# Testing Advanced Driver Assistance Systems with a Serious-Game-Based Human Factors Analysis Suite

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*Abstract*— **The development of Advanced Driver Assistance Systems (ADAS) is rapidly growing. However, most of the ADAS require field test, which is expensive, unpredictable and time consuming. In this paper we propose a multiagent-based driving simulator which integrates a human factor analysis suite and enables rapid and low-cost experimentation of mobile-device ADAS. Our architecture uses a microscopic simulator and a serious-game-based driving simulator. The latter allows the user to control a vehicle and change the correspondent simulation state in the microscopic simulator. The driving simulator also connects to an Android device and sends several kinds of data, such as current GPS coordinates or transportation network data. One important feature of this architecture is its suitability to serve as an appropriate means to conduct behaviour elicitation through peer-designed agents, so as to improve modelling of various driving styles accounting for different aspects of preferences and perception abilities, as well as other performance measures related to drivers' interaction with ADAS solutions. The potentials of our approach to aid experiments in human factor analysis are still to be tested, but are undoubtedly huge and encouraging.**

## I. Introduction

The mobile and transportation industries both have had remarkable technological advances. The bridge between these two industries results in a huge increase in the development of in-vehicle Advanced Driver Assistance Systems (ADAS). However, even though most high-end cars ship with built-in embedded systems, most of the older cars do not have such devices. An interesting research opportunity arises from these facts, which is to develop and test ADAS that run on low-cost devices, such as an Android tablet or smartphone. This development, however, requires a thorough investigation regarding the safety and efficiency of performing secondary tasks while driving. [1].

The main goal of this paper is to describe the methodology of our MultiAgent System (MAS) based driving simulator and its usage as a means to conduct experiments regarding human factors analysis. We discuss our architecture which comprises both a microscopic simulator and driving simulators. We also detail our implementation of a test-bed to easily develop ADAS, simulating their use in a low-cost and controlled environment.

There are several benefits to testing an ADAS in a simulated environment rather than on a real scenario. As the tests are not conducted in a real physical location, they are not subjected to travel times, traffic or other adverse conditions which could render them mute. This, as well as being able to deploy the simulator in low-cost computers, and therefore reaching more test subjects, leads to time compression of the tests. Noticeably, cost reduction is another significant benefit as the electrical cost of running a simulator is dismissive when compared to fuel costs of real world testing. Besides preventing the safety risks inherent to driving, simulation allows us to control the test environment and manipulate it according the specificities of the ADAS being tested.

The objective of our work was to develop the MAS and the human factors analysis suite. We also wanted to include a test bed that was easy to implement and replicate in low cost environments. We aimed to integrate SUMO microscopic simulator with IC-DEEP, which is a driving simulator developed at LIACC [2] and with the GeoStream framework developed at SI&CG. We also enhanced them with communication of the simulated GPS positions to a mobile device. A mobile application/service was developed as well, in order to receive this communication from the simulator and override the default GPS sensor of the device. Finally, we wanted to make it easy to extend the communication between the simulator and a mobile device. This communication provides the mobile device with more information such as the current speed limit, semaphoric information, or other data from the network.

This work aims to contribute with a novel multi-faceted methodology to simulate and research multiple human factors in Intelligent Transportation Systems (ITS). Particularly, contributing with a novel approach to test ADAS that will enable developers to validate and test their applications more easily and efficiently while reducing costs.

In the following sections we describe the development and results of our implementation. In section 2 we introduce some related state-of-the-art works on the subject of ITS, focusing on simulation, on the integration of different scope simulators and also on the topic of serious games. We then describe our approach, architecture and development details. Finally we present our preliminary verification as well as their analysis in section 4. We finish this paper with a set of conclusions and interesting future work.

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## II. Background

The Artificial Transportation Systems (ATS) [3] [4] concept has been one of the main research topics in the IEEE ITS Society [5]. A typical approach to ATS modelling and development is the MAS metaphor. In this approach each vehicle can be seen as an agent of the system. Another potentially concomitant approach to this modelling is the HLA concept. The concept is based on the idea of distributed simulation, that is, to meet the requirements of all usages and users more than a single simulation model should be used [6]. These concepts can be consolidated to integrate multiple simulators so as to achieve more realistic simulations.

Punzo *et al.* [7] propose to integrate SCANeR driving simulator and AIMSUN traffic-flow microsimulation model. Their attempt is to tackle the mutual-dependence between the driver's behaviour and traffic conditions.

Microsimulation regards simulating and tracking individual vehicle movements. Developed at DLR, the Simulation of Urban Mobility (SUMO) simulator aims at microscopic traffic simulation [8]. The MAS methapor arises as an indisputable methodology to perform microsimulation. Using MAS capabilities and coupling SUMO with other simulators has been researched elsewhere [9]. Macedo *et al.* [6] have studied a HLA-based approach to simulate electric vehicles in Simulink and SUMO. Driver-centric simulation has been research by Gomes *et al.* [10], where they have developed a simulation tool that provides feedback back to the network based on the driver's behaviour.

Our methodological approach to integrate multiple simulators is discussed in the next section.

## III. Methodological Approach

The proposed system architecture is as described in Figure 1. The main module of the system is the SUMO simulator, which is responsible for the network's multi-agent microscopic simulation, and has multiple driving agents. This module provides an overview of the whole MAS and can be manipulated directly. The SUMO module also acts as a "central server", providing all the essential information for both IC-DEEP and the High Fidelity Simulator. This information consists of the network infrastructure and the agents in the system, whereas terrain morphology and road or building geometry are provided by the GeoStream framework. Both of the driving simulators have a local representation of the whole MAS and are capable of controlling any driving agent. The simulators are also able to connect to an Android device and pass along all the information deemed necessary, such as the GPS coordinates of the current driving agent being controlled. The Android device is running a service that receives the incoming connections from the simulator and also the ADAS being tested. Finally, the most significant modules of the system are those that allow us to conduct human factor analysis studies. We describe these modules in more detail in the next sections. The dotted area in Figure 1 corresponds to the developed components as of the writing of this paper.

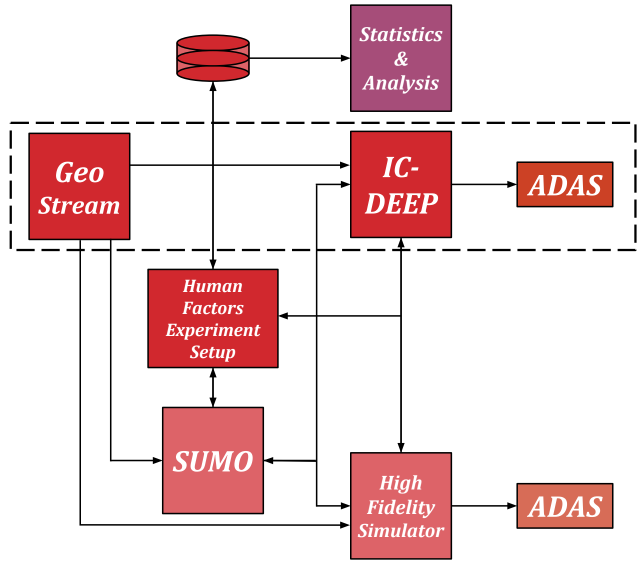

Fig. 1. Overview of system architecture

### A. Simulators & GeoStream Framework

The proposed system architecture has two simulators, however, as of the writing of this paper, only the IC-DEEP simulator has been enhanced and integrated with the system. The latter is implemented in Unity3D and has the GeoStream framework embedded directly. The GeoStream framework connects with OpenStreetMaps, Google Geolocation API, Google Altitude API and other data providers in order to fetch the required geographical information of a given location in real-time. This information is parsed in both simulators to generate a 3D scene that is representative of the chosen test location.

### B. Human Factors Analysis Suite

The most relevant modules of the system are those that comprise the Human Factors Analysis Suite. The "Human Factors Experiment Setup" module has tree responsibilities: i) defining the experiment scenario and preparing the simulators for the relevant data extraction ii) inducing changes in the simulation state in order to achieve the desired outcomes iii) collect and analyze the run-time data in order to adapt the simulation state in response to the driver's behaviours. This module also connects to a database to log all the required data necessary to conduct the studies. The collected data is then processed by the "Statistics and Analysis" module. Data preparation and presentation are the key responsibilities of this module. As discussed in the conclusions section, this module can also be used in a myriad of studies and experiments, such as peer-designed agents and behaviour elicitation.

### C. Mobile device

The Android service sets the current GPS location using *MockLocation* API to override the default location provider.

All applications running on the mobile device that use or perceive the current location will also be affected by the running service.

The new GPS coordinates are sent from the simulator every second, however, this value is a parameter of the simulator and so can be adjusted to the specific needs of each scenario. The developed service can be run as a standalone application, and thus testing the ADAS mobile applications independently, as shown in the left side of Figure 2. There is also the option to use the service as a library in any Android application, as long as it matches API level 19, as shown in the right side of Figure 2.

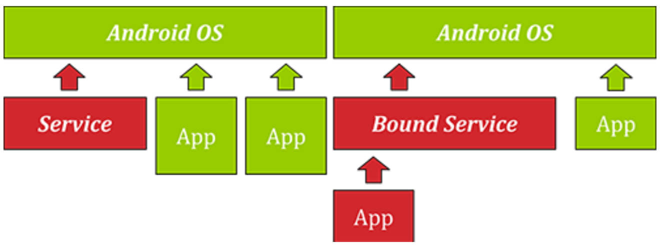


Fig. 2. Standalone mobile app. and mobile app. with library

### D. Interaction

A typical interaction between the simulators and the mobile devices is shown in Figure 3. The modules are connected via TCP sockets due to implementation simplicity. The communication messages are formatted in JSON and therefore the message contents can be easily changed to add different kind of data. The basic message template contains two obligatory fields, which are **latitude** and **longitude**. Other optional fields are the current *speed*, the GPS *accuracy*, the message *timestamp* or even the *speed limit* from the current location. A specific instantiation of this interaction is discussed in the next section.

## IV. Preliminary Verification

The preliminary verification to assess the proof of concept and also the efficiency of the developed architecture focused on the modules in the dotted area of Figure 1, the remainder of the system will be developed later, as mentioned on the next chapter. We have divided the verification into two independent tests. In the first one we test the simulator accuracy to represent real world scenarios using the GeoStream framework. The other test aims to test the emulation of the GPS signal on the mobile device. Both of the tests were performed in the same geographical location, which was Porto's downtown, at *Avenida dos Aliados*, seen in Figure 4.

### A. Simulator Accuracy

To test the simulator accuracy we have collected multiple GPS trace logs while driving a real car in the selected geographical location. We have then overlayered a visual representation of the obtained traces on the simulator and on Google Earth both, the results can be seen in Figure 5. The results show that the generated 3D scene is highly

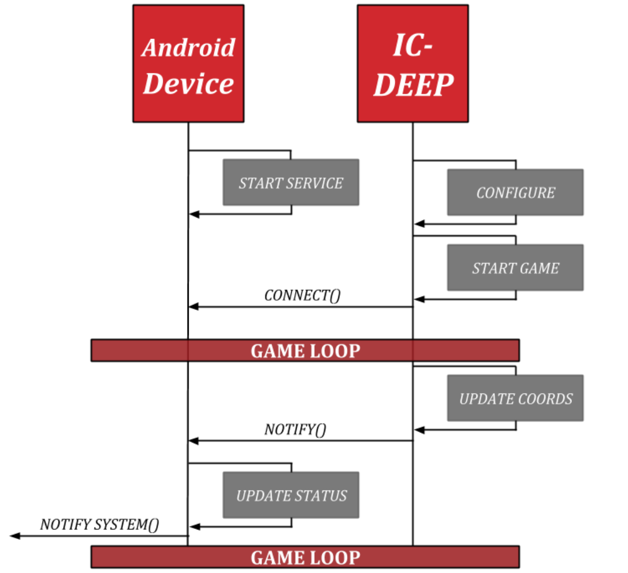


Fig. 3. Typical interaction between IC-DEEP simulator and an ADAS

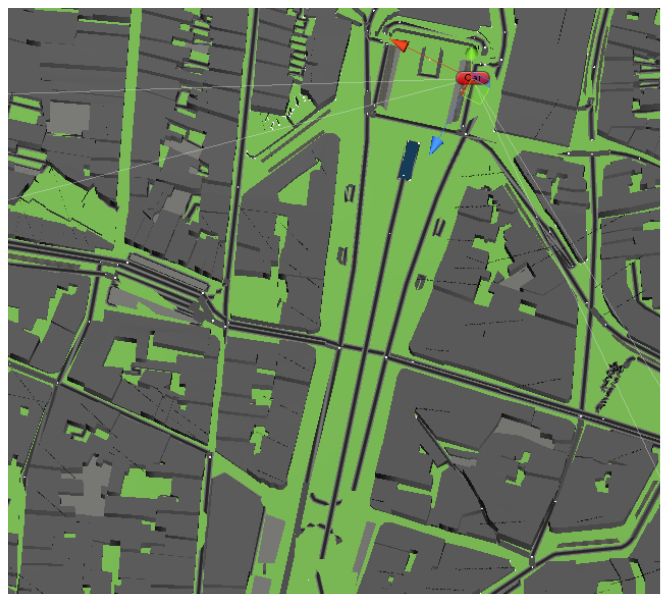

Fig. 4. Generated 3D Scene orthographic view

representative of the real world location. In one of the trace logs we have noticed an error and highlighted it in Figure 5, this error happens due to the data being collected as raw, untreated GPS, where the *road matching* algorithm [11] has not been applied. This is also an interesting result, as the error can been seen in both the simulator and Google Earth alike.

Apart from testing the fidelity of the simulation with GPS trace logs, it is also noticeable that orthographic view of the generated 3D scene very much resembles the satellite image of the same location, as can be seen in Figure 6.

### B. Mobile device ADAS

To test the communication and emulation in the mobile device the setup consisted of a basic usage scenario, using a simple *ADAS* that shows the user his current and average speed, the total kilometers travelled, and, most importantly, warns him when he exceeds the speed limit of the current location as shown in Figure 7.

The interaction between the simulator and the mobile application followed that of Figure 3. To run the simulation the mobile application must be started and the device's IP address, which is shown in the application initial screen, must be entered in the simulator configuration screen. After this the simulation can start and the simulator internally updates the geographical coordinates as the driver traverses the network. These coordinates are passed to the mobile device as described above, every second and via a JSON formatted message over a TCP socket.


Fig. 5. GPS Traces on the simulator (left) and Google Earth (right)

In this particular simulation the information sent to the mobile device consists of the current GPS coordinates and the speed limit of the current location. The heading of the vehicle is calculated internally by the mobile application using a simple algorithm that computes the bearing with the last two known locations and thus, even though this can be done easily, there is no need to pass an orientation variable from the simulator.

The main goal of this experimentation was to understand whether or not the mobile device simulated GPS position and calculated speed matched those of the simulator. We have used the driving simulator and Google Maps application to compare the marked position while driving. To compare the driving speed we have used the developed ADAS.

Even though the results from the simulator and the mobile device were not recorded, any inaccuracies were not noticed when testing. The only possible minor differences would be due to the fact that the Google Location API on the Android device automatically adjusts the current position to the nearest road, which is, as mentioned above, a technique called *road matching*.


Fig. 6. Satellite image of Av. dos Aliados

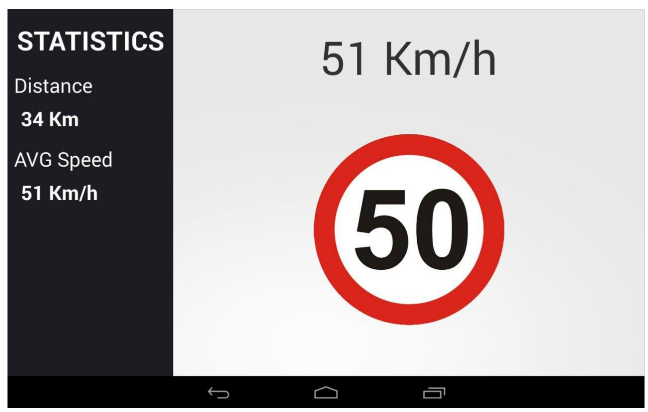


Fig. 7. Developed ADAS

## V. Related work

Driving simulators are no doubt an important tool when researching ATS, specially so when studying the influence of human factors in driving faults [2]. These faults often occur in direct consequence of performing secondary tasks while driving [12].

The top, state-of-the-art simulators are usually the high-fidelity, human-in-the-loop simulators [13]. Typically, these simulators have motion simulation and provide the driver a high field of view. The modern high-fidelity simulators have 9 DOF [14] and can even include a full 360 degree dome [15].

These simulators serve a multitude of purposes in terms of scientific research. For instance, the Leeds University simulator [16] is used to research topics such as the effects of automated systems on safety and driver comprehension of traffic signs. Just as the NADS-I [17] is used to conduct tests that are too dangerous or even illegal and/or unethical, such as the effects of illness, drowsiness, inattentiveness etc. A system comprising a large scale driving simulator, built in a 360 deg full dome with 3D scenes from real city area has been developed by [15]. The system contains a multitude of features such as real-time hardware-in-the-loop, wireless communication devices and bio signal analysis and is used to develop and test ADAS as well as Advanced Safety Vehicle, ITS infrastructure and others.

However highly technological and high fidelity simulators are typically expensive and lack the extensibility and portability of the low-cost simulators. A low-cost and reconfigurable driving simulator with several components to accommodate different ADAS testing or training is proposed by Hassan *et al.* [18]. A framework for ADAS assessment and benchmarking has been developed elsewhere [19], with configurable scenarios and 3D scenes and multiple sensors input. Miao *et al.* [20] introduce a game-engine-based simulator for modeling and computing platform for ATS. They describe the artificial population both in their macroscopic and microscopic aspects.

Gruyer *et al.* [21] developed a Full Speed Range Adaptive Cruise Control with their platform for ADAS prototyping and evaluation, SiVIC. The platform is capable of reproducing the vehicle and sensors behaviour in a realistic fashion, according with the configured environment in the simulator. The developed platform also simulates noised and imperfect data.

Finally, the IC-DEEP low-cost serious-game driving simulator [2] has been developed in LIACC. This simulator can be used to conduct human factors experiments in controlled scenarios. However, it also lacked extensibility, ie., the experimentation setup was hardcoded in the simulator. Therefore, in order to achieve the intended methodology, it as been integrated with the GeoStream framework and enhanced with communication with an Android mobile device.

## VI. Conclusion

In this paper we have proposed a multi-faced MAS-based driving simulator architecture. We have also proposed a methodology to use the system as a means to simulate and test multiple aspects in human factors in ITS, generally. More specifically, we have introduced a test-bed to easily develop ADAS and test them regarding the safety of the drivers or their influence on the transportation network.

We consider the system to have a wide spread of applications. Among others, we identify some that we find more expressive, such as: i) supporting a Serious Game [22] to test driving behaviours and ergonomics ii) conduct experiments with peer-designed agents to simulate driver's idiosyncrasies effects on the ATS iii) prototyping and validating Advanced Driver Assistance Systems.

The preliminary verification has proved the system efficiency and usability, as well as its ability to accurately represent real world scenarios without the need of extensive 3D modelling or expensive hardware setups. This ability allows researchers to conduct studies regarding singularities of the different geographical locations.

As discussed in the methodological approach section, one major issue of the system is the coherency in the representation and modelling of the real-world transportation network. This is a current limitation to the SUMO microscopic simulator as it generates unrealistic ways and intersections. However, we plan on tackling this issue by introducing a higher-level representation of the network which is parsed consistently by all the simulators.

In addition to implement the remaining components of the proposed methodology, there is an ambitious workload of further developments. We would like to point out some that we consider to be a priority and more challenging. We believe it would be interesting to support batch simulations, in order to collect significant data and extract more elaborate conclusions. There are also driving simulator specific improvements that we envisage, such as more detailed scenarios and improved physics. Another interesting improvement would be to allow multiple agents to connect to multiple ADAS, simulating distributed ADAS applications while extending SUMO capabilities. There are also improvements to be done in the GeoStream framework, specially regarding road generation and also importing models and textures for different buildings.

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