Prototyping an Automatic Notification Scheme for Traffic Accidents in Vehicular Networks

Manuel Fogue, Piedad Garrido, Francisco J. Martinez
Computer Science and System Engineering Department
University of Zaragoza, Spain
Email: {m.fogue, piedad, f.martinez}@unizar.es

Juan-Carlos Cano, Carlos T. Calafate, Pietro Manzoni
Computer Engineering Department
Universitat Politècnica de València, Spain
Email: {jucano, calafate, pmanzoni}@disca.upv.es

***Abstract*—The new communication technologies integrated into the automotive sector offer an opportunity for better assistance to people injured in traffic accidents, reducing the response time of emergency services, and increasing the information they have about the incident. Determining more accurately the human and material resources required for each particular accident could significantly reduce the number of victims. The proposed system requires each vehicle to be endowed with an On-Board Unit responsible for detecting and reporting accident situations to an external Control unit that estimates its severity, allocating the necessary resources for its assistance. The development of a prototype based on off-the-shelf devices shows that this system could reduce notably the time needed to deploy the emergency services after an accident takes place.**

***Index Terms*—VANET, Intelligent Transportation Systems, V2V and V2I communication, traffic accidents.**

I. Introduction

During the last decades, the total number of vehicles around the world has experienced a remarkable growth, increasing traffic density and causing more and more traffic accidents. This scenario represents a serious problem in most countries, as an example, 2,714 people died on Spanish roads in 2009, which means one death for every 16,949 inhabitants [1]. A close look at the accidents shows that many of the deaths occurred during the time between the accident and the arrival of medical assistance. In a traffic accident, completing the assistance of the seriously injured passengers during the hour immediately following the incident (the so-called *Golden Hour*) is crucial to minimize the negative effects on the health of the occupants. Therefore, a fast and efficient rescue operation after a traffic accident occurs significantly increases the probability of survival of the injured, and reduces the injury severity.

For a noticeable reduction in assistance time, two major steps must be taken: (i) fast and accurate accident reporting to an appropriate Public Safety Answering Point (PSAP), and (ii) fast and efficient evacuation of occupants trapped inside a vehicle. The first of these objectives can be accomplished using telecommunication technologies and systems that have been recently incorporated into the automotive world, where mobile communications and GPS systems are the main representatives. In recent years, there have been many advances in the development of technologies for communication between vehicles (V2V), also known as (VANETs or *Vehicular Ad hoc NETworks* [2]). These technologies are based on short-range communication systems, or *Dedicated Short-Range Communication* (DSRC) [3], offering support for cooperative security applications between vehicles. In fact, it is expected that the 802.11p working group will soon approve the IEEE 802.11p standard [4], offering a viable solution for inter-vehicular security applications. Moreover, many efforts and research from academia and industry have prompted the development of technologies to support vehicle-infrastructure interaction (V2I), which has particular relevance for road safety applications, mobility, and monitoring.

Regarding the second objective, the effectiveness of the assistance to passengers involved in a traffic accident could be significantly improved if emergency services had available relevant information on the conditions under which the accident happened before moving to the area of the accident. This extra information, provided by sensors inside the vehicle, would be used to estimate the severity of the injuries to the occupants. Also, having more information would allow determining the optimal set of human and material resources to send to an accident situation, with the consequent cost reduction and increased assistance quality.

In this paper we prototype the e-NOTIFY system, designed for automated detection, reporting, and assistance of road accidents using the capabilities offered by vehicular communication technologies. This proposal does not focus on reducing the number of accidents, but on improving post-collision care with a fast and efficient management of the available emergency resources, which increases the chances of recovery and survival for those injured in traffic accidents.

The rest of this paper is structured as follows. Section II includes the architecture of the proposed system. Section III shows the steps to design a prototype based on general-purpose off-the-shelf devices, and how they provide the required functionality. Section IV presents the environment in which the system was validated and the results of its evaluation. Finally, Section V concludes the paper.

II. e-NOTIFY architecture

Figure 1 presents the basic structure used to develop the e-NOTIFY system. The goal of our proposal is to provide an architecture that allows: (i) direct communication between the vehicles involved in the accident, (ii) automatic sending of a

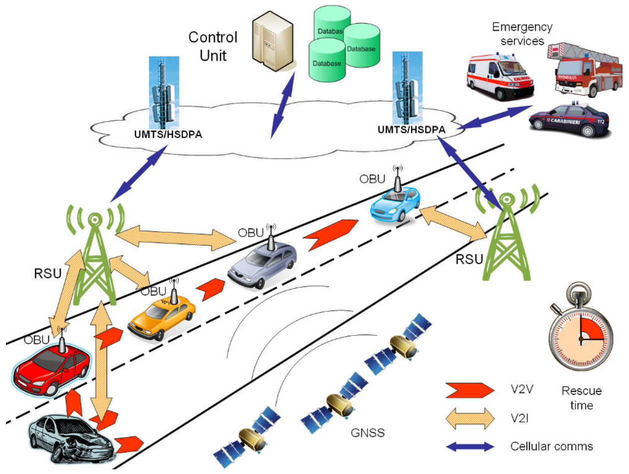

Fig. 1. e-NOTIFY architecture based on the combination of V2V and V2I communications.

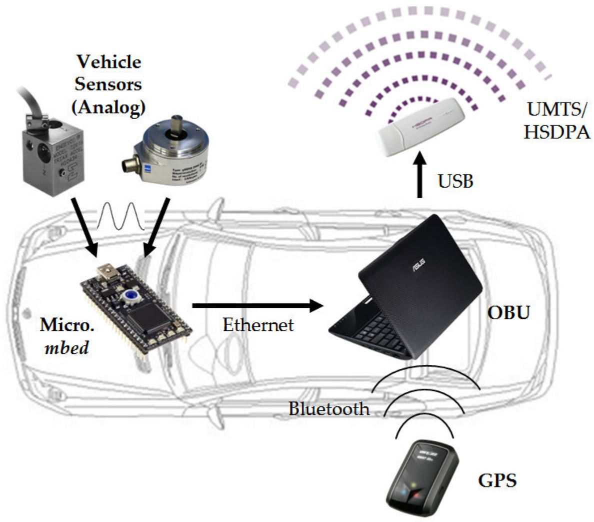

Fig. 2. On-Board Unit prototype structure.

data file containing important information about the incident to the Emergencies Coordination Center, and (iii) a preliminary and automatic assessment of the damage to the vehicle and its occupants, based on the information received from the involved vehicles and a database of previous accidents, which would help adapting the rescue resources necessary for a proper assistance.

The e-NOTIFY system combines both V2V and V2I communications to efficiently notify an accident situation to the Control Center. Different vehicles should incorporate an On-Board unit (OBU) responsible for (i) detecting when there has been a potentially dangerous impact for the occupants, (ii) collecting available information from sensors in the car, and (iii) communicating the situation to a Control Unit (CU) that will address the treatment of the warning notification and its subsequent sending. Among other features, the CU should integrate mechanisms to estimate the severity of the accident and the injuries to passengers, and so it must have access to a database as complete as possible with information on other collisions. This estimation can be done with data mining classification models using the records in existing data bases [5].

The OBU definition is of utmost importance for the proposed system. This device must be technically and economically feasible, as its implementation in a wide range of vehicles could become massive when communication systems begin to spread on vehicles. In addition, this system should be open to future software updates. Although the design of the hardware to be included in vehicles initially consisted of special-purpose systems, this trend is heading towards general-purpose systems because of the constant inclusion of new services. Therefore, the OBU must include enough interfaces to allow connection to the communications system.

The information exchange between the OBUs and the CU is made through the Internet, either through vehicles providing Internet access (via UMTS, for example), or by reaching infrastructure units (*Road-Side Units*, RSU) that provide this service. If the vehicle does not get direct access to the CU on its own, it can generate messages to be broadcast by nearby vehicles until they reach one of the two referred possibilities. These messages disseminated among the vehicles in the area where the accident took place also have the function of alerting drivers traveling to the accident area about the state of the affected vehicle, and its possible interference on the normal traffic flow.

III. E-NOTIFY PROTOTYPE DESIGN

Using the architecture in Figure 1 as a framework, we have developed a prototype using general-purpose devices that can be used to carry out preliminary tests until the required technology (that is, the IEEE 802.11p standard) and the infrastructure (RSUs) are available for its deployment in a real environment. The configuration of each system component is detailed in the following paragraphs.

A. On-Board Unit (OBU) design

The main objective of the OBU lies in obtaining the available information from sensors coming inside the vehicle to determine when there has been a dangerous situation that must be reported to the nearest answering point, as well as to other nearby vehicles that may face this situation. The structure of the developed prototype is shown in Figure 2, in which the main unit is an Asus Eee PC netbook equipped with solid state disk (SSD) to minimize the possibility of damage due to impact. The vehicle position and speed are obtained using a GPS device *Qstarz BT-Q818XT* [6] accessible via Bluetooth.

When developing an On-Board Unit prototype, the connection to the vehicle sensors can be complicated as each manufacturer differs in how the data is represented. In addition, most of these sensors are analog, and hence a prior transformation into digital format is necessary in order to properly handle the provided data. These problems have been solved by using an ARM *mbed NXP LPC1768* microcontroller [7] that can be

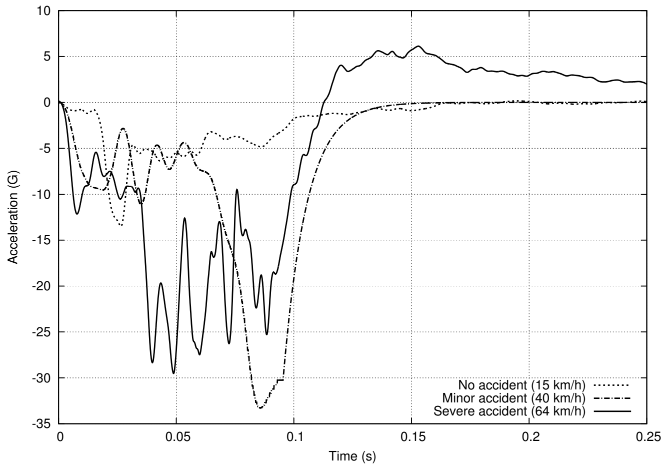

Fig. 3. Acceleration pulses for different front crash ratings. Data provided by Applus+ IDIADA Corporation [9].

used for rapid prototyping because, among other features, it includes a built-in compiler for the C++ language, it can read directly from an analog input, and it can communicate with a PC through different interfaces, including USB and Ethernet ports. Other studies have successfully used this system in automatic control tasks [8].

The microcontroller is programmed to periodically collect data from sensors, and will determine when a vehicle has suffered an accident that requires informing to the appropriate authorities. Basically, these sensors are accelerometers and gyroscopes that indicate the severity of the impacts received by the automobile or the occurrence of a rollover that might endanger the integrity of the occupants. Communication between the microcontroller and the On-Board Unit is done by sending UDP packets with variable frequency (in the test runs, we used a frequency of 50 packets per second) through the Ethernet interface.

The OBU is responsible for collecting the data sent by the microcontroller and for generating a time series with measured values. The evolution in the measures of acceleration and horizontal tilt will determine when the vehicle has suffered extensive damage. The treatment of the horizontal tilt is quite simple, since measurements deviating more than 90 degrees from the horizontal indicate that the vehicle overturned and needs to be rescued. Interpreting acceleration values is more complicated since the received pulses have very limited duration, and both their amplitude and duration should be considered in the classification. This effect can be observed in Figure 3, which contains different pulses corresponding to front crashes with different severities, i.e., (i) a low speed impact not considered an accident, (ii) a minor accident with injury possibility, and (iii) a severe collision where the occupants may have suffered serious injuries. It can be seen that the peak acceleration recorded in the minor accident exceeds the maximum value registered in the severe collision, although the duration of the pulse is much smaller. So, it is clear that using simple acceleration thresholds to distinguish the acceleration pulses is not enough, and hence our approach will use the value of the integral function defined as the variation of acceleration over time. This approach does allow defining different thresholds with sufficient margin among the different situations. The integral of the function is approximated by the numerical method of the trapezoidal rule, with which the integral of a function f defined in a number of n regular intervals is:

$$\int_{x_0}^{x_n} f(x)dx \approx \sum_{i=1}^{n}(x_i - x_{i-1})\frac{f(x_i) - f(x_{i-1})}{2} \qquad (1)$$

The acceleration function begins to be integrated when a measurement with absolute value above a given threshold is detected. This threshold is set between 3 and 5 Gs (1 G = 9.80665 m/s^2) depending on the kind of impact (front, side or rear) and the segment to which the vehicle belongs. After a period of time (which approximates the duration of the pulse), the integral value will determine the type of accident depending on whether or not it exceeds the limits set in the test traces. If the accident is considered as severe enough, the OBU will send UDP packets with information about the event to its neighbors to warn about the danger of the situation. In addition, a TCP connection is opened towards the response point to alert the accident and request the dispatch of an emergency operation. To this end, the message sent will contain as much relevant information as possible about the incident.

B. Warning message structure

The messages exchanged between the vehicles and the Control Unit should be concise, avoiding irrelevant information, but they should not ignore any possible information that might be useful for the emergency services to determine the necessary resources. Thus, the information delivered to the response point should include data about the conditions under which the accident occurred, the occupants of the vehicle and the different security systems included. These data are sent to the emergency services to provide a more detailed view of the conditions of the accident before they arrive to the affected area [10]. For the designed system, we implemented a message containing the following fields, accessible via the sensors included in the vehicle (see Figure 4):

TIME

- to inform exactly when the accident occurred.

LOCATION

- **geographical position of the vehicle**, to determine the exact location of the injured.

VEHICLE-OCCUPANTS

- **characteristics of the vehicle**, to adequate the equipment to send to the accident scenario and to warn the rescue team about the level of complexity and dangers. Critical areas at the vehicle which must be avoided by cutting

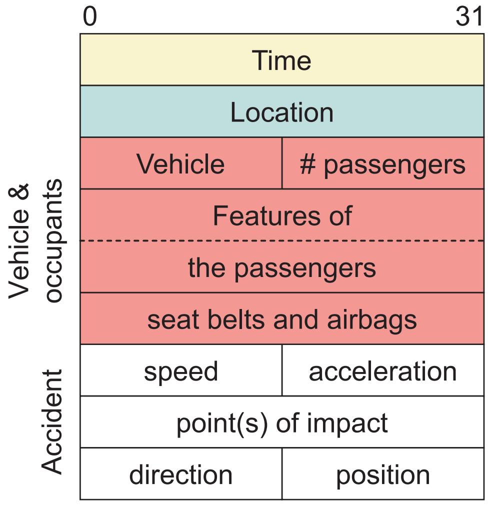

Fig. 4. Warning packet format for the proposed system.

procedures (e.g. gas inflators) are mostly not labeled and might cause critical/dangerous situations for rescue workers. (e.g. in modern electrical engines, etc.).

- **number of passengers**, to adequate the medical team required to attend them.
- **features of the passengers**: weight, height, age, etc. The more information, the better.
- **information about seat belts and airbags**, to estimate the severity of the injured ones, how the accident occurred and the severity of the accident.

ACCIDENT

- **speed and acceleration** of the vehicle just before the accident, to estimate the severity of the accident.
- **point(s) of impact**, i.e. exactly where the impact(s) has been produced.
- **direction of impact force**. This is a mechanical concept. If we consider the top of the car as a clock, we can describe the direction of impact force as an hour. (12 for front side, 3 for right side, 6 for rear side, etc.).
- **position of the vehicle** after the crash to estimate the severity of the accident and to warn the emergency team about the level of complexity of the rescue.

C. Control Unit (CU) design

The Control Unit (CU) is associated to the response center in charge of receiving notifications of accidents from the OBUs installed in vehicles. The Control Unit is responsible for dealing with warning messages, obtaining information from them, and notifying the emergency services about the conditions under which the accident occurred. The Control Unit prototype has been structured as shown in Figure 5.

After receiving the message, the CU must store the crash data in a database to record that the accident information has been successfully delivered. The CU should have an available database providing information on different manufacturers and models of existing vehicles. The critical areas of the vehicle to be avoided during rescue procedures (e.g., fuel tanks) are not marked in most vehicles and could cause a hazard to the emergency teams. Thus, when the emergency services receive an accident alarm, they can obtain the information regarding the damaged vehicle (manuals, information on hazardous areas, etc.) before rescuers arrive to the area where it happened.

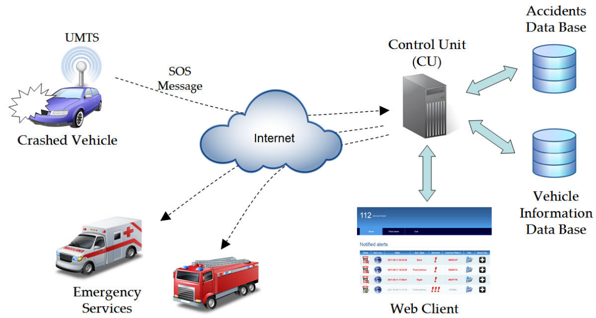

Fig. 5. Control Unit prototype structure.

The CU prototype includes a web interface that provides (with prior authentication) information about the different notifications received so far. The user can then obtain detailed and visual information about the position and conditions of passengers (seat belt use, airbag deployment, cutting areas for the release of the occupants, etc.), date and time, location of accident (with visualization through Google Maps API [11]), etc. Figure 6 presents an example of a simulated accident with 3 occupants.

IV. System validation

The designed prototype was validated at the Applus+ IDIADA Passive Security Department facilities [9] in Santa Oliva (Tarragona, Spain). These facilities house one of the most sophisticated crash laboratories in the world and constitute an official center for approval under the EuroNCAP program [12].

Due to the cost of using real vehicles in the collision experiments, the e-NOTIFY prototype tests were performed using a platform (known as "sled") that moves on rails in order to collide against a series of metal bars that simulate the deformation suffered by a vehicle body to absorb the impact. The speed at which the stroke occurs and the configuration of bars used in the test determine, respectively, the kind of accident detected and the segment the simulated vehicle belongs to (family car, off-road, multi-purpose vehicle or compact vehicle). Tested speed are determined by European standards and vary from 10 km/h to 64 km/h to represent different severities.

Figure 7 shows the sled used in the tests, to which a series of weights were added to complete the simulation of the behavior of a conventional vehicle. Validation experiments consisted of front crash tests (which accounted for severe accident, minor accident, and no accident situations), side collisions (accident, and no accident situations) and rear-end collisions (accident, and no accident scenarios.) The classification of the severity

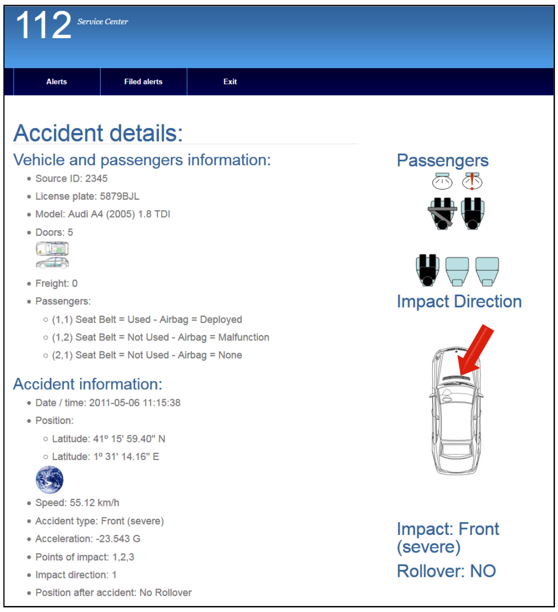

Fig. 6. Web interface screenshot with information about a notified accident.

of the collision is dictated by the parameters used in Applus+ IDIADA in the EuroNCAP and RCAR tests [13].

The test system included an external computer receiving regular information from the sled (via a wireless network) of the measurements recorded by the OBU to ensure the proper behavior of the sensor reading module, along with another computer that simulated a Control Unit in charge of receiving alert messages. The test helped to show that the OBU was able to correctly detect both the magnitude and direction of the impact, and to generate an appropriate warning message from the sensor data and send it using UMTS technology to the Control Unit in all the tests.

V. Conclusions and Future Work

In this paper we presented the e-NOTIFY system, which allows fast detection of traffic accidents, improving the assistance of injured passengers by reducing the response time of emergency services and the submission of relevant information on the conditions of the accident using a combination of V2V and V2I communications. This architecture replaces the usual mechanisms for notification of accidents, based on witnesses who may provide incomplete or incorrect information in an inappropriate time. The development of a low-cost prototype shows that it is feasible to massively incorporate this system in existing vehicles. We validated our prototype at the Passive Security Department of Applus+ IDIADA Corporation and showed how it can successfully detect traffic accidents, reporting all the detailed information to a Control Alert System on time.

Future work in this area includes deploying the system in a real environment with the OBUs installed in real vehicles to check the system behavior when moving at high speeds.

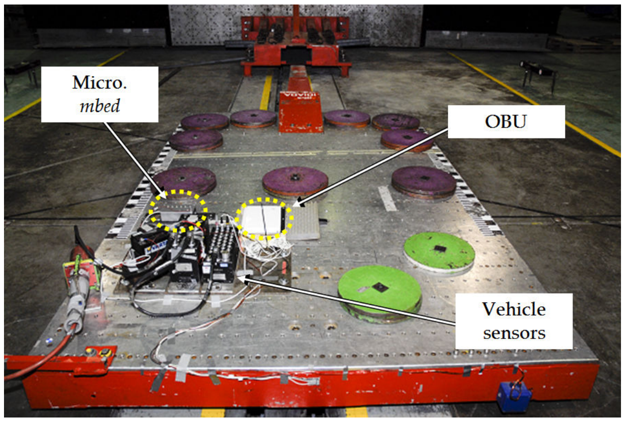

Fig. 7. Sled with the e-NOTIFY prototype installed before a crash detection test.

Acknowledgments

This work was partially supported by the *Ministerio de Ciencia e Innovación*, Spain, under Grant TIN2008-06441-C02-01, and by the *Diputación General de Aragón*, under Grant “subvenciones destinadas a la formación y contratación de personal investigador”.

References

[1] Dirección General de Tráfico (DGT), “The main statistics of road accidents. Spain 2009,” 2009, available at http://www.dgt.es/portal/es/seguridad_vial/estadistica.
[2] H. Hartenstein and K. Laberteaux, “A tutorial survey on vehicular ad hoc networks,” *Communications Magazine, IEEE*, vol. 46, no. 6, pp. 164 –171, june 2008.
[3] H. Oh, C. Yae, D. Ahn, and H. Cho, “5.8 GHz DSRC packet communication system for ITS services,” in *Vehicular Technology Conference, 1999. VTC 1999 - Fall. IEEE VTS 50th*, vol. 4, 1999, pp. 2223 –2227 vol.4.
[4] Task Group p, “IEEE P802.11p: Wireless access in vehicular environments (WAVE),” IEEE Computer Society, 2006.
[5] M. Chong, A. Abraham, and M. Paprzycki, “Traffic Accident Analysis Using Machine Learning Paradigms,” *Informatica*, vol. 29, pp. 89–98, 2005.
[6] Qstarz International Co., “Qstarz BT-Q818XT Bluetooth GPS: Features and Specification,” 2011, available at http://www.qstarz.com/Products/GPS%20Products/BT-Q818XT-F.htm.
[7] “MBED NXP LPC1768: Reference information,” 2011, available at http://mbed.org/nxp/lpc1768.
[8] K. B. Hornfeck, “A Customizable Socially Interactive Robot with Wireless Health Monitoring Capability,” Master’s thesis, Case Western Reserve University, Cleveland, OH, USA, 2011.
[9] Applus+ IDIADA: Instituto de Investigación Avanzada del Automóvil, “Information and resources,” 2011, available at http://www.idiada.es.
[10] F. Martinez, C.-K. Toh, J.-C. Cano, C. Calafate, and P. Manzoni, “Emergency services in future intelligent transportation systems based on vehicular communication networks,” *Intelligent Transportation Systems Magazine, IEEE*, vol. 2, no. 2, pp. 6 –20, summer 2010.
[11] “Google Maps API Family,” 2011, available at http://code.google.com/apis/maps.
[12] EuroNCAP (European New Car Assessment Programme), “Evaluation procedures and test results,” 2011, available at http://www.euroncap.com/testprocedures.aspx.
[13] RCAR, the Research Council for Automobile Repairs, “Design guides and information for manufacturers,” 2011, available at http://www.rcar.org.