AI FOR DRIVING SIMULATOR VEHICLES AND ACCIDENT EVENTS

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ABSTRACT
A synthetic driving simulation environment requires a fleet of intelligent vehicles which can perform manoeuvring decisions in real-time and mingle orderly to form mixed traffic environments. The development of a driving simulator was part of a bigger project that evaluated a prototype Head-Up Display (HUD) interface. We therefore opted for a custom simulator that could effectively adapt to the needs of the given experiment. This paper presents the challenges we encountered during the implementation of realistic artificial intelligence (AI) in the traffic vehicles, which produced the analogous complexity driving events. A discussion follows regarding the design and modelling challenges of the *robot* drivers involved in the simulated accident scenarios. The paper discusses the outcomes of the user trials, suggests solutions to intriguing problems that derived from the experiment and reveals the phasma of our future work.

KEY WORDS
Artificial intelligence, modelling behaviour, driving simulation, HMI

1. Introduction

Driving in potentially dangerous situations such as low-visibility in high speed motorways can be a challenging process, not only for human drivers but also for virtual ones. Given that the subject under investigation was the evaluation of a novel Head-Up Display (HUD) interface [1], the development of a driving simulator, which could replicate specific accident scenarios, was considered crucial. Kenichi Yoshimoto has asserted in [2] that: "Simulators use illusion to reproduce the feel of driving. Accordingly, it is impossible to create a system which has exactly the same response as a real vehicle. It is important to determine the exact purpose of using the simulator, and to develop one that suits this purpose. Rather than to create one expensive multi-purpose system, it is more cost effective to create a number of special-purpose systems and to use them accordingly." Hence, we produced a driving simulator that provided us with two special-purpose simulation parts. The first simulation part was managing the complexity of the scenarios and the idiomorphic functions of the HUD system (full-windshield projection). The second part was simulating the delays which occur in real life due to time differences in emission and reception of the signal transmitted by the vehicular sensors [3]. Further on we unfold these two simulation categories that formed the basis of the Artificial Intelligence (AI) of the *robot* vehicles.
The rest of the paper is organised as follows: The next section offers rationale for the driving simulator. The AI requirements of the simulation are presented in relation to the events creation, vehicle categorization, embedment of AI per vehicle and development trials. Finally, we outline our conclusions and present a plan for future work.

2. Simulation AI Requirements

2.1 Head-Up Display Overview

The majority of instrumentation panels are accommodated in the dashboard, thus providing space and mind share for navigation and infotainment devices [4]. Due to recent technological advances, the number and variety of such devices has increased, resulting in the overuse of the Head-Down Display (HDD) dashboard space. Inevitably, driver's attention is distributed along several information outlets. In contrast, the position of a HUD interface (within the driver's immediate field of view) may effectively provide vital information, minimizing in this way driver's response times in critical situations [5]. The proposed HUD interface offers a graphical representation of incoming information, thus enhancing driver's spatial and situational awareness, particularly under low visibility weather conditions.

2.2 Driving Simulator Overview

Driving simulators are an indispensable tool for industry and academic research, and evaluation. However the construction, upgrading and servicing of such equipment and software can be exceptionally costly. Especially for academic institutions the endeavour of designing and implementing a driving simulator, even of low fidelity, can be forbidding. Hence, often academic institutes rent the facilities of traffic research centres or automotive industry studios which offer specialised driving simulators and ideal environments for testing various automotive systems and devices. Yet, in some cases, financial constraints may require an alternative solution.

Under this category falls our effort to produce a low-cost driving simulator to evaluate the HUD system. Given that the proposed HUD is part of a doctoral research, funding for equipment was inadequate to cover the cost of a professional driving simulator. Consequently, purchasing off-the-shelf components and developing the code on the open source software (TORCS) proved to be the most cost efficient and flexible solution. The idea of this custom driving simulator project was the initiative that brought together a multidisciplinary group of researchers from different Scottish and other European universities. A screenshot of the simulator can be seen in Figure 1.

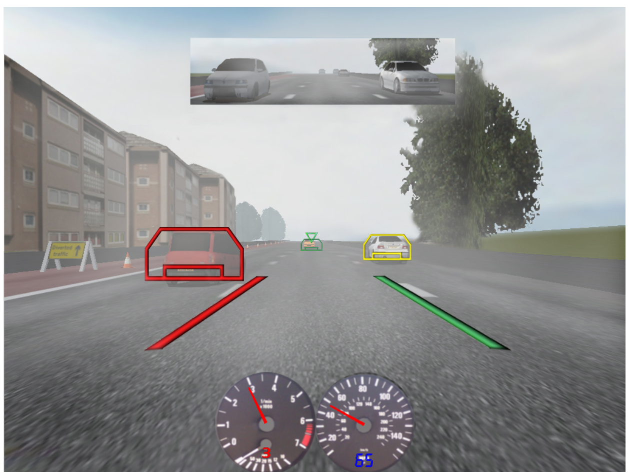


Figure 1. A screenshot of the driving simulator and the symbols used in the full-windshield HUD

Even though the code was based on the open source software, re-programming the simulator for the specific research was particularly challenging. The *robot* vehicles, involved in the simulated scenarios, have been programmed to react and manoeuvre according to the flow of traffic and external events, while demonstrating a natural behaviour [6]. Every vehicle and its possible actions have been categorised by incremental development of hierarchies which incorporated types of vehicles (traffic vehicle, accident vehicle), sensors (radar sensors, ad-hoc network, GPS) and collision objects (side barriers, walls, bridges, traffic cones) [7]. By clustering the above information, we created logical strings among the possible events and responses, which formed the framework for the individual agents' AI.

2.3 Simulation of Sensor Signal Delays

A parallel research on sensor systems provided data regarding the possible time-losses and delays between emission, reception and projection of information on the HUD interface, which we thereafter incorporated into the simulation. The detection of the headway and positioning of the neighbouring vehicles can be identified by a collaborative system of Mobile Ad-hoc networking system (MANETS) between vehicles, GPS and sensors as presented in [8]. To realistically imitate the above systems, each *robot* vehicle was infused with the ability to "sense" the surrounding environment and act accordingly.

3. Creating the Events

3.1 Driving Scenario Development

The development of traffic scenarios was accomplished through a distilling process of Traffic Police information; statistics and planning diagrams aided to predict drivers' possible reactions [9]. The analysis also showed that two particular car-following scenarios occur more frequently and have a high fatality rate (a detailed description of these two scenarios is given below).

For validation purposes, the movement, speed and distances of the vehicles had to consent to the British traffic code. Moreover, in order to augment the realistic representation of the scenarios, the *robot* vehicles had to perform potential human misjudgements [10]. As Park et al. argue in [11], the driver has to be challenged in order to react and produce driving skills who he/she would normally apply in a real accident situation.

The first scenario was a variation of a generic car-following model [12]. While the user was driving along the motorway, after a 2km distance, the lead vehicles had been scheduled to brake abruptly, causing approaching vehicles to decelerate rapidly [13]. As anticipated, this event increased substantially the chances of vehicle collision.

In the second scenario the user had to drive for 5km following the lead vehicles' group, without any major events. After the 5km, the road was forming a sharp turn (120 degrees) underneath a bridge. The difficulty of the simulation had been increased by the addition of slow moving traffic congestion positioned at the exit of the turn.

In both scenarios the user was forced to respond instantly, either by manoeuvring around the accident or by braking. The *robot* vehicles involved in the scenarios had been programmed to minimise the possibility of accident avoidance as we were particularly interested in measuring drivers' response times and distance from the lead vehicle.

3.2 Macroscopic & Microscopic Approach

Further investigation on drivers' behaviour modelling showed that the majority of the high-fidelity traffic simulators utilize the macroscopic simulation method. This method exploits mathematical models, often deriving from fluid dynamics, that translate the vehicles' flow as one entity. An advanced version of this method disperses the main mass into three or more segments of vehicles that share identical characteristics such as cars, motor-bikes,

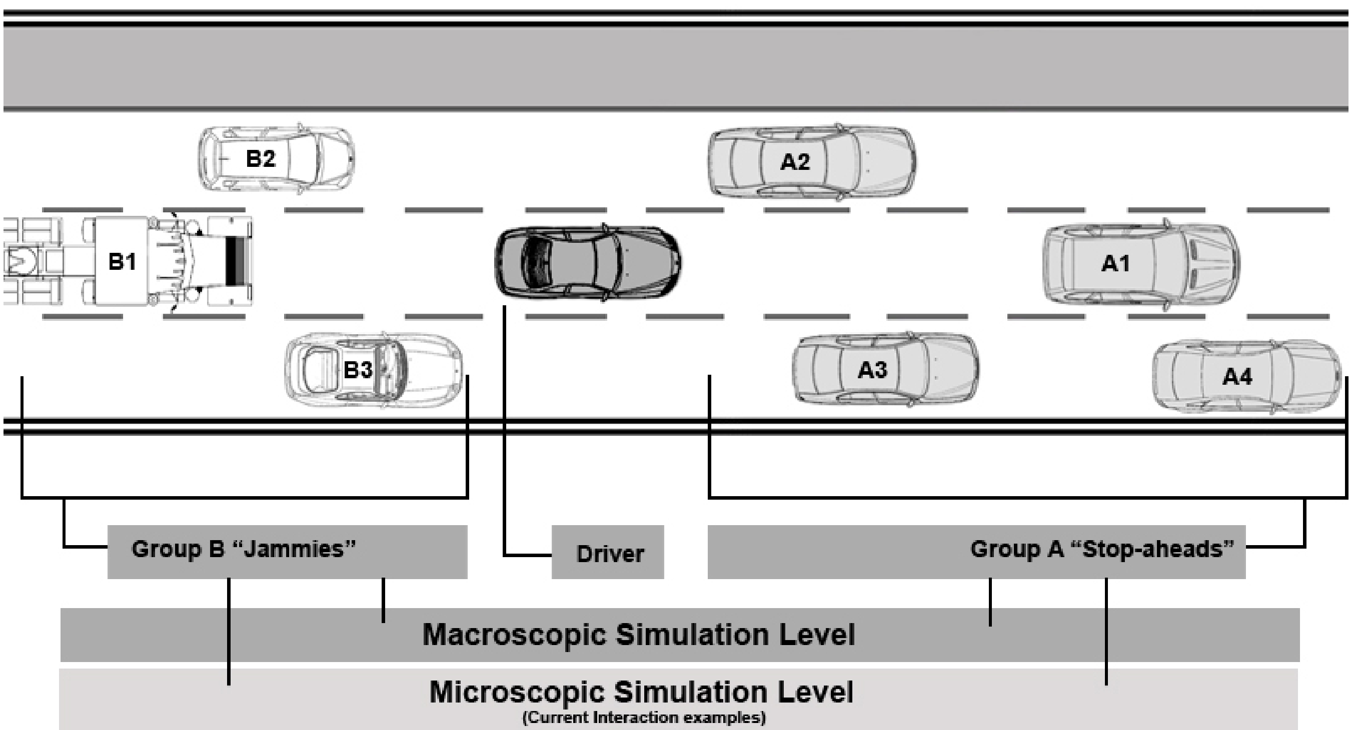
buses, etc. Nevertheless these segments do not have any differentiating attributes per vehicle in the same group, obliterating any individual driving characteristics [14].
However, imitation of real life requires a wealth of different vehicles, driving patterns and reactions to possible events that create an unpredictable traffic flow with unlimited trajectory combinations. Yet, a number of driving constrains should be considered and a simplification model should be applied.
Typically, variation in a scenario depends on the number of different groups of vehicles. Every group is denoted as a set of vehicles that have the same driving pattern within a driving session. Therefore we developed traffic complexity analogous to the demand of our experiment, by using initially a macroscopic method. By clustering the vehicles into two main categories, namely *stop-aheads* and *jammies,* we achieved a better control on the generation of the accident scenarios. Figure 2 shows a diagram of the main categories and their functions in the macroscopic and microscopic method respectively.
In addition we utilized the microscopic method to embed AI into the *robot* vehicles thus creating different driving characters (agents) [14]. The individual behaviour of each agent provides realistic interactions between the *robots* regardless of their group identity. The agent's behaviour can be altered by affecting the setting of values such as general speed, top speed for session, speed close to turns or linearity to lane (distance from centre of lane). Nevertheless, certain restrictions had to be pre-programmed for all agents in order to keep autonomous behaviour within acceptable levels as otherwise some undesired affects could take place.

4. Embedding AI into robots' categories

Human cognition complexity poses the largest obstacle for ideal driver-modelling for any type of traffic flow. Presuming that specific driving characteristics apply to all human drivers namely "common sense", we attempted to mould a generic-reaction form through a list of possible reactions to given situations [15].

4.1 Types of Driving Constraints

Further investigation of the Highway Code and driver's possible reactions identified a number of *soft-constraints* and *rules* that define the uncertainties involved in a simulation model.
The constraints in a driving scenario are set either by road rules, which are obeyed in *normal* situations (i.e. not crashing into the car in the next lane) or by the agent's behaviour (i.e. speed limited by 'fear of crashing'). These



Agent	Vehicle Specs	Current Action	Speed Lmitations	Avoiding	Role	Possible Event
A1	SUV	Accelerates	60-120 km/h	Collision with A4	Stopper	Rear Collision
A2	Limousine	Changing Lane	70-100 km/h	Collision with Driver	Stopper	Rear-Side Collsion
A3	Medium saloon	Accelerating	50-120km/h	Collision with A4,A1	Stopper	Barrier Collision
A4	Large Saloon	Overtaking A1	80-120 km/h	Collision with A3	Event Car	Side Collsion A1
B1	Truck	Following Driver	10-80km/h	Collsion with B2,B3	Pusher	Front Collsion
B2	Small car	Following Driver	20-100km/h	Collision with A2	Constrainer	Side Collision
B3	Sports Car	Following Driver	60-260km/h	Collision with all cars	Chasher	Chase "Bandit"

Figure 2. A diagram of the main robot vehicle categories and their functions

soft-constraints are exactly the ones violated in crash situations. There are also the *hard-constraints* (e.g. moving against the direction of the traffic flow) which if violated render a model utterly void of realism. A simulation therefore can vary its parameters as long as it does not violate the hard-constraints. If a particular variation or *value set* for parameters stays within the soft-constraints then it denotes normal driving conditions, whereas any violation would signify a particular scenario, such as car-following collision due to low visibility.

4.2 "Robot" Vehicles' categories

The two driving accident events mentioned previously, have been stimulated by the *robot* vehicles that populated the track. To achieve the seamless integration of the *robot* vehicles into the traffic flow, a part of the code had to be re-compiled as the initial open source programme has been designated for racing purposes only. Thus, the driving behaviour of 20 vehicles has been individually re-programmed to follow the Highway Code (e.g. speed limits, lane keeping, signalling, etc.).

In the first scenario (sudden braking of the lead vehicles), the *robot* vehicles have been divided into 3 groups called *traffic waves*. The primary purpose of these waves was to intentionally constrain the users from exceeding the speed limit which eventually implicated them in car following accident events. The secondary objective of the waves was to augment the sense of realism.

So, when the simulation starts, the test car is positioned amongst the third wave of vehicles ensuring that the driver would be accompanied at all times during the simulation. At a predetermined point, the lead vehicles of the second wave have ben set to brake abruptly, thus instigating the accident scenario. The succeeding vehicles respond randomly to that event either by braking on time or by colliding with the front vehicles. Given that visibility is limited due to simulated thick fog, the driver has little time to decide on what action to perform. There are two common reactions: harsh braking or manoeuvring around the stopped vehicles via the hard shoulder lane. In the case where collision with the second wave has been circumvented, the first wave of vehicles is repeating the scenario, 300m ahead, maximising in this way the possibilities for accident involvement.

Similarly, for the purposes of the second scenario, we formed two traffic waves groups: the accompanying group and the congestion group. Whereas, the accompanying vehicles had the same driving behaviour as in the first scenario, the congestion group had been allocated virtually motionless behind a sharp left turn, under a complex of bridges. Especially when visibility is low, this accident scenario can be equally hard to avoid, as it is difficult to identify the sharp turn and traffic congestion in advance.

Achieving a high level of realism for the scenarios, was the most important feature for effective evaluation of the proposed HUD. The sense of immersion can be achieved, initially by the presence of a sufficient number of vehicles on the track with a distinguishable variation of behaviours comparable to the variation in reality.

A particularly interesting re-enaction of that driving pattern variation was achieved in the second scenario. As the user is driving along the light traffic he/she encounters a sharp bend under a bridge and traffic congestion at the exit of the curve. It is worth noting that this scenario is actually an existing real problem, so there were no pre-programmed accident events which challenged the driver to react as he/she would normally do. The *robot* vehicles, which were forming the traffic around the driver, were also expected to improvise and react in an analogous manner. A variation of reactions has been recorded when *robot* vehicles attempted to stop behind the static traffic; others tried to manoeuvre around and utilise the hard-shoulder lane while some crashed into the rear of the static traffic. The interaction amongst the different agents and groups enhanced considerably the feeling of reality since the driver could witness a realistic conclusion to the event.

As described in the microscopic method of the simulation, different categories of agents have been applied depending on their role in the forthcoming events. The *major agents* have strongly influenced the particular *key-event* (e.g. an imminent collision) and the *observer agents* indirectly have influencing the final event. The ambiguity in any model is that in real life every driver can alter his/her category status in regards to a hypothetical accident. However in hindsight of a particular key event it is clear that the majority of the drivers behave in a similar fashion so as to be grouped appropriately.

4.3 Driving pattern appearance

Distances between cars and length of simulation are the solution if more and more realism is to be added with randomness also present. A formulation that specifies the changing factors is provided below:

S = (T, User, BrakeVehicle, Observers,…)
Observers = (Gear, Wheel, Speed, stopping Condition...)
Variation(Observers_speed) = within 5% of max_speed
Variation(Observers_brake) = brake to within braking distance of front car
Variation(Observers_stoppingCondition) = stop after traversing X miles or upon being at full brake for more than 3 minutes
BrakeVehicle = (Gear, Wheel, Speed,Brake, stoppingCondition,..)
Variation(BrakeVehicle _speed) = within 5% of max_speed, slow round corners
Variation(BrakeVehicle _brake) = full brake at Track position x
Variation(BrakeVehicle_stoppingCondition) = after crash or after X miles

The simulated groups (*stopaheads* and *jammies*) have 3 specified soft-constraints, yet there are many unspecified constraints due to the vehicle models and road model. Hence there are many variables that must be balanced; more groups increase the number of overall constraints and the chances of having a 'test scenario' on which conclusive judgements can be minimised. When additional events occur in a scenario, it becomes harder to deduce the reason for the key event to happen – as the user might get distracted by many un-realistically 'non-key events' taking place due to vehicles' variation. Nonetheless, that would only add to the realism as such variations exist due to the numerous groups of users on the real road. For achieving both necessary variation for realism and sufficient, non-exaggerated variation the driving time has to be prolonged. In this way, each group in a simulation can exercise its own personality while their influence gets slightly diluted over time (in accordance with general realism) – so that their behaviour will not appear more peculiar than the key-event.

5. AI System Trials and Evaluation

5.1 Challenges and Solutions

During the development of the system we thoroughly tested the vehicles' autonomous reactions and identified possible problems which were later on partially or completely resolved. Although, our initial predictions had minimised the problems for the majority of the participants, in certain cases we had to devise more creative ways to overcome unexpected behaviour. The following two solutions were applied in order to retain the driver amongst at least one of the traffic waves.

"Bandit-Driver" Phenomenon: Even though drivers had been instructed to follow the Highway Code for the entire duration of the experiment, a number of users had exceeded the speed limit substantially. This led to an event-free journey as they had managed to over-take all the traffic waves. After trying out different speeds and chase techniques for the driving agents, we concluded that one of the vehicles should play the role of the "super-car". Hence, one of the vehicles was given the ability to chase and dangerously over-take the "bandit-driver" forcing him/her to slow down until the rest of the traffic would merge into the picture. That ability was triggered by a chosen agent as soon as the "bandit-driver" was out of range of any possible event (1km).

"Timid-Driver" Phenomenon: The antipode of the previous category was a segment of exceptionally slow drivers who are alternatively known as "timid-drivers" [16]. Even when the *robot* vehicles were decelerating significantly, these users were travelling with a speed of less than 30 km/h, thus allowing a considerable distance from the preceding main traffic. This resulted once more in the participant missing out the accident events. The remedy to this was the incorporation of the "fear factor". Ideal for that role was a black truck which was travelling in a conveniently slow speed following in close proximity (not visible due to the fog-effect) the slow vehicle. So, when the user was permitting a greater distance than 1km from the last leading vehicle, the agent of that *robot* vehicle had been programmed to initiate a close-vicinity pursuit. Yet, if the driver persisted with the same driving pattern the truck was also using the horn.

For the validity of the experiment it would be reasonable to exclude the results of both "bandit" and "timid" users from the final statistical analysis. Nevertheless, driving behaviours similar to the ones described above exist in real life, therefore we opted to develop these extra agents with increased selection abilities and trigger events in order to embrace the wider majority of possible driving patterns.

We acknowledge the fact that these initial solutions may not be addressing a number of other possible driving scenarios and driving styles. Hence, it is on our future plans to develop even further these agents and elaborate on suitable distances both for the entire simulation and also between the events with respect to a certain set of groups/drivers. Although this research can initially be purely empirical, particular setups can be tested over time to make sure there are no ill-effects due to randomness. In such simulation scenarios, constraint programming is an avenue for analysis into the trade-off between realism and potential for ill-effects. Further formalisation is envisaged through use of chaos theory for analyzing the extreme scenarios where simulated elements behave unpredictably in the presence of some specific randomly generated value.

6. Conclusions

The substantive safety of the proposed HUD interface was mainly proved through the simulation/reconstruction of the accident events analysed above. The recreation of such complicated scenarios required specific *robot* vehicles to populate the road and create homogenous traffic. These vehicles had to improvise accordingly in order to create the proper conditions under which a selected type of accident could occur. The development of the AI was founded on real drivers' reactions and driving patterns. In addition the highly detailed 3D environment and the driving seat mock-up also contributed towards enhancing the feeling of real motorway driving.

Human reactions and driving patterns can be predicted and recreated to a certain degree as limitations occur due to human cognition complexity. A number of problems that rose during the testing process prompted us to develop additional *robot* vehicle types which would be triggered by specific driving patterns. Although we resolved the problems temporarily, vehicles' AI has to be extended to serve other driving scenarios which could be potentially used for testing the HUD system or for learning purposes.

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