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SACAT: An Instrumented Vehicle for Driver Assistance and Safety

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Abstract—**The present paper describes the framework and components of an instrumented vehicle for driver assistance and safety. The experimental platform is based on the use of an on-board computer vision system to capture the traffic signs, and on a multiple of electronic components to capture the vehicle state and identify drivers. The hardware architecture is designed with the purpose of making the deployment of functionalities related to driver assistance and road safety easy. The paper covers firstly the description of the hardware architecture, and then describes some of the implemented functionalities such as driver assistance based on traffic signs detection and recognition, traffic violation recorder, and a realization of an emergency call system.**

I. Introduction

Road safety is one of the major policy subjects within the transport policy of the European Union Commission. In 2009 around 35,000 people were killed and more than 1.5 million injured in about 1.15 million traffic accidents on roads in the European Union. This represents approximately 160 billion€ of cost for society [1]. Concerning data in Spain [2], in 2010 there were 1548 accidents, where 1739 people were killed and 7954 seriously injured. It is worth to point out that human error is involved in 95% of all traffic accidents [3], where the majority of these accidents were caused by driver inattention [4] and fatigue [5].

To improve road safety and reduce the number of accident victims, the European Commission is highly committed by integrating technology in cars and road infrastructure through various initiatives such as e-Call [3], ERTRAC [6], or the "Intelligent Car" [7]. For example, from ERTRAC policies [6] point of view, in order to improve traffic safety, the work lines should be focused on three elements: the driver, vehicle and infrastructure. Thus, technological measures should be adopted as primordial solutions to promote safety and encourage responsible driving.

In fact, many researchers are currently working on the problem of making of the driving safer by developing driver assistance systems based on computer vision technology focused on identifying traffic signs and then warn accordingly the drivers [8], [9], [10], [11], [12] and [13]. Important research issues on road safety are also focused on enhancing driver behavior. Understanding driver actions requires the use of data recorder devices for monitoring and providing drivers with feedback on their behavior [14], [15], [16], [17]. Safety for motorists and commuters involves also having an appropriate response time towards emergencies in case of accidents, in order to mitigate the severity and the consequences of injury [18]. In this aspect, the e-call promoted by the European Commission [3] and the OnStar developed by General Motor [19] are two example of solution with a potential to reduce the time needed for emergency services to arrive at the place of the accidents, and therefore reduce the risk of deaths and the severity of the injuries.

Research on driver assistance and safety requires the use of an instrumented vehicle test-bed able to capture the vehicle surround and state. This task is not trivial given the excess of hardware and software choices. Besides being affordable, the different alternatives create a challenge for selecting the right equipment.

This paper presents an experimental platform, hereafter referred to as SACAT, which combines the three aforementioned aspects of road safety: a driver assistance system based on computer vision for traffic sign recognition, able to operate during both day and nighttime, a system for traffic violation recorder for providing feedback to drivers, and a realization of an emergency call system in case of accidents.

The rest of the paper is organized as follows: First, system hardware architecture is presented. Afterwards, the system functionalities are described discussing some preliminary results. Finally, some conclusions are drawn.

II. System Overview

The experimental platform is based on a Nissan Note car model as shown in Fig. 1. Its embedded hardware consists of a Mini-ITX board as a host computer, and a conventional PC as slave computer for real-time image processing. Both of them are placed in a single rack located in the vehicle's boot. The Mini-ITX board integrates various readily available chipsets, such as flash memory card adapter, a slot for connecting smart cards reader, a Bluetooth adaptor for connecting to mobile phones, and a number of external devices necessary for driving assistance like a GPS unit, an CAN interface, and a touchpad screen. All the electronic devices are powered by a dc/ac inverter, transforming 12V from the vehicle battery to 600W of 220V AC. The hardware architecture, summarized in Fig. 2, is designed

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with the purpose of making the deployment of functionalities related to safety easier.

Fig. 1. SACAT: The experimental platform.

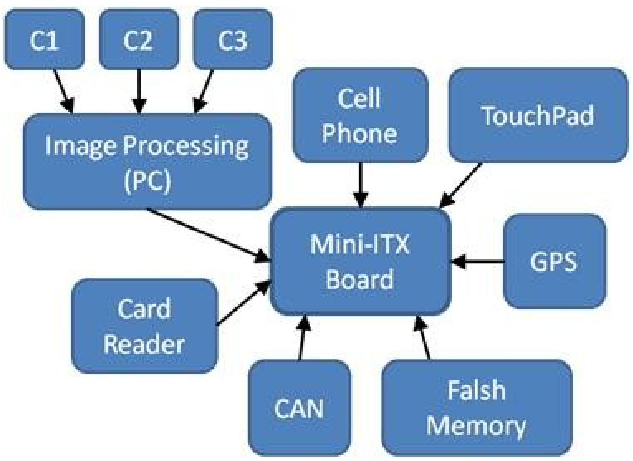

Fig. 2. System hardware architecture.

A) Vision subsystem

SACAT vision system is equipped with three cameras mounted on the vehicle's roof: a panoramic camera for video recording and two high-resolution (1392×1040) digital color cameras used to constantly scan the road ahead looking for traffic signs. These two digital cameras have a focal length of 12-mm, and their field of view allow the vehicle to detect traffic sign at farther distance (up to 80 meters). As far as night vision is concerned, SACAT system is equipped with an active infrared source of illumination obtained with a spotlight with an infrared pass filter, and one of the two cameras is with its infrared filter removed.

B) Emergency call subsystem

SACAT is equipped with a 3G mobile phone connected to the Mini-ITX board via Bluetooth, through which the system is able to automate the notification of a traffic accident. The emergency call is triggered by the airbag signal or manually by pushing a SOS button inside the car.

C) Data acquisition system

As far as data acquisition is concerned, some of vehicle´s internal data (rpm, acceleration, or speed) are accessed throw the ODB-CAN interface. This interface is normally used with specific scan tools for diagnosis issues, and the ODB data transfer protocol follows several standards, none of which are directly compatible with PCs. To deal with this aspect, the ELM327 IC is used as a bridge between the ODB port and the standard RS232 interface. So, with this device, the raw data from the vehicle's ECUs are translated into short messages that are transmitted to a PC via a standard RS232 connection. From programming point of view, the ELM IC is viewed like a modem supporting AT commands. Thus, from a standalone application, vehicle's data are accessed using techniques emulating a conventional terminal and by issuing corresponding AT commands to a serial port.

The Mini-ITX integrates other devices and sensors to obtain data not supplied by the vehicle's ECU. For example, to measure steering wheel position, a 7-bits absolute encoder is mounted on the steering shaft. The steering wheel turning is then transformed into wheel angle information with respect to the neutral position. The full range of steering wheel is about 3 complete revolutions (-540º to 540º), so the encoder offers a resolution of 8.5º of steering wheel per bit (or approximately 1.2º wheel angle per bit). The Mini-ITX is also connected to a GPS receiver with an update rate of 1Hz, which is fairly enough for automotive navigation. Finally, the system is also equipped with several contact sensors to register interactions with the vehicle pedals, seat belts, indicators, and some other devices.

D) Smart cards and user profiles

As far as system users are concerned, SACAT supports three types of users: namely a driver as end users, a transport company agent acting as a system administrator, and a traffic enforcement agent (reserved for future use). User identification is carried out through smart cards, which are granted with different permissions to access the different system functionalities. For example, drivers can only view their own recorded traffic violations, but they are not allowed to modify any recorded data. Transport company agents have access to the different functions, but they could not modify stored data. If no smart card is used, the system will record events for the anonymous driver count.

E) Event data recorder

The event data recorder (EDR) implemented in SACAT uses a compact-flash memory plugged into the Mini-ITX and it used especially to save vehicle's internal data, and uses an external hard disk for storing images and video. Data are continuously collected throughout the trip with approximately a rate of 4 records per second. The data acquisition process is controlled by multithreaded program responsible for gathering data into the EDR unit. Recorded data are time-stamped and organized according to drivers identified by their smart cards.

Besides vehicle internal data, special attention is given to traffic violation when they take place. In such situations, the identification of the traffic sign, its GPS location as well as the photography of the surrounding are recorded. In case of accidents, the EDR unit records up to 2-minutes of video.

As far as data writing is concerned, there is a little conflict between the parallel nature of data acquisition and the constraint of sequential data-writing in the EDR (i.e. no more than one event can be written at once), since the amount of data and the frequency at which they are acquired vary from one device to another. In this aspect, the adopted approach consists in organizing the program in multiple threads collecting data from the different devices and a single thread does the ultimate writing.

The purpose of the EDR unit is not only to retrieve data after a crash, but also to provide drivers with feedback on their unsafe behavior and traffic violations record. It can also be used in other avenues to the mentioned ones. For example, for analyzing movement patterns, journey times, for acquiring more specific driver parameters, study of why drivers make some decisions in certain scenarios, and thereby by use it to analyze driver behavior.

F) Human-Machine Interface

SACAT is equipped with a tactile screen located on the dashboard running an HMI application as shown in Fig. 3.

Fig. 3. The tactile screen on the vehicle dashboard.

The SACAT HMI application has its front-end organized in multiple tabs that give users access to the different functionalities. In the main HMI screen are displayed all the detected and recognized traffic signs. In case of traffic violations, warnings are emitted in the form of acoustical messages through the vehicle loudspeakers. Finally, drivers can also selectively activate or deactivate some of functionalities. Fig. 4 shows a snapshot of the SACAT software GUI.

As far as software development is concerned, SACAT is mainly developed using the C++Builder rapid application development, and computer vision issues are handled using the Matrox Imaging Library (MIL). MIL is a comprehensive set of optimized functions for developing machine vision and imaging software applications. MIL are also hardware-independent solution, meaning that a developer does not require an in-depth knowledge of the underlying hardware, and it includes tools for every step in image processing using C, C++, or C# programming languages.

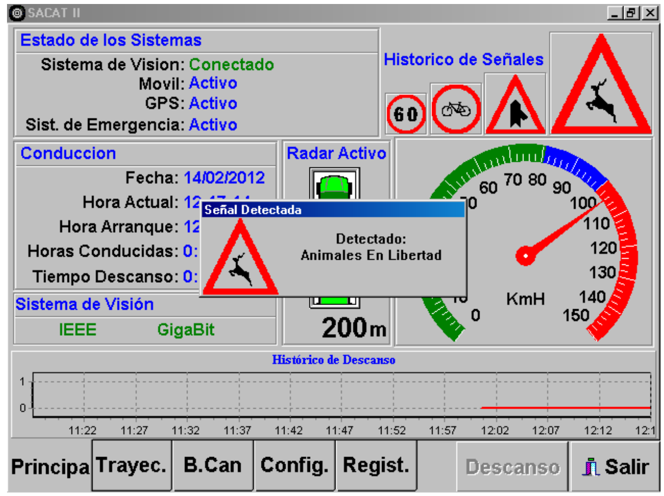

Fig. 4. The snapshot of the SACAT HMI software application

III. Functional Description

This section presents some of the developed functionalities: namely the traffic sign detection and recognition system used for driving assistance, the traffic violation recording subsystem for providing drivers with a feedback about their traffic violation, and an emergency call realization in case of accidents.

A) Traffic sign detection and recognition

The traffic sign detection and recognition (TSDR) module, operating during both day and nighttime, is used to detect vertical signs present along the road and is aimed at alerting drivers in certain dangerous situations, such as “speeding”, “no passing zone”, “intersections”, “stop signs”, “yield signs”, “dangerous turns”, “steep slopes”, or “road works”.

The TSDR is performed in several steps. First, when a traffic sign is detected and its image isolated, color segmentation is performed in HLS space. The result of this step is a series of objects that are subject to shape analysis, which is performed by filtering according to geometric restrictions followed by a probabilistic adjustment of straight and curved lines into the shapes. Afterwards, all the objects obtained from the previous steps are potential traffic signs, and their recognition is performed by a simple matching operation with a set of legal traffic signs, which are discarded if no match is produced. In the cases of positive matches, the result is normally an interpreted sign, which is then used for driver alerting policies. In some situations, warnings in the form of acoustical messages are emitted through the vehicle loudspeakers, and they are issued in advance in order to provide the driver with enough time to react to the on-coming traffic situation.

The traffic sign detection and recognition during nighttime is slightly different from the processing performed during daytime. Since the image histogram is strongly bimodal, segmentation is performed by dynamic thresholding. For each segmented image thus obtained, contours of the white regions are extracted. The steps related to shape detection and matching are similar to steps performed for daytime images.

The SACAT vision system is capable of processing up to 4 frames-per-second (fps). So, at normal speed, i.e 100 km/h, the system offers two opportunities to identify traffic signs at distances of 50 and 30 meters respectively, and more opportunities at low speed.

The system was tested under different daytime conditions, such as sunny and cloudy, on highways as well as in an urban area at normal driving speeds. A total of 2000 kilometers of test have been performed. Generally, the system performs well during the daytime, where the detection rate reaches 90% in clear weather conditions, and it performs even better under cloudy conditions. This rate does not depend on the type of road (highway or urban road). However, the aforementioned detection rate falls slightly during rainy conditions. There are many other negative factors such as shadows caused by trees, the presence of fog, the low contrast of vertical signs due to bad lighting conditions, the sun's position in front of the camera, or when the vehicle is over the brow of a hill.

The experiments performed for night vision are conducted in an off-line fashion using a record of 1800 images collected over a number of tests in approximately 3-hours driving, and about 200 images correspond to true traffic signs. The detection rate is about 92%, slightly better than the daytime score. False positive detection rate is less than 1%, and are mainly caused by objects that have similar shapes to some traffic signs.

B) Traffic Violation Recorder

The traffic violation recorder (TVR) is a module which depends on the TSDR module and the EDR unit described above. At present, the TVR module supports only three traffic violations: namely "speed limit", "stop sign", and "forbidden turning", but more situations such as "parking violation", "no passing zone", and "red light", are under consideration.

From implementation point of view, each sign has its own specific policy. For example, the "speed limit" violation is handled by comparing the actual vehicle speed, obtained from the ECU unit, with the detected speed limit. The issued alert is maintained during a predefined time-out period before recording the traffic sign violation. In the same way, "Stop Sign" violation is managed by checking whether the vehicle speed has fallen to zero or not, and finally "forbidden turning" violation is handled by comparing the driver's intended direction, computed on the basis of the steering wheel angle and the vehicle's speed.

When a traffic violation is committed, its corresponding scenario (the type of the traffic sign, its GPS location, a photograph of the surroundings, vehicle speed, etc) is recorded. The time elapsed from traffic sign recognition to traffic violation recording depends on the traffic signs and vehicle speed. In the case of speeding, when driving at 100km/h and if the speed limit sign is detected at (50 and 30 meters), the system offers an alert reaction time of about (1 to 2) seconds. Furthermore, an extra time-out is provided before recording the traffic violation, (approximately, 25 meters later). In the case of "stop sign" and "forbidden turning", which normally take place within urban areas, the typical driving speed is about 50-70km/h or lower, and in this case, drivers have an alert reaction time of about (3 to 4) seconds. In all cases, warnings are issued with sufficient notice to provide the driver with enough time to react to the on-coming traffic situation.

Drivers can also be provided by their own traffic violation record allowing them to retrieve their data, and therefore, making a self-diagnosis of their driving behavior. Fig.5 shows a snapshot of a tool used to retrieve traffic violation record committed by a driver.

Fig. 5. Snapshot of traffic violation record.

Finally, an auxiliary module allows divers to visualize and explore the spatial and temporal information associated with a given journey on the standard Google Earth. This tool is essentially graphical and gives drivers a precise idea of the vehicle path, the GPS locations of the registered traffic violation. An example of such visualization is shown in Fig. 6. By using this map, drivers can retrieve hidden data such as photographs of the surroundings where traffic violation are committed by just moving the mouse around the map.

From an implementation point of view, the raw data stored in the database is translated to Keyhole Markup Language (KML) file used for modeling geographic features such as points, lines, images, polygons, and models for display in Google Earth. Like HTML, KML has a tag-based structure with names and attributes used for specific display purposes, and a KML file is processed by Google Earth in a similar way as HTML or XML files are processed by web browsers.

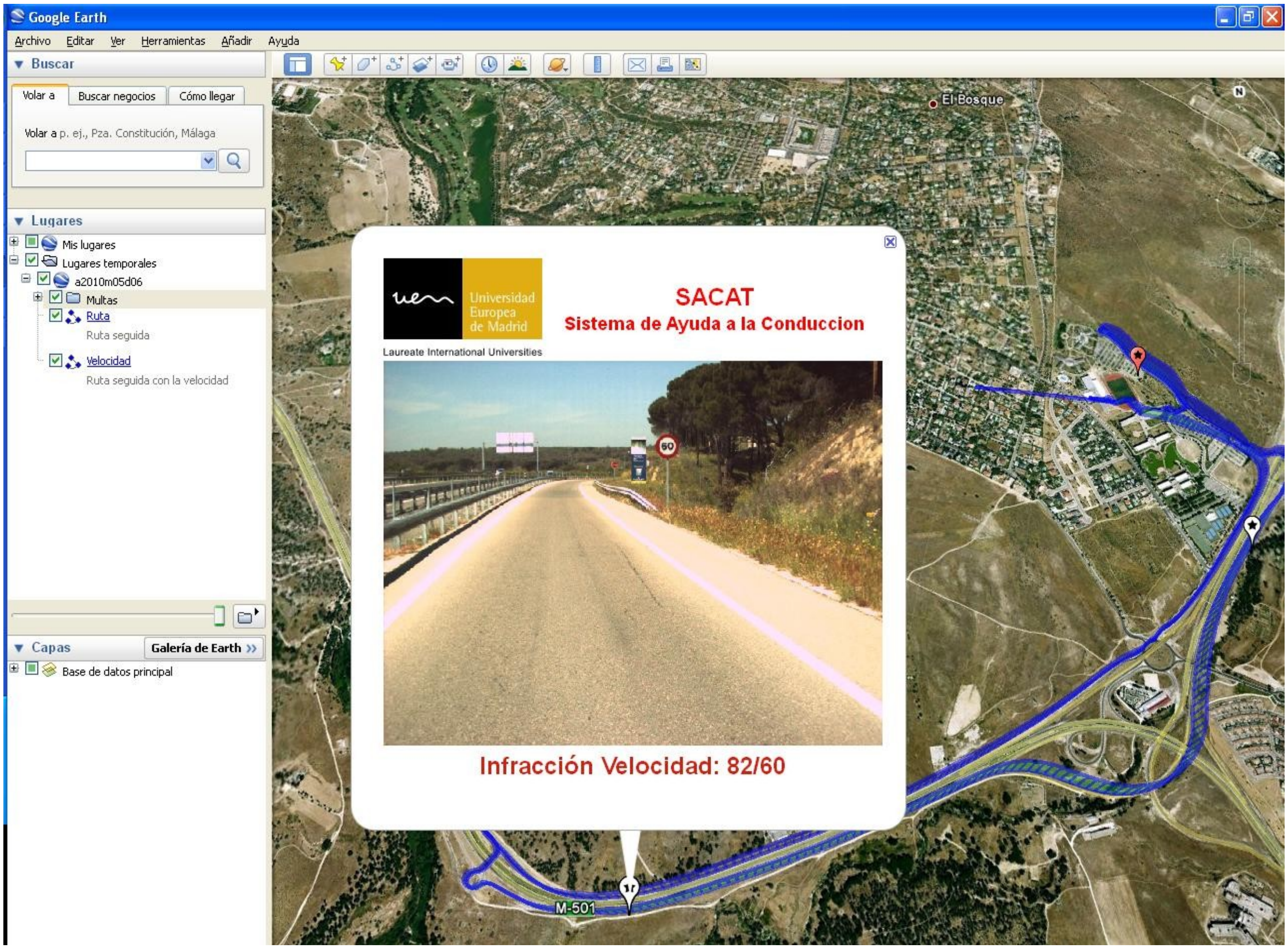

Fig. 6. Snapshot of a Google Earth view showing an example of a traffic violation of over speeding

C) E-Call implementation

The emergency call is triggered by the airbag signal or manually by pressing a SOS button inside the car. The mobile phone sends an SMS phone to the public safety answering point (PSAP) with the number 112. The message contains the so-called minimum data set (MDS) consisting in "When" as time stamp of the accident, "Where" GPS location and direction of driving, and "Who" to identify the driver, the load of the vehicle, and so on. The system implemented in SACAT can be easily adapted to send the so-called full data set that would contain additional data such as enterprise information, insurance data, etc. Besides sending the SMS, our implementation is able to find the best coverage to establish a voice connection, and make possible a talk between the emergency services and the vehicle occupants.

Regarding the system status, SACAT implementation uses a simple HMI that indicates whether the mobile phone is powered or not, if the phone is connected to the GSM network or not, and if it is ready to send messages. The HMI informs finally the driver if the eCall system does not work properly.

IV. Conclusion

In this paper, an instrumented vehicle for driver assistance and safety has been presented. The system is aimed at assisting drivers, and more particularly for reminding them the presence of some specific traffic signs on the road. Despite the alert and the allowed reaction time, if a traffic violation is committed, it is finally recorded in an EDR unit. The violation record consists of indicating the type of traffic sign, its GPS location, a photograph of the surroundings, and some internal vehicle's data. The recorded data are used to provide drivers with a feedback about their traffic violation. Finally, SACAT has an implementation of an emergency call system based on a use of a conventional mobile phone. Although, it is far from being commercial, SACAT system offers real and promising framework for experimentation, and its architecture permits implementing most of the possible applications related to driver assistance and safety in a flexible way.

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