Replicating Reality: Driver Assessment using Dual-Fidelity Simulator

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Abstract – This paper presents a driving simulator constructed for the purposes of allowing a direct comparison between two levels of fidelity in the driver interaction stream. The driving simulator itself is described, followed by an overview of two types of simulation; the first uses a three-dimensional model of a real world route, based upon data acquired from the Open Street Map standard. The second is a high-fidelity video sequence of the same route, acquired using a portable mobile mapping system. A comparison of the driver response to the route in terms of speed for each the data fidelities are then presented.

Keywords – Driving Simulation, High-Fidelity, Low-Fidelity, Models, Comparative Study

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I INTRODUCTION

Vehicle-based simulation can be traced back to at least the Second World War, when aircraft simulators were used for pilot training, and continue to be used for different scientific and training purposes [1], although the earliest examples of driving simulation date back to the mid-1950s, where a driving cab was constructed in front of a wall with a painting of a road scene on it. Modest advancements in this approach included changing the wall to a projector screen, and projecting an image of a road scene [2]. The first interactive driving simulator was introduced at the University of California in 1960 [3].

Progress in video projection technologies allowed this to be extended to an “on-the-rails” video sequence that the driver had no control over; any changes to the road trajectory required the reacquisition of road scene data. An alternate method of video-based driving simulation involved the use of miniature road models. A camera was linked to the steering mechanism of the driving simulator, and allowed the miniature scene to be projected to the driving simulator screen, giving some level of control to the pseudo-real world visuals [2]. A major disadvantage to the real world video datasets employed by these early simulators was the lack of ability to introduce scenarios following the acquisition of data. There was no way to allow a scenario such as a car failing to stop at a stop sign to be tested, unless this occurred during data acquisition. With the advent of the computer age, virtual worlds could be constructed, allowing the point of view of the user to be changed directly by the user themselves. Besides this inherently useful aspect of virtually-generated worlds, an unlimited amount of scenarios could now be introduced, once the virtual world had been established [2].

One area in which the original video-based simulators still hold an advantage over even their most modern counterparts is that of the fidelity of the visual cue system. Early computer-based systems had visuals based upon the graphical abilities of the computing systems of the era, moving from early flat-shaded polygons through to graphics cards that offered shading with improved graphics modelling, and on to the present day systems that offer graphics cards with texturing. An early example is shown in Figure 1 [2].

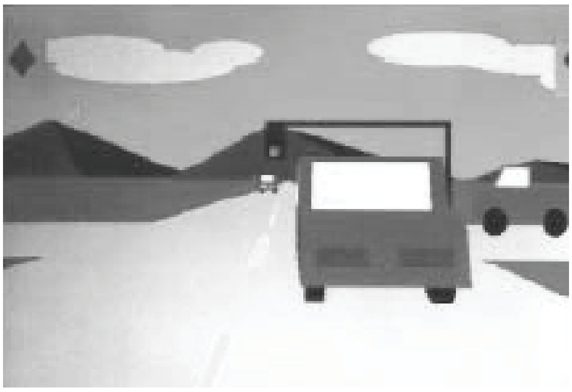


Fig. 1: Early example of driving simulator model [2]

The main advantage of using simulators is that they enable drivers of any expertise to operate a vehicle with no real movement, but under realistic conditions. Simulation models are used as an abstraction of reality to create an environment that can be used for experimentation and real-time manipulation. Käppler defines simulation as the "*simplified replication of any system or process by means of another system or another process, and experimenting with this model*" [4]. There are a number of different types of research-based simulators with a wide range of capabilities and fidelities. An example of a high-fidelity simulator is the VTI's simulator in Sweden that consists of a partial car mock-up, hydraulic movement and a moving screen [5]. These high-fidelity simulators are of a high-cost and require specialist dedicated hardware, with Toyota's simulator costing in the region of stg£30 million [6].

Low-fidelity simulators are more common, due to their low-cost and readily-available components. Most use a basic PC-based setup to allow the user to interact with a road-based model to simulate the driving experience. A single or multi-screen set-up is used to view the modelled world, a PC is used to interface the driver with the model, and driver input is allowed typically using a low-cost gaming steering wheel and pedals. The driver cabin ranges from a typical PC seat to a faux-driving seat. As low-fidelity driving simulators require no independent movement, a low-cost is associated with these (although small, hydraulic-based Stewart platforms have been adapted for used, albeit with a significant increase in cost) [7]. Notwithstanding the hydraulic platforms, the low-cost, low-fidelity simulators are popular amongst academic researchers.

This paper discusses the use of a low-fidelity driving simulator to replicate a driver's journey along a real world route, using two alternative playback streams; the first playback stream being a three-dimensional graphical model created using data obtained from the OSM standard [8]. The second playback stream is a high-fidelity video sequence acquired from a vehicle while driving along the same real world route. During the acquisition of this video sequence, the vehicle's position was recorded using a time-stamped GPS system, allowing for a ground-truth of the driver's speed along the route to be logged. This validates the use of the simulator itself, as a direct comparison between driver behaviour whilst using the simulator can be made with the ground-truth data.

This paper is divided into six sections; section one provides a brief overview of the paper and review of relevant literature; section two gives an overview of the driving simulator system used for the comparative study. Section three describes the method by which a three-dimensional graphical model was generated using the Open Street Map (OSM) standard. Section four describes the acquisition and integration of the real world video sequence with the driving simulator. Section five describes the testing and results of the simulator and its two data sets, followed by conclusions based on these results in section six.

II DRIVING SIMULATOR

A static, fixed-base driving simulator was used for the experiment, which was conducted at the National University of Ireland, Maynooth. The simulator consists of a wooden mock-up cabin with primary controls; a Logitech G27 steering wheel with force feedback, three pedals and gear stick [9]. For the purposes of the experiments, the steering component was disabled, allowing for a single measurement (i.e. speed).

A Matrox Triple Head To-Go was used to output the driving simulator's interface across three standard 1280 x 1024 monitors to form a single 3840 x 1024 display [10]. The driving simulator is shown in Figure 2. The PC is a standard 32-bit Microsoft Windows 7-based PC, with an Intel Dual Core 2 Duo processor (2.33 GHz) with 6 GB of RAM.

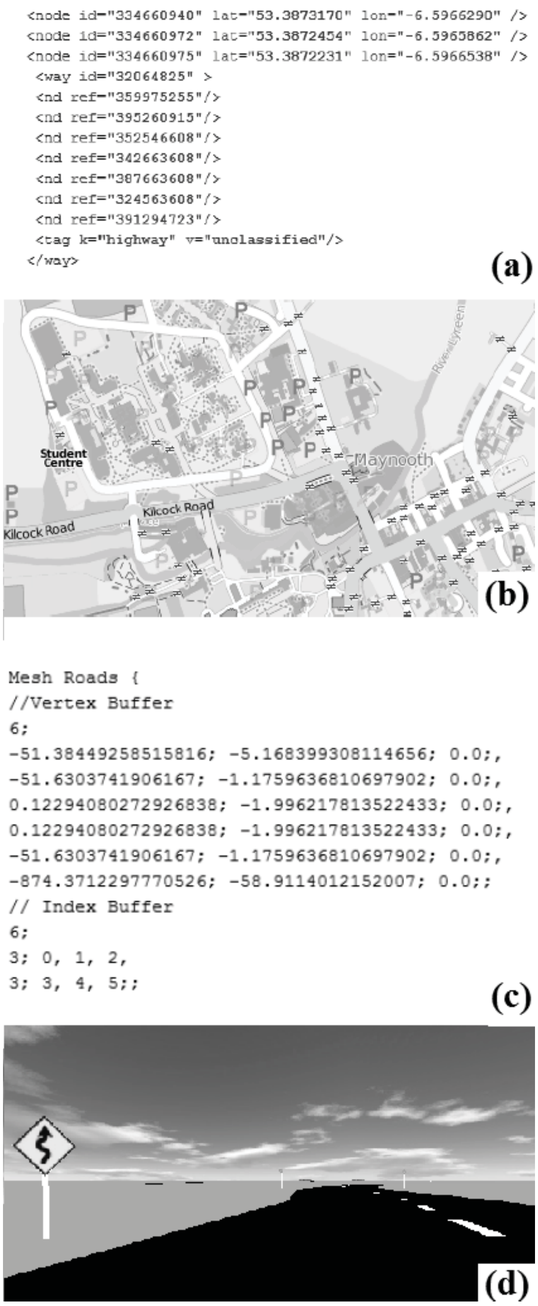
Fig. 2: Driving simulator consisting of triple-screen display, PC-based steering wheel and pedals, and car seat

Two input data streams are now presented: the first being the three-dimensional graphical model, and is detailed in section three, and the real-world video sequence is detailed in section four.

III SIMULATOR MODELLING USING OPEN STREET MAP

Extensible Mark-up Language (XML) files which describe the geographical layout of areas can be accessed from the OSM website [9]. The generation of a three-dimensional environment from these XML files was developed using a three-step process: a parser process, co-ordinate converter process and model constructor process. The first parsed the XML file for relevant geographic data while discarding irrelevant information. The co-ordinate converter process transformed the geodetic OSM data to the standard Eastings and Northings format which ensured that the final model was dimensioned in metres.

The final process calculated the parameters required to construct a three-dimensional model, including the vertices, materials and mesh normals. The resulting data were then used to construct a data file in the DirectX (.X) format. The program also produced a Comma Separated Value (CSV) file of the road paths so that the simulator could preview a journey on the roads. Figure 3 (a) shows an extract of XML data which was taken from a file used to model the two-dimensional digital map in Figure 3 (b). These data were converted to the DirectX modelling format as shown in Figure 3 (c). The DirectX model was then integrated with the driving simulator, as shown in Figure 3 (d).



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<node id="334660972" lat="53.3872454" lon="-6.5965862" />
<node id="334660975" lat="53.3872231" lon="-6.5966538" />
 <way id="32064825" >
 <nd ref="359975255"/>
 <nd ref="395260915"/>
 <nd ref="352546608"/>
 <nd ref="342663608"/>
 <nd ref="387663608"/>
 <nd ref="324563608"/>
 <nd ref="391294723"/>
 <tag k="highway" v="unclassified"/>
</way>
```

```
Mesh Roads {
//Vertex Buffer
6;
-51.38449258515816; -5.168399308114656; 0.0;,
-51.6303741906167; -1.1759636810697902; 0.0;,
0.12294080272926838; -1.996217813522433; 0.0;,
0.12294080272926838; -1.996217813522433; 0.0;,
-51.6303741906167; -1.1759636810697902; 0.0;,
-874.3712297770526; -58.9114012152007; 0.0;;
// Index Buffer
6;
3; 0, 1, 2,
3; 3, 4, 5;;
```

Fig. 3: XML file (a) describing geographical area (b) converted to Direct X file (c) and generated three-dimensional model (d)

Models of additional road signs and markings were created using Microsoft XNA, and the visualisation of the model-view was built in Trimble SketchUp and then mapped onto a two-dimensional plane in the C# language [11]. This allowed for a real world route to be modelled accurately, and then augmented with relevant road signage. Examples of these road signs can be seen in Figure 3 (d).

IV INTEGRATION OF VIDEO SEQUENCES WITH THE DRIVING SIMULATOR

a) Data Acquisition

The video sequence integrated into the low-cost driving simulator was adapted from a data set acquired by a portable Mobile Mapping System (MMS). This MMS acquires full-colour stereo images alongside Global Positioning System (GPS) positional data and Inertial Measurement Unit (IMU) orientation data (Roll, Pitch and Yaw) at a rate of 10 Hz. The system consists of a stereo camera system mounted on the vehicle, and a navigational system that acquired the positional and orientation data placed in the boot of the vehicle. The system was driven at standard road speeds along the selected route; the R156 from Dunboyne to Summerhill. The chosen route is 17 km in length with a maximum speed limit of 80 km/h, and takes approximately 17 minutes to complete. The route was chosen as it offered a rapidly-changing geometry with a wide range of road signage and other delineation features. The route is shown in Figure 4.

Fig. 4: Data acquisition route

This allowed two data forms to be extracted; a monocular video sequence of the chosen route, and also a time-stamped GPS log. This time-stamped GPS log allowed for the speed of the vehicle to be recorded, thereby generating a ground-truth data set by which the speed of drivers using the driving simulator could be compared.

b) Generation of Ground-Truth Speed

Each GPS co-ordinate is time-stamped, meaning that both the distance and time between image acquisitions is available. The speed and location of the vehicle during the data acquisition was therefore recoverable from this information.

c) Integration of Video Sequence

The video sequence was integrated into the driving simulator by way of the OpenCV image processing library [12]. This allowed for the video sequence to have its playback speed linked directly to the pressure applied to the driving simulator's accelerator pedal. The pedal's value is presented as a 16-bit value, ranging from 0 (fully released) to 65,535 (fully pressed). The playback speed of the video was adjusted based on this value – a fully pressed accelerator pedal was interpreted as full speed playback, returned to the user *via* an on-screen display as 130 km/h. Similarly, a fully released accelerator pedal was interpreted as a paused playback speed, again, returned to the user *via* an on-screen display as 0 km/h. An example of this is shown in Figure 5.

Fig. 5: Example of speed being relayed to user

The driver's speed was logged alongside the corresponding frame of the video sequence, and, as each frame has an associated GPS co-ordinate, the driver's response to the geometry of the road could be related directly to a map.

V TESTING AND RESULTS

Ten participants were subjected to one of the input streams; five interacted with the modelled environment, and five interacted with the video environment. The speed of the driver was logged at multiple points along the route; the speed of each driver at each frame in the video sequence, and the speed of each driver with each frame of the model sequence. This generated data consisting of 10,000 speed-frame points in the video and 60,000 speed-frame points in the model (due to the difference in the frame rates between the two).

The same scene represented by both fidelity models is shown in Figure 6.

Fig. 6: Same scene represented by both fidelity inputs

To normalise these data, an averaging process was applied, allowing 50 points to be generated for each model, with each point representing the speed across approximately 340 metres. This allowed the speed of the drivers to be compared across the two different fidelities. This averaging was also applied to the ground-truth speed, which allowed the two fidelities to be shown alongside the ground-truth average. The speeds of the three data sets are shown in Figure 7.

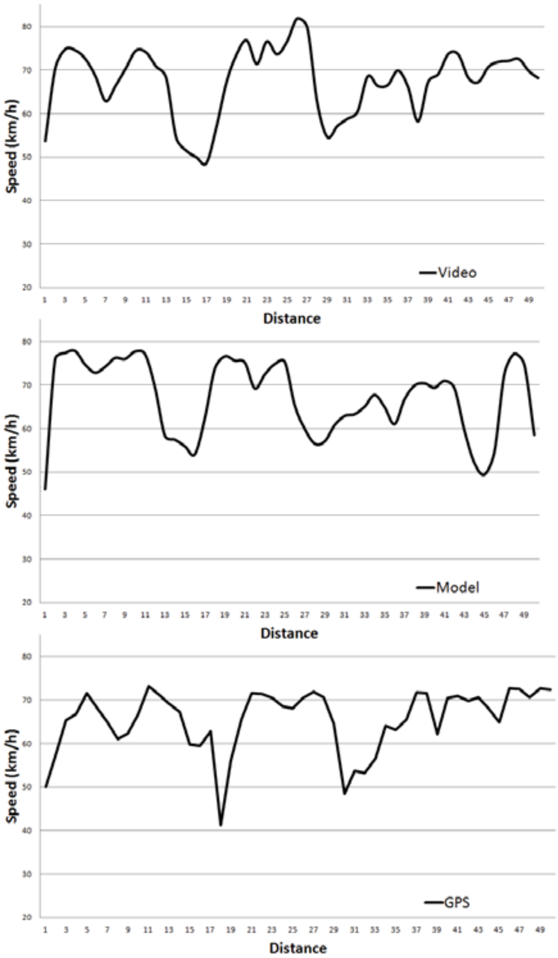

Fig. 7: Averaged speed points (~340 metres) along test route (a) average video, (b) average model and (c) average ground-truth

The general shape of the graphs across the three sets of data was consistent. A reduction in speed corresponding to turns in the road was observed.

VI CONCLUSIONS

This paper has described a driving simulator, mounted on a fixed base and consisting of a standard PC and PC-based steering wheel/pedals. Two forms of data were also presented, one being a low-fidelity three-dimensional graphic model, and the other being a high-fidelity video sequence, both describing the same route. The three-dimensional graphic model was generated using a novel method which parsed Open Street Map XML files, extracted the relevant data, transformed these data from geodetic to metric, and created a virtual model of a real world route.

As this model described a real world route, it allowed for a direct comparison of a video sequence acquired by a Mobile Mapping System being driven along this road. This system acquired time-stamped geo-tagged image sequences, allowing not only the video sequence to be used, but also the ground-truth speed of the system during data acquisition. The integration of these two data fidelity models with the driving simulator through Microsoft XNA (graphical model) and OpenCV (video sequence) was also presented.

Testing of the driving simulator and its two input fidelity streams was conducted by recording the speed of a number of participants across the same 17 km route. This paper has demonstrated a driving simulator that allows a driver’s speed to be recorded based on one of two different fidelities of input streams. Future work will involve an analysis of the difference between the two, and may offer an insight into any possible cognitive reasoning for this difference

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