, accurate vehicle physics, and full support of force-feedback steering wheels. And while it does not offer the complete flexibility of an open-source product, the game does allow for a deep degree of modification and customization. There is a large community of enthusiasts who produce everything from custom tracks to custom vehicles and camera angles. The game's "out of the box" support for the D-Box chair is also a distinct advantage. In addition, rFactor provides a plug-in API whereby vehicle telemetry (including position, velocity, and acceleration), and user input (steering angle and throttle/brake positions) can be captured at rates up to 90 Hz.

Our own rFactor plug-in simply dumps comma-delimited raw data to a file for later processing. This processing allows us to report higher-level results using standard metrics from the driving simulation and human factors literature [12][18]. These include, for example, lane position variance, speed variance, and following distance variance.

For one study we used a mixed city/highway course that ships with the paid version of rFactor itself ($40), for another we used a third-party highway-based course that we found on the fan site "rFactor Central" [15], and for a third study we built an entirely custom course from scratch using a basic 3D modeling tool called Bob's Track Builder [3].

4. SUPPORTING TOOLS

4.1 Eye tracker

There is wide consensus that the measurement of eye glances and fixations is crucial to determining how distracting any given in-vehicle interface is [4], [7]. Distracted drivers tend to reduce their tactical and strategic scanning behavior, narrowing their focus to the area immediately in front of their vehicle and missing peripheral stimuli [1], [12], [18].

For this reason we consider it essential to measure glances and fixations, and to report excessive (e.g. greater than two second) glances away from the forward roadway in our study results. An extremely powerful tool for making these sorts of measurements is Seeing Machines' FaceLAB system [16]. This system incorporates a dedicated laptop and two Firewire cameras that are placed at either end of a stationary mount, allowing them to triangulate the position of the subject's head. Infrared light is emitted from a pod at the center of this mount, and the cameras track the glint produced as this light bounces off the corneal surface of each eye. This allows the FaceLAB system to generate both head position and eye gaze vectors.

For each study setup, one creates a model of the primary screen, noting any coordinates of interest (e.g. of the virtual roadway surface or a lead vehicle), as well as of any objects of interest in the real world outside the screen, such as a navigation system display or steering wheel-mounted buttons. The bundled software can thereby create a report showing exactly which screen coordinates or real-world objects a user fixated upon, and for how long.

Not counting the re-purposed MegaView DLP displays, the FaceLAB system was the single most expensive component in our simulator. It cost approximately $40,000, with options, when we purchased it in 2008. Based on our experience so far, it was money well spent.

4.2 Experimental tools

We use a suite of in-house software tools to automatically generate and time the in-vehicle interface tasks that subjects must carry out. These tasks may include, for example, destination entry or music retrieval. A simple USB-based device (Figure 3) displays information to the experimenter so that he or she may prompt the subject to carry out one of these tasks. The experimenter then presses the device's buttons to mark the beginning and end of the task, and to annotate it in various ways within the task log.

Figure 3: Experimenter's tool

Another tool merges and synthesizes the various logs – rFactor, FaceLAB, and the task log – creating time series that can be queried during the analysis phase by means of simple SQL statements.

5. ADVANTAGES and LIMITATIONS

The major advantages of our approach versus traditional research simulators are cost and time. Typical simulation software, which starts in the $100,000 range, does not usually include input/output hardware or eye trackers. We built a comparable system with arguably superior motion feedback and rendering quality for under $60,000, *including* the eye tracker.

Table 1. Approximate cost breakdown, as of 2008

Component	Cost (USD)
Computer	2500
Primary display	1245
Driving chair, steering wheel, speakers	15,000
Eye tracker, with options	40,000
Simulation software and modeling tools	100
Total:	**$58,845**

Our choice of rFactor as the simulation engine also meant significant time savings. Rather than painstakingly modeling vehicles and roadways and painstakingly scripting scenarios, we let the worldwide community of rFactor enthusiasts do most of the work for us. If we cannot find a custom course design that suits our needs, we can build one within several hours using Bob's Track Builder rather than taking the many days necessary to learn and use a full-scale modeling suite such as 3D Studio Max.

The reliance on off-the-shelf components is not without significant disadvantages, however. rFactor is primarily a racing simulation game. Thus, it is difficult to model the complex street layouts and intersections found in urban areas. The game engine furthermore requires that there be a single, designated "best path" around the course. It is unclear, based on our initial investigations, whether this path may branch or double back on itself, as would be required, for example, to enable the simulation of opposing traffic flow.

Our degree of control over other vehicles on the roadway is currently very poor as well. The game's developers offer very little programmatic control over the computer-controlled "AI" drivers; one can merely tweak relatively opaque "strength" and "aggressiveness" settings in the configuration files. Combined with vehicle handicapping, this has allowed us to slow the AI driver enough so that it may act as a pace car for studies that require such a design. However, we currently have no way of causing AI drivers to perform specific maneuvers at specific times.

6. FUTURE PLANS

In situations where a study's protocol calls for the subject to react to specific situations at specific times during a scenario, we may populate the simulation with one or more human "Wizard of Oz" drivers who are aware of the study protocol and receive specific instructions or signals as to when and where to carry out specific maneuvers – for example, sudden swerving or braking. As it is by design a multiplayer game, rFactor would support this approach well.

We plan to further enhance the immersion and realism of the driving experience by angling the two side displays toward the subject, such that the subject's gaze vector remains orthogonal to the surface of the display no matter which display she fixates upon. This will reduce the distortion evident at the periphery of the rendered driving scene, as well as increasing the effective field of view.

Finally, we plan to evaluate our driving simulator against typical research simulators in order to determine the validity of HCI studies performed in it.

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