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I-WAY, intelligent co-operative system for road safety

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Abstract — **Fatalities and injuries connected with road accidents and its social and economic implications are dramatic issues nowadays. In this paper we present a strategy to improve road and mobility safety addressed by the I-WAY system. I-WAY is an innovative system able to improve road safety based on a cooperative driving platform which will ubiquitously monitor and recognize the road environment and the driver's state in real time using data obtained from three types of sources: the in-vehicle sensing system, the road infrastructure and neighbouring cars. It supports both, road-to-vehicle and vehicle-to-vehicle communication in order to enhance drivers' perception on road environment and improve responses in critical scenarios. This work addresses the I-WAY technical solution and its overall architecture.**

I. Introduction

One of the most dramatic problems which has been arisen during the last decades along with the economic, industrial and technological development, is fatalities and injuries connected with road accidents. The problem has other implications like social and economic [1]. Many solutions for this problem have been proposed, typically based on independent devices oriented to increase driver and driving security – ABS, ESP, airbags, etc -, and other sensors (radar, lane-trackers, etc) whose produced data are individually considered to produce warnings only under specific driving situations. I-WAY is a system which faces safety issues in a comprehensive way, joining and sharing data collected from sensors placed in vehicle and along the road; those data are managed and processed by a central system. The rationale is that the *share and elaboration in a single system* of information [2] collected by cars in different locations and by fixed sensors, could add great value to the information itself, leading to an enriched vision of the whole road infrastructure: I-WAY can get *knowledge* from a set of *data*. The system provides a tool for optimized traffic management, and contributes to the reduction of accidents by providing the drivers with updated and meaningful information of the environment. I-WAY aims to enhance drivers' perception on road environment and improve their responses in time critical situations by providing real-time information from other vehicles in the vicinity and from effectively located roadside equipment as well. I-WAY processes also multi-sensorial signals using advanced sensor management and data fusion techniques.

The I-WAY system is based on various scientific and technological domains in order to provide the previously described functionalities. The scientific objectives include:

- Amalgamation of various sensors in an innovative way which facilitate the proper acquisition of the required information [10], according to specific conditions in a multi-sensor management environment.
- Development of innovative and efficient signal, image and video processing algorithms [17], able to extract relevant information regarding both the road and driver status in order to assess the sensor's recordings. The data sources include sensors and dynamic databases containing updated information from the road infrastructure. The use of multimodal data provides a unique opportunity for these data to be fused.
- Optimization of a text-to-speech module for use in the car environment, in order to reinforce its intelligibility in noisy environments and to enable a natural and situation-dependent speech output.
- Provision of a decision support system component for automated identification of an accident [13], potential hazards in the road environment and low driving skills due to driver's fatigue or sleepiness [20].
- Creation of a sophisticated mechanism based on a context aware approach that will define the best way to give the information to the driver (sound, image, text) taking into account the driver workload, the different environment conditions and traffic scenarios.

II. State of the Art

The improvement of road safety is of vital importance and many research groups have devoted a great effort towards providing tools and services to vehicles and roadways in order to offer adequate level of quality, efficiency and safety in the transport sector. From the social point of view research focuses on integrated safety, comfort and efficiency in road transport and mobility [3].

Many aspects of I-WAY constituted the basic research of several previous RTD projects. Those covered mainly two general areas, the development of Advanced Driver Assistance Systems (ADAS) and the common platforms and technologies [4] development.

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Only to mention European projects, the AWAKE project [5] deal with hypovigilance issues, the CarTALK2000 project [6] addressed car to car communication, the AIDER [7] project focused on the direct cooperation between in-vehicle Systems and rescue Control Centres, the COMUNICAR [8] project developed a new concept of in-vehicle multimedia HMI, the CARSENSE project[9] developed a sensing system based on image processing.

I-WAY utilizes the latest technological advances and provides several functionalities targeting co-operative driving and road safety improvement. The system is an integrated multi-sensorial one which processes the data using data fusion and effective decision support mechanisms.

Multi-sensor systems are becoming increasingly important in several road safety applications [10]. Since single sensor generally can only perceive limited partial information, multiple similar and/or dissimilar sensors are required to provide sufficient information. The potential advantages of multi-sensor systems are:

1. redundancy: reduced uncertainty and increased reliability in case of sensor error or failure,
2. complementary: multiple sensors allow features in the environment to be perceived using just the information from each individual sensor,
3. timelines: more timely information as compared to the speed at which it would be provided by a single sensor due to either the actual speed of operation of each sensor, or the processing parallelism that may be achieved as a part of the integration process..

Data fusion has been tackled by several methods [11,12]. The *Kalman filter* can be used to fuse low-level redundant data in real time. *Bayesian estimation* using consensus sensors has also been used for data fusion. Here, sensor information that is likely to be in error is eliminated and the information for the other "consensus sensors" is used to calculate the fused value.

Decision support, based on the processing and feature extraction of obtained signals, is based on pattern recognition [13]. The employment of neural networks in pattern recognition has expanded its applications to a wide range, largely because *neural networks* can be trained to identify nonlinear patterns between input and output values and can solve complex problems much faster. Another approach is the *Hidden Markov Models*. A Hidden Markov Model is a stochastic process, which attempts to model a series of observations and then to provide the probability that sequences of observations are produced from the same process.

Regarding *GIS applications*, the Transport Systems Centre (TSC) at the University of South Australia has developed an integrated Global Positioning System (GPS) - Geographical Information System (GIS) for collecting on-road traffic data from a probe vehicle.

A lot of research involves also the *communication aspects* related to the Intelligent Transport Systems [14,15]. There are two basic types of ITS communications: i) road-to-vehicle communications and ii) vehicle-to-vehicle communications. The road-to-vehicle communication involves base stations located along the road which communicate with the vehicles on the road and are coordinated by several control stations. Vehicle-to-vehicle communication in an ITS demonstrates properties of both *peer-to-peer (P2P) networks* and *mobile ad-hoc networks*. In P2P systems, participants rely on one another for service, rather than solely relying on a dedicated and centralized infrastructure. A mobile ad-hoc network is a collection of mobile hosts with wireless communication capabilities, forming a temporary network without any established infrastructure.

III. SYSTEM DESCRIPTION

I-WAY [16] is a system which in its final version will result in an innovative cooperative driving platform which will ubiquitously monitor and recognize the road environment and the driver's state in real time using data obtained from three types of sources: i) the in-vehicle sensing system, ii) the road infrastructure and iii) neighbouring cars. It supports both road-to-vehicle and vehicle-to-vehicle communication and uses intelligent classification techniques to detect hazards and risky situations on the road.

A. *System functionalities*

The key feature of I-WAY is that refers to a co-operative system for road safety, where vehicles co-operate not only by receiving information from the existing infrastructure but also by serving as scouts.

I-WAY provides an intelligent platform which:

- receives dynamic data from diverse and distributed sources. Dynamic input is considered the real-time information received from the on-car sensors and the sensors embedded in the infrastructure and the road-side equipment. Preceding cars act as scouts being able to identify significant road transport parameters.
- handles the transfer of data among the vehicles moving in a specific geographical area. Communication can be road-vehicle communication, twofold communication between cars and the road infrastructure, or vehicle-to-vehicle communication, in which data are sent directly from the scout car to the neighbour vehicles.
- interprets and aggregates all data from different sources and assesses the status of road transport for specific locations.
- provides real-time information regarding the road conditions to each vehicle moving in a certain geographic area and alerts the drivers to effectively lead to on time critical operations and necessary actions taken by the drivers.

IV. SYSTEM ARCHITECTURE

The I-WAY system integrates several independent sub-systems. The overview of the I-WAY integrated system is shown in Fig.1, indicating the three architectural tiers (mobile unit's interface, communication and server-side processing).

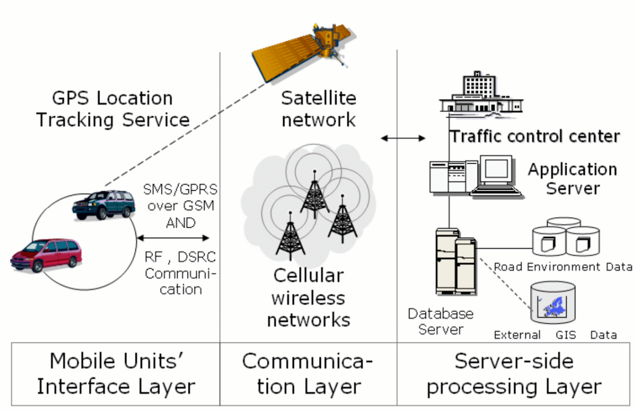

Figure 1: I-WAY layered architecture view

It is composed by two main subsystems: the in-vehicle subsystem and the external transport subsystem. The in-vehicle subsystem consists of the following modules which are located in the interior of the vehicles:

- The **vehicle sensing module**. It is a sensor platform consisting of a number of individual on-board sensors. This module is set-up at each vehicle and is responsible for the acquisition, processing and analysis of raw data coming from the on-board sensors.
- The **data acquisition module**. It is responsible for the aggregation, combination and correlation of acquired information provided by the vehicle sensing module and by external sources (infrastructure/ neighbouring vehicles).
- The **situation assessment module.** Its aim is to produce an estimation of the road condition based on prior knowledge and real-time information coming from the different sensors. Whenever needed, an integrated alerting mechanism creates and forwards messages to drivers and/or to the road management system.
- The **Communication module** which handles the real-time exchange of data among the vehicles [14] and between a specific vehicle and the Road Management System.

On the other side, the External Transport Module [18] includes:

- The **Roadside equipment** (the infrastructure). It is composed by a set of fixed sensors, placed at specific points along the highway which are responsible for data acquisition referring to the road environment.
- The **Road Management System** including a database server which holds and manages in real-time the information coming from both infrastructure and vehicles.

A. *The vehicle sensing module*

It refers to a sensing system and an appropriate flexible architecture for driver assistance systems during complex traffic and driving conditions. Therefore, sensors capable of detecting hidden dangers and hazards under most weather conditions are included. This platform is mainly composed by the **road sensing board** [19] and the **driver sensing board** [20]. The road sensing board captures specific information on the environment around the vehicle (road model, neighbouring vehicles, potential objects); the driver sensing board captures information about the driver status. Different parameters (physiological signals and facial features) are measured and combined in real-time so as to predict a state of drowsiness, or collapse before it actually occurs.

B. *The data acquisition module*

The objective of the Data Acquisition Module (Fig.2) is to acquire all the signals measured with the on car sensors and process them before transmitting the information to the other modules of the system. The module amplifies, filters, formats and temporally stores the signals obtained from the sensors (when required) to adapt them for further analysis in later stages of the I-WAY system. It consists of both hardware and software components which are placed inside the vehicle. A block diagram of this module's components is presented in Figure 2

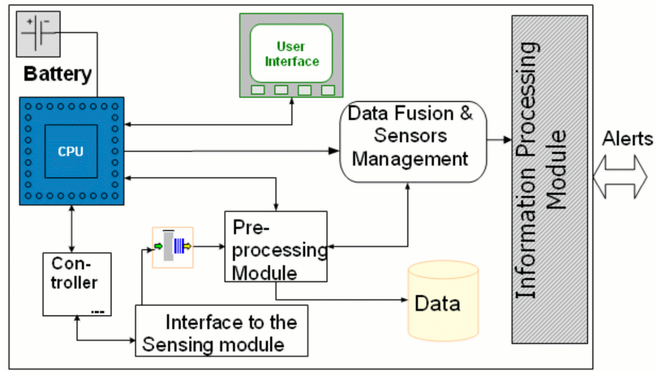

Figure 2: The data acquisition module

This module is characterised by a **time-alignment** feature (to normalize measurements coming from different sensors at different times); **pre-processing units** embedded in sensors, to reduce CPU workload, a **local data storage unit** and **data fusion** features.

Data Fusion exploits differences in sensor coverage, utilises complimentary sensor information, and combines different data. For example, two sensors apart from providing different coverage can detect the same object, but with differing accuracy of the parameters (for instance, range and angle) describing that object. This component combines different sensors and relies on the fusion of the information coming from these sensors in order to achieve better accuracy, robustness and increase of the information content. To implement the desired data fusion functionality [11,12], intelligent techniques such as the Bayesian approach is used.

C. *The situation assessment module*

The Situation Assessment module is composed by a feature extraction submodule, a decision support system and an alerting mechanism. The first module processes incoming data to extract features that can be used next by a decision support system. Efficient real-time image and video analysis techniques are applied to extract accurate road-models and detect possible obstacles with relative positions to the vehicle. The extracted information together other environmental and driver data coming from dedicated sensors, is provided to the decision support system. This decision support system combines multi-sensorial measurements with various data coming from road infrastructure and other vehicles [13] in order to extract the conditions of the environment around the vehicle, as well as, the level of driver's attention. Our main effort is concentrated on the use of intelligent techniques for the analysis and classification and knowledge extraction for the recorded signals. The main functionalities of the Situation Assessment module can be summarised as follows:

- Processing and feature extraction, that is the conversion of patterns to a condensed representation of features which contain the important information
- Identification of a smaller number of meaningful features that best represent the given pattern without redundancy (feature selection).
- Combination of the extracted key-feature findings and proper classification. During classification, a specific pattern is assigned to a specific task according to the characteristic features selected for it.
- Production of indicative diagnosis based on the fusion of data coming from multi-signal measurements, vehicle-to-vehicle communication and vehicle-to-infrastructure communication

The implementation of this module is based on the implementation and experimentation with several techniques, such as Decision trees, Computational intelligence methods (neural networks, fuzzy logic), Statistical based techniques (Gaussian mixture models, Hidden Markov models) and Support vector machines, in order to identify those that provide the best results.

The module is completed by an alerting mechanism, a component delivering alerts resulting from the Decision Support System to drivers or to the Road Management System.

D. The communication module

The I-WAY system vastly relies on the robustness of the communication infrastructure [14,15]. This is very important for road safety and during emergency situations, like accidents. All the available means of communications ranging from broadband mobile (GPRS, UMTS) to satellite physical means are exploited. One of the critical points for the successful implementation and utilization of the I-WAY platform is the development of a scalable communication network, empowering for direct and fruitful information exchange, establishing a solid collaboration environment between the involved actors and providing the drivers with vital up-to-date information on road conditions and other drivers' state. The I-WAY vehicle is equipped with a transceiver and a GPS/Galileo receiver which enables its any-time, any-place localization and information exchange with the environment. Communication here refers to both inter-vehicle communication and the communication of the I-WAY vehicle with the outside world.

The different Communication Layers incorporated in the I-WAY system are shown in Fig.3.

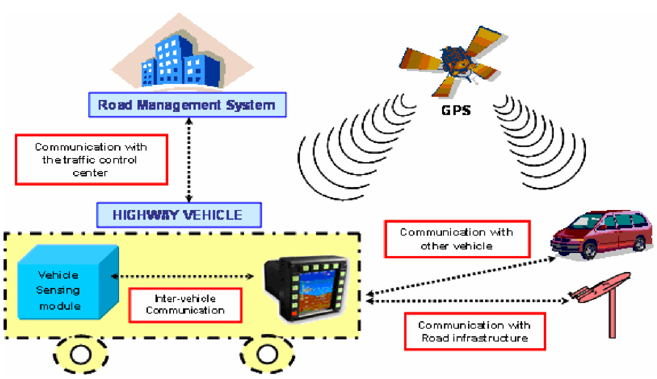

Figure 3: The communication module

The communication module is divided in two parts: the inner vehicle communication and the communication with the outside world.

The **inter-vehicle communication** is related to data transfer from the established sensing module including data acquisition and situation assessment to the mobile user interfaces located in the car interior.

The I-WAY **vehicle communication with the outside world** includes the exchange of information with:

- the Road Management System (communication with a centralized system),
- Road infrastructure (road-to-vehicle communication),
- other vehicles in the vicinity (vehicle-to-vehicle communication).

The communication between *the vehicle and the Road Management System* enables an I-WAY car to provide the centralized system with real-time information about the road environment. The use of GSM/ GPRS or W-LAN would ensure service provision in almost any location.

The *Road-to-vehicle* communication system is configured from wireless facilities (base stations and aerial wires) installed along the road and on-board unit installed on vehicles. The base stations and on-board unit conduct two-way radio communications. The radio signals are limited to a range of several tens of meters, and information is exchanged instantly within that area. This type of road-to-vehicle communication is referred to as Dedicated Short Range Communication (DSRC). With the aim of enhancing the usability of current DSRC system, small-sized DSRC zones are interconnected along a road to provide continuous road-to-vehicle communications even for high speed vehicles. DSRC system and W-LAN are used to provide communications between a vehicle and an access network.

Vehicle-to-vehicle communication demonstrates properties of both peer-to-peer networks and mobile ad-hoc networks. In peer-to-peer (P2P) systems, participants rely on one another for service, rather than solely relying on a dedicated and centralized infrastructure. Peers in the system both provide and consume services.

E. The external transport module

This module comprises the components of the I-WAY platform which are located outside the car [18], which means that they are not parts of the in-vehicle subsystem but there is an all-time bidirectional communication between the external transport subsystem and the driver. The operation of this subsystem including the **Roadside Equipment** and the **Road Management System** is presented in Figure 4.

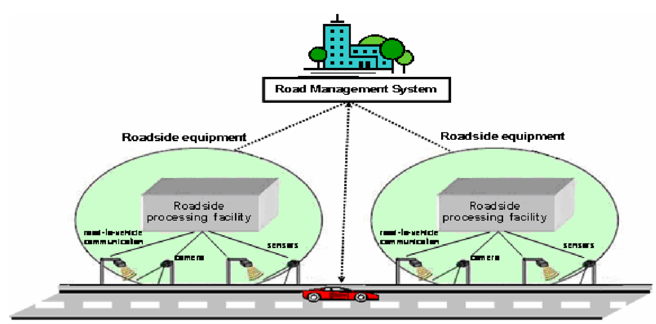

Figure 4: The external transport system

1) The Roadside Equipment

Apart from the amount of data coming to the I-WAY driver from the on-board subsystem and other vehicles in the vicinity, additional information is provided from the road infrastructure effectively established at predefined locations.

Information provided by the infrastructure consists of data not easily perceived from the vehicle, such as obstacles on curved roads or in intersections, and distant road surface conditions.

The roadside equipment includes both hardware and software components:

- **Cameras and some extra sensors** which are adjusted on the roadside equipment such as obstacle detection sensor and road surface sensors.

- **The roadside processing facility** which incorporates an *image processing module* and a *function processing unit.* The image processing module uses image processing to detect road obstacles and other vehicles, and to observe traffic, identifying slow traffic, traffic jams, potential obstacles and risks. The *function processing unit* implements functions which cannot be performed efficiently by the vehicle autonomously. Such functions include wide-area functions, and functions shared by or involving multiple vehicles.

2) The Road Management System

It is a centralized system located in an authorised department such as the Ministry of Transportation and communicates directly with the roadside equipment and the I-WAY vehicles in order to acquire useful information about road and traffic conditions. This information is stored in a dynamic database system (road database) and displayed on a digital map which describes the road network. Whenever a critical event occurs, asynchronous alert messages are received by the situation assessment module so as to inform on potential changing constraints (e.g. blocked roadway, damaged road, fatal accident etc). The Road Management System can also synchronously request information on the traffic conditions from any I-WAY vehicle or roadside equipment.

The road management system is completed by the research and statistics module, a knowledge-based environment utilising appropriate intelligent knowledge extraction techniques for the data analysis (intelligent statistical methods and data mining operations) in order to produce thorough statistical data on road conditions and risks during driving. The module is driven by users' requests for statistical data and it is a valuable tool for transport research and an endless source of information for continuous education of drivers.

V. Discussion

I-WAY goal is facing several **social and economic problems**. The use of this system will improve everyone's (not only drivers') quality of life, tackling the problems caused by transport such as congestion, harmful effects to the environment and public health, as well as the heavy toll of road accidents [1]. I-WAY promises a higher situational awareness of potential unforeseen danger and this is a key for safe driving and avoidance of a large number of accidents, which will reduce the percentage of deaths and injuries from road accidents.

Transportation means are becoming more and more comfortable and self secure day by day. The electronic apparatus controls more than the 80% of the car and truck equipments and sensors start to become more and more interconnected with the communication infrastructure present on the territory and even more with satellite communication. The IT performance of the transportation means [2] is evolving faster than the transportation infrastructure communication facilities. Nevertheless, the number of road accidents and the number of road victims are still unacceptably high.

The I-WAY system is strongly committed to achieve, using ICT technologies, the two strategic objectives of:

i) increasing road safety
ii) bettering the transport efficiency.

Furthermore, I-WAY promotes co-operative driving and in order to fulfil this goal it involves multidisciplinary research and aims to produce both scientific and technological results as well as advanced system prototypes. The key point of I-WAY is the definition of a European standard for car-cooperation oriented to road safety enhancement, with the following main objectives:

1) Definition of a car cooperation paradigm based on innovative Data Fusion algorithms for Dynamic Hazard Assessment, using "real time" data input incoming from different sources.
2) Standardisation of Car Services to be accessed by the subscribers driving.
3) Definition of the main functionalities/performance to be allocated into the Building Blocks (Car On Board" sensors, "On the Road" equipment, Information Centre) composing the infrastructure used for Car Cooperation.
4) Utilisation of a common protocol for car data interchange.

VI. Conclusions

The primary goal of I-WAY is to **increase safety in road** transport, to face up the huge problem of road accidents and related social and also economic implication; injuries and fatalities in road are in fact not only dramatic events but they are also a burden for healthcare system, public authorities and the economy in general. This goal will be achieved by *empowering the information exchange* among vehicles and between vehicles and the surveillance control system.

Further benefits could be obtained by I-WAY system. Providing vehicles with on car sensors that collect and disseminate a huge amount of information to other vehicles and to the infrastructure, I-WAY will improve *traffic management control*, reducing congestions, queues and traffic jams: as a side benefit, I-WAY will lead to reduction of harmful emission and air pollution.

By supporting drivers with warnings and suggestions thanks to an intelligent decision support system and an intelligent driving control system that monitors, collects and manages information and communications to the driver, I-WAY will make *transport more efficient and effective*.

Finally, benefits concern also *quality of life*: I-WAY will make voyages more friendly and comfortable for drivers and passengers that, endowed with a large amount of information, have the chance better plan their route for a more relaxing trip.

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