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A numerical tool for reproducing driver behaviour: Experiments and predictive simulations

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ABSTRACT

This paper presents the simulation tool called SDDRIVE (Simple Simulation of Driver performance), which is the numerical computerised implementation of the theoretical architecture describing Driver–Vehicle–Environment (DVE) interactions, contained in Cacciabue and Carsten [Cacciabue, P.C., Carsten, O. A simple model of driver behaviour to sustain design and safety assessment of automated systems in automotive environments, 2010]. Following a brief description of the basic algorithms that simulate the performance of drivers, the paper presents and discusses a set of experiments carried out in a Virtual Reality full scale simulator for validating the simulation. Then the predictive potentiality of the tool is shown by discussing two case studies of DVE interactions, performed in the presence of different driver attitudes in similar traffic conditions.

1. Introduction

This paper aims at discussing a simulation tool called SDDRIVE (Simple Simulation of Driver performance) that implements, in a computer program, a set of algorithms and numerical expressions which follow the theoretical model describing Driver–Vehicle–Environment (DVE) interaction discussed in Cacciabue and Carsten (2010). In particular, the theoretical model gives the architecture and main guidelines for representing decision making processes and error generation, whereas, the simulation algorithms includes also the behavioural part, i.e., how decisions are actually transformed into actions and human performances. For the behavioural part, the simulation tool has applied the modelling structure known as SRK, for Skill-Rule-Knowledge (Rasmussen, 1983) and a number of paradigms which enables to account for sensory-motor activities.

This type of implementation is universally recognised as a very difficult endeavour. However, the ability to represent by theoretical architectures different features and aspects of a complex Human-Machine-System (HMS) has evolved with the scientific progress, and the possibility to transform such theories into numerical expressions has equally improved with the advances in computer technology. As an example, nowadays, the use of "agents" and Object Oriented Programming offers the possibility to represent in computerised architectures a variety of "almost" autonomous components that describe quite complex mental and behavioural activities (Amditis et al., 2006).

The use of numerical solutions for describing complex systems requires computerised programs which are able to reproduce and represent realistic behaviours of the systems that they aim to simulate. In the case of SSDRIVE, in order to assess the ability of the simulation to capture the basic driver performances, a set of experiments have been carried out in a Virtual Reality (VR) full scale simulator. The collected data have been analysed in detail. This offers the basis for evaluating the ability of the simulation tool to reproduce the behaviour observed in the experiments.

In this paper, the SSDRIVE tool is initially briefly described with the objective to recall its essential algorithms and correlations, with no specific and detailed discussion, as this is found somewhere else (Cacciabue and Carsten, 2010). Then, the set of experiments carried out in a VR full scale simulator are reported and discussed in detail, with the goal to offer the reader the complete overview of the collected data and the analysis performed. In the following section, the predictive ability of the tool is documented, showing the type of analysis and evaluation that can be performed when attitudes and personal characteristics of different drivers are modified by input data. In particular, two case studies are analysed in the presence of different driver behaviours in similar traffic conditions. Finally, the conclusions focus on possible further development of the simulation and its potential exploitation for improving safety and design approaches.

It is important, for the reader of this paper, to realise that the theoretical stand for the driver model has been presented and discussed elsewhere in this volume, and the goal of this paper is

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mainly to demonstrate the ability of the simulation to predict and represent basic and logical driver behaviour. This is an essential requirement that must be fulfilled before embarking in more complex and elaborated software developments that would otherwise turn out to be too fragile, in terms of simulation power.

Moreover, the ability of the overall DVE model to cope with the challenges posed by increasing levels of complexity is also an important aspect of the simulation to be considered. This derives from two main issues: 1) the imbedding of cognitive variables such as driver intentions, motivation, or attitudes; and 2) the inclusion of driver assistance systems like speed limiter, adaptive cruise control, lane change assistant etc. The discussion about these issues from the theoretical point of view has been performed in the above mentioned paper on the driver model. From the software development perspective, the basic architecture of the simulation has been designed from the early stages to allow for future complexity and for the inclusion of more and more variables, in order to enable the representation of complex predictions of decision making and actions, in the presence of advanced driving support systems. However, the description of the overall ontology that sustains the DVE simulation is considered outside the scope of the present paper and is not discussed here.

2. Simulation tool and modelling behavioural performance

The overall model of the Driver, Vehicle and Environment (DVE Model) is based on the concept of the "joint" cognitive system, where the dynamic interactions between driver, vehicle and environment are represented in a harmonized and integrated manner. The model aims to represent the interaction between Driver–Vehicle–Environment in a simple and fast running way, which retains the essential correlations between the independent variables and enables to predict driver behaviour in *dynamic* and rapidly changing conditions. For this reason, the model focuses on the Driver cognitive and behavioural performances, whereas the other two components of the joint DVE system, i.e., Environment and Vehicle, are dealt with relatively simple correlations.

The DVE model and simulation offer a valuable tool for the designer and evaluator of control systems, such as Advanced Driver Assistance Systems (ADAS) and In-Vehicle Information Systems (IVIS). In this sense, the DVE model allows the rapid and very cheap performance of many different simulations giving an overview on a spectrum of different initial and boundary conditions, enabling to study different driver profiles, environmental conditions and scenarios.

At present, the overall DVE modelling architecture is governed by the concept of *parameters* which enable the consideration of dynamic behaviour and interaction between the three components of the DVE system, as well as the simulation of the error making process. The *parameters* that govern the mode, according to its theoretical formulation (Cacciabue and Carsten, 2010) are: *Experience/competence* (*EXP*), i.e., the accumulation of knowledge or skills that result from direct participation in the driving activity; *Attitudes/personality* (*ATT*), i.e., a complex mental state involving beliefs and feelings and values and dispositions to act in certain ways; *Task Demand* (*TD*), i.e., the demands of the process of achieving a specific and measurable goal using a prescribed method; *Driver State* (*DS*), i.e., Driver physical and mental ability to drive (fatigue, sleepiness…); and *Situation Awareness/Alertness* (*SA*), i.e., perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near futures.

The model is based on the well known and "classical" Information Processing System (IPS) paradigm (Neisser, 1967; Newell and Simon, 1972). Since the 70 s, this metaphor generated many formulations of theoretical models of cognition, which assume that a human behaviour can be described in as similar way of a "system" that "processes" the information and signals to which it is exposed. The most known examples of the IPS paradigms are the Skill–Rule–Knowledge (SRK) model of Rasmussen (1983, 1986) and, specific for the domain of automotive transport, the Michon's (1985) scheme, where the (primary) driving task can be described at different levels of abstraction, namely strategic, tactical and operational. While a detailed description of the theoretical framework and modelling of the DVE and of the Driver in particular, is given elsewhere in this volume, this paper concentrates on some specific aspects of the computerised numerical simulation.

The overall requirements of the simulation associated to the driver model are that of being *predictive*, *simple* and *fast running*, accounting for *dynamic interactions*, *human errors*, and *adaptive behaviour*. A very simple model that respects the principles of the IPS paradigm, and enables the consideration of these requirements is the PIPE (Perception, Interpretation, Planning and Execution) model (Cacciabue, 1998). The PIPE model is fully focused on four basic *functions* that govern the IPS mechanisms. These are: 1) Perception of sensorial inputs (signals) generated by the Vehicle and Environment; 2) Interpretation of relative information; 3) Formulation of goals and intentions and/or selection of tasks to be carried out (Planning); and finally 4) Execution or performance of actions.

The five *parameters* that govern the theoretical formulation of the SSDRIVE cover mainly the first three *functions* of the PIPE modelling architecture, namely Perception, Interpretation, and Planning. They offer the possibility to account for *decision making*, associated to "normative" as well as "descriptive" behaviour, in the presence of limited resources or adaptive aspects. Moreover, *Human error* can be considered at this level, i.e., in terms of erroneous mental processes and decision making.

In other words, this modelling part utilises the environmental and vehicle variables perceived and interpreted by the driver to develop typical decision making quantities, such as *intended speed*, decisions to *overtake* or *stop the vehicle*, to *attain higher speed*, or *lower speed*, or to *maintain speed*, etc. Most importantly, the error generation model, based on the so-called BIDON model (Basic Indicators of Driver Operational Navigation) (Cacciabue et al., 2007) also resides in this part of the model. In this way, the root causes of human erroneous processes at perception, interpretation and decision making level can be traced, whereas the visible forms of erroneous behaviour are shown as result of the behavioural part of the model.

The behavioural part of the simulation, described by the 4th *function* of the PIPE modelling architecture, i.e., Execution of actions, has not been particularly dealt with at theoretical level, as it simply devoted to the implementation of actions and the manifestation of errors. These are the actual actions performed by the driver, according to the decision making part of the simulation, and the implementation of activities derived by sensory-motor reactions. The most known and recognised modelling architecture that accounts for this type of activities is the "skill-based" behaviour component of the SRK Model of Rasmussen (1983). Examples of typical "skill-based" activities are the control of *lateral* and *longitudinal safety margins*, as well as the acceleration (or deceleration) applied, once the decision of overtaking or attaining higher (or lower) speed has been taken, as result of a process of *Perception–Interpretation–Planning*.

In particular, the behavioural part of the simulation implements a number of algorithms for the control of steering and the attainment of intended speed (acceleration/deceleration) as follows:

- The control of the speed and acceleration has been developed on the basis of empirical correlations (Oregon State University