Intelligent Agents for Supporting Driving Tasks: An Ontology-based Alarms System

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Abstract: This paper presents a rule-based alarm system as part of an ADAS. This work is developed by using a multi-agent framework, and it focuses on the driving safety, in particular, in urban environments. The main point of the proposed system is that it takes decisions based on the fusion of the information from the driver, the vehicle status and the state of the road ahead, and it is designed to alert the driver of the car (without taking control of it) only when the system considers that it is necessary. Five dangerous scenarios are defined, analysed and studied, and a repository of rules is designed to help the driver in that situations. In order to represent the concepts and its relation about the urban traffic environment, the system uses an OWL Ontology based on a previous research and extended in this work.

1 INTRODUCTION

Road traffic safety is a subject that is of a great importance worldwide. Public administrations, especially European Commission, are concerned about it. The percentage of people who die on the road each year has been growing in recent years. According to the Global status report on road safety 2015 by World Health Organisation (WHO, 2015), road traffic injuries claim more than 1.2 million lives each year, which causes a negative social impact, and a negative economic impact too. In addition, it is known that about 78% of crashes are due to driver distractions.

That is why both industrial and academic communities are interested in Advanced Driver Assistance Systems (ADAS). ADAS are systems developed in order to help the driver in the driving process, increasing car safety and, more generally, road safety. Nowadays, more and more vehicles incorporate ADAS, not only in high-end cars, but also mid-range cars and even few low-end cars.

These systems use information about the car, and also contain information about the environment and/or the driver himself. After a process of reasoning with obtained data, an ADAS produces a response in order to avoid or face, for example, dangerous traffic situations or driver distractions. ADAS responses can be as a visual alarm, sound alarm, or even taking control over the car (e.g. turning the steering wheel, braking, etc). However, researches about system warning design show that an incorrect design can influence negatively on the driver's behaviour, on one hand, increasing his/her workload therefore decreasing his/her situation awareness (Vahidi and Eskandarian, 2003) and, on the other hand, ignoring the warning produced by the system (Lee et al., 2004).

In this work, a multi-agent system is developed to integrate the information provided by a driving simulator and to use this information in order to help the driver on his driving task in an urban environment using an ADAS. This support is given by triggering and showing visual and sound alarms (depending on the type of launched alarm) when dangerous traffic situations are occurred.

After this introduction, this paper is organised as follows. The next section provides an overview of the background and related work of ADAS and alert systems. Section 3 describes the conceptual framework in which this research is set. Section 4 details the data modeling and the definition of traffic scenarios, rules and HCI messages. Section 5 explains the experimentation process, including materials, testing process and results. And finally, Section 6 presents the conclusions and suggests some future works guidelines.

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2 STATE OF THE ART

As mentioned in Section 1, road traffic safety is a serious area because of its social and economical impact. For years, the number of investments and investigations oriented to this topic has grown both privately (by automotive companies) and academically. One recent example of cutting-edge private technology is *IntelliSafe* in Volvo. It consists in a number of ADAS that are incorporated in Volvo cars in order to enhance their safety such as the world-first intersection braking technology or the bird's-eye view of the car and its surroundings that allows driver to see obstacles all around him (Volvo, 2016).

However, industrial community usually do not communicate their research results apart from advertises of released products or not specific enough reports. On the contrary, academic community has been very focused on this topic, aware of affordable technology for mass-market vehicles.

Examples of ADAS that are already incorporated in current vehicles are Lane Keeping Assist (LKA) (National-Safety-Council, 2016), Autonomous Emergency Braking (AEB) (Euro-NCAP, 2016) or Maximum Speed Permitted Assistant based on Automatic Signal Detection (Tu and Fuh, 2016).

A recent publication about ADAS is a real time driver distraction alert system for highway driving for trucks where, taking account of the controls of the vehicle, the system is capable to identify distractions on the driver and to notify him using alerts (Dababneh, 2016). More recent publications are a smartphone-based warning system in area of a construction zone that notifies drivers about upcoming conditions within a construction zone (Qiao et al., 2016) and a driver intention algorithm for pedestrian protection and AEB systems (Diederichs et al., 2015). The latter is an algorithm developed to detect driver's intention before initiating such transitions to automated driving as AEB in order to avoid annoyance, and it is based on eye tracking of the driver and pedal activity of the vehicle. These systems are not included in vehicles yet, but they represent new opportunities for the future vehicles.

The research presented in this paper is based on (Gutierrez et al., 2014). This paper presents an agent-based system as part of the development of an ADAS focused on urban driving safety. This system takes decisions using information from the driver, the vehicle status and the state of the environment. To represent the concepts and its relation about the urban traffic environment, an OWL Ontology is developed (Feld and Mller, 2011).

Most of new researches and discoveries require the reproduction of dangerous, extreme or even unusual or impossible driving situations. Play this situations in real life would be sometimes unhealthy and unethical, so that is why most of them use a driving simulator (i.e. a truck driving simulator in (Dababneh, 2016)). This allows making any experiment, to recreate any situation and to obtain all possible data of it.

Nowadays, there is a hard inter-brand competition in ADAS and road safety in the car sector. Thus, most of published research reports are too unspecific or unclear, so there is limited information about driving simulators employed. Each brand usually has its own driving simulator and doesn't share much information about it.

Examples that have been obtained of driving simulators able to researchers are Carnetsoft research driving simulator (Carnetsoft, 2016), VS500M car driving simulator for educational and research activities (Simulation, 2016) or ST Software driving simulator for research (Software, 2007).

In relation with these work, the realised works in (Olmeda et al., 2013) (Peláez et al., 2012) (Musleh et al., 2012) are focused on the development of ADAS modules with the integration of new physic sensors on vehicles, such as laser technology or cameras, and the development of analysis methods that take the signal produced by these sensors and obtain high level information about the driving environment.

3 CONCEPTUAL FRAMEWORK

As it has been exposed before, there is a growing trend of incorporating each time more ADAS with safety features. Consequentially, SAE International (Society of Automotive Engineers) defines a scale for identifying an ADAS according to the automatisation level that offers while a driving task is been performed (SAE, 2014). Focusing our attention on ADAS without automatisation of driving controls and whose purpose is only to warn about potentially risky situations, they don't take account whether the driver is aware about the risk or not. Therefore, to increase this kind of systems on the instrumentation of the car, keeping the independence between themselves and ignoring the driver's perception could become counterproductive, because the driver may be saturated with a lot of irrelevant warning messages. Thus, the direct consequence of this fact is that these systems could lose their effectiveness and all the meaning for which they were designed.

We propose a system that acts as a human Co-driver, providing to the driver of the car only the relevant information for him/her on each moment. High-level ADAS that manages all the other ADAS with safety features and identify whether the driver of the car really needs the information provided through these ADAS according to his/her attention level. All this information will be unified under the same interface and the interaction with the driver of the car will be adapted to the environment requirements, where the driver must pay attention on the driving task at most of the time.

The Figure 1 shows an overview of the conceptual framework for the development of the Intelligent Co-Driver where are included the involved concepts for designing this ADAS approach based on providing to the driver relevant high-level information about driving task on real time.

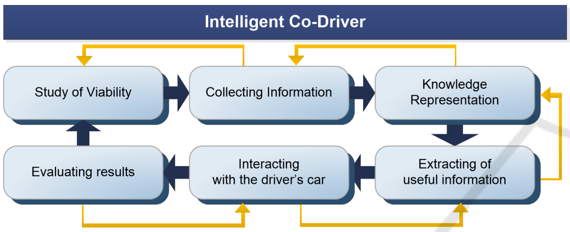

Figure 1: Overall Conceptual Framework for development intelligent Co-Driver.

The Intelligent Co-Driver development process involves several disciplines and research fields such as Electrical Engineering, Signal Theory, artificial intelligence including the computer vision and the predictive computational models.

How it can be seen in Figure 1, the Intelligent Co-Driver development follows a continuous improvement cycle composed by five activities basically.

At first, this cycle starts by studying how an Intelligent Co-Driver functionality can improve the *road safety* and *User Experience* (uEx), analysing what are the needs of a driver while he/she is performing a driving task, studying its viability and evaluating its acceptance level and the socio-economic impact that would mean its implantation on the vehicles.

Secondly, it is performed the *collecting information activity* that consists of the researching about what information is required for the development of Intelligent Co-Driver and what are technological resources that provide that information.

Next, on the *knowledge representation activity* it is studied the best way of modeling all the information obtained on the previous activity through the ontology. The main goal is the standardisation of a data model that should consider all the possible aspects involved on a driving task.

Then, it is conducted the *extracting of useful information activity* that consists on a research process that takes the data model as input for obtaining cognitive model for a specific Co-Driver functionality that provides relevant information for the driver.

After, the *driver interaction activity* studies what is the better way for transmit this useful information to the driver regardless of age, sex and his/her level of familiarisation with the new technologies.

Finally, the Co-Driver is evaluated in terms of usability, reliability and performance. At the end of this activity, the cycle comes back to its first activity.

Each activity is feedback for its next activity, going back if it will be necessary in order to accomplish the established requirements at beginning of the development process.

4 SYSTEM DESCRIPTION

In this section, it is described the alarm system based on rules that has been developed, by detailing the data modeling and the traffic scenarios, rules and HCI messages that have been defined.

4.1 Data Modeling

The alarm system works in the driving simulator environment, and it has to read, interpret and understand all the information that is in there. That is why all the data has to be modeled, structured and integrated.

Data modeling is done by designing an *OWL/RDF Ontology*, which provides a formal definition that gives semantic structure to data. It represents the concepts and its relation about the urban traffic environment, and this concepts contain information that comes from the driver, the elements outside the vehicle, and from the vehicle itself. Therefore, each instance of the ontology is a traffic situation that is going to be analysed, and making queries to the ontology allows getting this instances.

As mentioned in Section 2, this research is based on (Gutierrez et al., 2014). In that paper, it is designed and described an *OWL/RDF Ontology* that represents the starting point for data modeling in this work. It can be observed that concepts of car, driver, car context, pedestrian and pedestrian crossing the street are defined, and each one of these concepts has its own attributes. Right after, it is described the discrete values that have been used in this work for each attribute.

- **Car**:
  - **Distance to car**: far away, far, normal, close, very close.
  - **State (of the vehicle)**: moving, stopped.
- **Driver**.

  - **Area of vision**: front, front-right, front-left, left, right, behind-left, behind-right, interior rearview mirror, left exterior rearview mirror, right exterior rearview mirror, speedometer, radio / air conditioning / down, roof / up.
  - **Attentive**: yes, no.
  - **Horizontal/vertical direction of the eyes**: centre, left/up, right/down.
- **CarContext**.
  - **Existence of car in front/left/right**: yes, no.
  - **Existence of pedestrian/pedestrian crossing**: yes, no.
- **Pedestrian**.
  - **Angle (relative to driver)**: front, front-left, front-right.
  - **Distance**: far away, far, normal, close, very close.
  - **Trajectory**: N, S, E, W, NW, NE, SE, SW.
- **PedCrossing**.
  - **Distance to pedestrian**: far away, far, normal, close, very close.

As mentioned before in this section, this ontology represents a starting point. It represents basic concepts, but it is incomplete. For this actual research, the ontology is extended in order to encompass a wider range of information and, thus, be able to address more complex danger situations with the rule-based decision-making system developed.

It is added to the car context the existence of cars near the considered, in more positions: behind, behind-left, behind-right, front-left and front-right. Besides, it is included a new concept: the concept of the driver's vehicle (*MyCar*). This concept has the following attributes:

- **MyCar**.
  - **Brake/Clutch/Throttle**: full, none, medium.
  - **Gear**: -1, 1, 2, 3, 4, 5, 6.
  - **Lat/long accel.**: high, medium, low, null.
  - **Revolutions per minute**: [0, maxRev].
  - **Speed**: high, medium, low, null. (It is defined medium speed as approximate values relative to maximum track speed).
  - **Steering wheel angle**: left, centre-left, centre, centre-right, right.

The proposed ontology diagram is shown in Figure 2.

4.2 Defining Traffic Scenarios

This research is oriented to urban driving. In addition to the fact that most of researches are based on road driving (Dababneh, 2016), in urban driving there are many potential dangerous situations.

In this work, five dangerous traffic scenarios are defined and analysed. To identify and define these scenarios, an online survey was conducted to drivers with different profiles (age, sex, experience, among others) about dangerous situations of urban driving and the acceptance of an ADAS in such cases (surveys and results can be found on http://www.caos.inf.uc3m.es/adas-driver-modeling/).

Consequently, a previous work about identifying risky driving situations and the survey results, the following five driving scenarios were defined, considering them as representative for this first approach. The concepts that are included in the proposed ontology are used in order to define them.

- **Scenario 1: Risk of frontal collision**. The driver is distracted on a road where there is medium-intense traffic, and the distance to the car that precedes the driver is reduced, becoming very short.
- **Scenario 2: Risk of running over**. While the driver is circulating through an urban environment, a pedestrian crosses the road at a distance relatively close to the vehicle.
- **Scenario 3: Risk of rear collision**. An overtaking is going to take place, but the car behind the driver's vehicle is overtaking or initiates the passing too.
- **Scenario 4: Risk of lateral collision**. While the driver is circulating through an urban environment, a stopped car starts and initiates the movement in a relatively short distance.
- **Scenario 5: Pedestrian not visualised**. While the driver is circulating through an urban environment, a pedestrian crosses the road from behind a parked vehicle or there is an object that makes the pedestrian not visible to the driver. The difference between scenario 2 and this scenario is that now the pedestrian is not always visible, so now the situation is more critical.

4.3 Defining Rules

Once data have been integrated, modeled and structured, and the scenarios have been designed, the rules can be defined. Specifically, seven rules are defined to identify the five dangerous scenarios established, with the objective of helping and warning the driver in order to avoid road accidents.

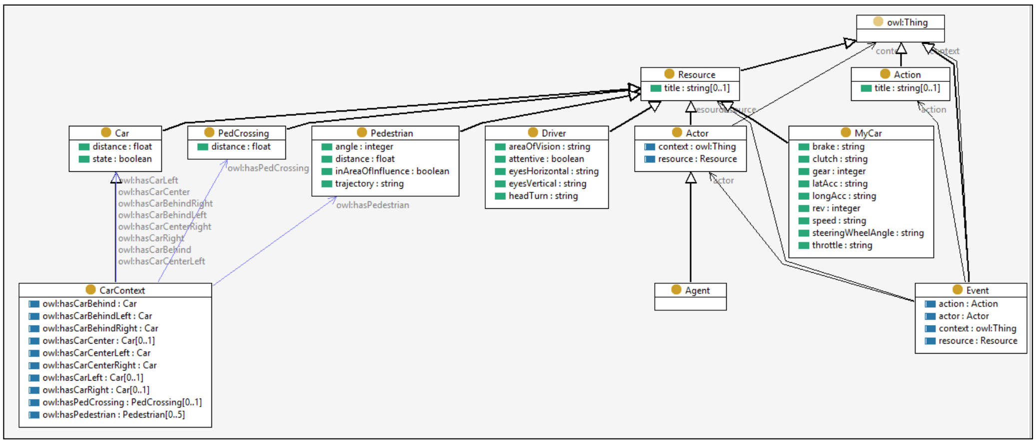

Figure 2: Proposed ontology diagram.

An expert system design process was carried out for the rules definition. This process required gathering information from several sources such as (1) conducting interviews with driving instructors, (2) analysing the Spanish driving regulation and driving manual (DGT, 2017) that define how the driver must deal with each driving situation and (3) obtaining the drivers' opinion with the conducted surveys.

Each scenario has one or several rules that detect the potential danger and launch an alarm to the driver. It is shown each rule/set of rules for each scenario below. It is described the situation that makes the rule to be activated, and, thus, the rule produces an output.

- **Scenario 1**: Risk of frontal collision.
  - There is a car, close or very close, in front of the vehicle.
  - The driver is not attentive.
  - The speed of the vehicle is medium or high.
- **Scenario 2**: Risk of running over (two rules, one for pedestrians that cross to left and one for pedestrians that cross to right).
  - There is a pedestrian, close or very close, crossing the street.
  - The driver is not attentive.
  - The speed of the vehicle is medium or high.
- **Scenario 3**: Risk of rear collision.
  - There is a car, close or very close, in front of the vehicle.
  - This car is going to be overtaken by the vehicle.
  - There is a car in movement behind the vehicle, close or very close, that could want to pass the car too.
- **Scenario 4**: Risk of lateral collision.
  - There is a car parked on the right side of the road that may start and join the road.
  - This parked car is very close, close or medium distance.
  - The driver is not attentive.
- **Scenario 5**: Pedestrian not visualised (two rules, one for pedestrians on the left side and one for pedestrians on the right side).
  - There is a parked car ahead of the vehicle.
  - There is a pedestrian behind of the parked car.
  - The trajectory described by the pedestrian's movement indicates he/she is going to cross the road.

Since the system has only one output, a hierarchy of alarms is needed and has been implemented. The same process as the dangerous situations has been followed in order to design the implemented hierarchy. This hierarchy is shown below (Table 1).

Table 1: Alarm hierarchy (ordered from highest to lowest priority).

Scenario	Alarm	Priority
Scenario 2	Risk of running over	1
Scenario 1	Risk of frontal collision	2
Scenario 5	Pedestrian not visualised	3
Scenario 4	Risk of lateral collision	4
Scenario 3	Risk of rear collision	5

Consequently, if two different alarms are launched, only the one with the highest priority will be processed. The highest priority scenario is given by the risk of running over, because human life is in danger. Next, there is the risk of frontal collision, followed by the hit of an unseen pedestrian. This order is followed because a car cannot hit a pedestrian if the vehicle has something in front that prevents the passage. Then, there is the risk of lateral collision and, finally, the risk of rear collision, since an overtaking is only going to be made if no other situation of danger occurs.

4.4 Defining HCI Messages

Now, the dangerous scenarios that have been defined are detected and alarms are generated by the rules. These alarms are oriented to warn the driver, and are designed to be clear but not annoying (an alarm is launched only when it is truly necessary).

For each risk scenario rule/set of rules, there is a different kind of visual alarm. Each alarm corresponds with an image that is showed in the HCI interface, as shown in Figure 3.

Figure 3: An alarm is showed in the HCI interface of the driving simulator.

The images that correspond with the different alarms for each scenario are shown below (Figure 4). They are ordered from left to right (scenario 1 is the first image, scenario 2 is the second image, etc.).

Figure 4: Visual alarms that are produced by the rules.

In addition to the visual alarm, due to the level of danger, in certain cases there is also a sound alarm. These cases are the alarms associated with the scenarios 1 (risk of frontal collision), when the distance is very short, and 5 (pedestrian not visualised). Again, this sound alarm is designed to be clear, but not annoying to the driver.

5 EXPERIMENTATION

In this section, the process of experimentation is described, by detailing the used material, the design of the testing process and the obtained results.

5.1 Experimental Setup

For the performing of this work has been used several resources that will been described as follows. The Figure 5 shows a simplified scheme about the testing infrastructure used for this work where it can distinguish the interaction between three systems.

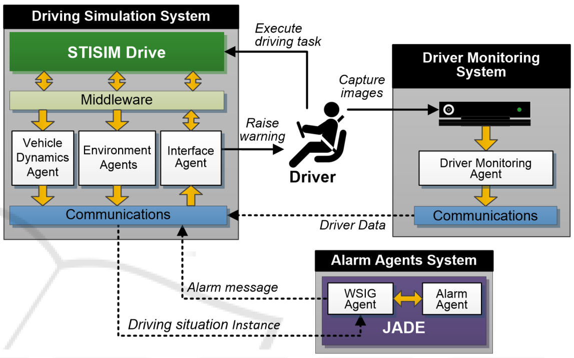

Figure 5: Testing infrastructure scheme.

Firstly, the Driving Simulator System with the STISIM Drive Simulation Software (Systems Technology, 2013), driving devices and three screens for 135 degrees vision that provide a more realistic driving experience. This simulation software includes several driving scenarios that reproduce real driving situations and allows getting access and managing to all simulation parameters on real time through a middleware layer. In addition, a Route Management Module is developed in order to give the capacity to the driving simulator of reproduce real routes for testing the system (Zamora et al., 2016). So, this system provides the next aspects:

- Vehicle Dynamics. All the parameters related with the driven car such as speed, gear, steering wheel angle, pressure level of the pedals, among others.
- Driving environment. The extraction of high-level information about the driving environment is performed by the Environment Agents described in (Sipele et al., 2016).
- Interface Agent. It is a virtual Human-Computer Interface (HCI) is deployed on the simulator screen and it will raise the received alarms by the Alarm System through visual and sound messages to the driver's car.

Secondly, the Monitoring System uses the Microsoft Kinect camera and a software implementation for extracting useful information about the driver such as the orientation of his/her head and a driver's eye gaze estimation.

Thirdly, the Alarm system has been implemented using the Java Agent Development Environment Framework (JADE) (Italia, 2016) and its third-party Add-on Web Service Integration Gateway (WSIG) (Board, 2015). This implementation allows to establish a communication system based on Service Oriented Architecture (SOA). Thus, from the driving simulation system is sent a Driving situation instance as a web service request message to the Alarm System. This request message is received by the WSIG Agent where is processed and transferred to the implemented Alarm Agent. Finally, if the implemented Alarm Agent produces an alarm, it will be communicated to WSIG Agent that will send the alarm message to the Interface Agent.

5.2 Testing Process Design

The objective of the testing process is to check if the created repository of rules is able to detect the given dangerous scenarios and if it is able to launch the corresponding alarm (visual or visual and sound).

The system is tested with black box tests in two different ways. The first way is directly in the designed web environment, where each test is codified in XML. Then, the XML is introduced to the system as a request, and it generates a response indicating whether a dangerous situation is detected or not, and the corresponding alarm. These codified tests corresponds with ontology instances, where each concept and its attributes are described and take concrete values.

The second way of testing the system is performing the tests on the simulator. While the driving task is in process, the simulator creates instances of the ontology with values according with the actual driving situation, and these instances are sent to the system as a request. This way, when a dangerous scenario is given, the corresponding visual (or visual and sound) alarm is shown.

5.3 Results

As mentioned in Section 5.2, the system is verified following two different processes: directly in the designed web environment and using the driving simulator. The first of the described processes is used during the rule design phase, since it is possible to test each rule separately. In this way, it could be checked that all rules work correctly while they are being designed, one by one. However, this testing process is not enough, because the used instances are "artificial" (implemented manually).

The second of the described processes is used to test the complete repository of rules. The progress of the testing process is similar to driving a real car. Examples of alarms launched in the HCI of the driving simulator are shown in Figure 3.

This testing process is more complete than the previous one, because the system is tested as if it were implemented in a real-world environment by using the driving simulator. It is checked that all the defined dangerous scenarios are detected and the corresponding alarms are launched.

As far as we know, there are no other related works about this specified research line focused on establish a hierarchical alarm system based on urban driving situation analysis that works as a co-driver, only warning the driver when it is necessary. Therefore, a comparison cannot be showed.

6 CONCLUSIONS AND FUTURE WORK

In this paper, it is presented a rule-based alarm system based on a multi-agent system previously proposed (Gutierrez et al., 2014).

This work is developed to integrate the information provided by a driving simulator and to use this information to help the driver on his driver task by triggering and showing visual or visual and sound alarms when dangerous traffic situations happen. It is focused in urban environments, where there are many potential dangerous situations caused, in most cases, by distractions of the driver.

The entire project represents an approach to an ADAS, so the final objective is to be embed in real vehicles and to use real data provided by real sensors. Consequently, as a future work there is the extension of the system in order to take account of more dangerous situations, by obtaining more information and by defining more rules, and in order to complete the existing scenarios.

One limitation of the system correspond with the value of the attributes of the concepts, since they are categorical. The system would be more precise if data were numerical, so it is a future work to be accomplished.

Since the system only can give one output, it is necessary to implement an alarm hierarchy. If the number of scenarios is extended, this hierarchy would be much more complex. That is why it is a future work the implementation of this system using fuzzy logic, which allows considering all the rules at the same time and, this way, dispensing the need of the hierarchy of alarms.

Finally, taking account the human factors involved on the driving warning systems, aspects such as time reaction, situation awareness, divided attention, among others, will be studied for improving of the designed alarm system.

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