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Advanced Driver Assistance System for road environments to improve safety and efficiency

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Abstract

The advances in Information Technologies have led to more complex road safety applications. These systems provide multiple possibilities for improving road transport. The integrated system that this paper presents deals with two aspects that have been identified as key topics: safety and efficiency. To this end, the development and implementation of an integrated advanced driver assistance system (ADAS) for rural and intercity environments is proposed. The system focuses mainly on single-carriageways roads, given the complexity of these environments compared to motorways and the high number of severe and fatal accidents on them. The proposed system is based on advanced perception techniques, vehicle automation and communications between vehicles (V2V) and with the infrastructure (V2I). Sensor fusion architecture based on computer vision and laser scanner technologies are developed. It allows real time detection and classification of obstacles, and the identification of potential risks. The driver receives this information and some warnings generated by the system. In case, he does not react in a proper way, the vehicle could perform autonomous actions (both on speed control or steering maneuvers) to improve safety and/or efficiency. Furthermore, a multimodal V2V and V2I communication system, based on GeoNetworking, facilitates the flow of information between vehicles and assist in the detection and information broadcasting processes. All this, combined with vehicle positioning, detailed digital maps and advanced map-matching algorithms, establish the decision algorithms of different ADAS systems.

The applications developed include: adaptive cruise control with consumption optimization, overtaking assistance system in single-carriageways roads that takes into account appropriate speed evolution and identifies most suitable road stretches for the

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maneuver; assistance system in intersections with speed control during approximation maneuvers, and collision avoidance system with the possibility of evasive maneuvers. To this end, mathematical vehicle dynamics models have been used to ensure the stability, and propulsion system models are used to establish efficient patterns, Artificial Intelligence and simulation are used for experimentation and evaluation of algorithms to be implemented in the control unit. Finally, the system is designed to warn the driver if a risk is detected and, if necessary, to take control of the vehicle. The system has been implemented on a passenger car and has been tested in specific scenarios on a test track with satisfactory results.

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1. Introduction

On Spanish roads, almost half of traffic accidents were reported on interurban roads. Moreover, most of them occurred in single-carriageways roads due to their high level of dangerousness (DGT, 2011). Or the other hand, the increase in transport costs and the rise in the prices of motorway tolls has resulted in increased traffic on conventional roads, both heavy traffic and non-professional transport. On interurban roads, 36% of the fatalities occurred in accidents whose type was run out of the road. In addition, 20% of deaths occurred in frontal collisions and 16% in side and frontal-side accidents. Furthermore, there are a non-negligible number of accidents involving pedestrians and cyclists. Most of these accidents occur in single-carriageways roads, where the variability of the scenarios is higher, with less structured environment (World Health Organization, 2009). It is in these environments, where road users are more vulnerable and accidents have a higher mortality rate due to least prepared infrastructures in terms of safety. It is in these areas where driver assistance systems have a more important role, helping to prevent accidents or mitigate their consequences. But to reach the goal of Vision Zero, new actions that go beyond conventional should be carried out.

Another aspect that must be highlighted is the concern in the field of transport energy consumption and emissions, especially in road transport, which must take into account that in the EU-27, 73% petrol (and about 30% of primary energy) is consumed by this sector, and 23% of emissions are associated to it. In this respect, great efforts in developing new technologies in all areas of transportation to reduce these figures are devoted, from optimizing the operation of internal combustion engines and developing hybrid and electric vehicles, as well as the development of technologies aimed at improving efficiency of existing systems. This means the next ADAS generation systems does not look only to provide safety but efficiency. Improving efficiency in traffic can be approached from two levels: the global traffic management and the circulation of the vehicle itself. In addition, in the first case, urban areas and intercity measures can be distinguished, although some may be common (Jimenez, 2012). The efficiency from the point of view of the vehicle itself is focused on improving driving behavior to minimize environmental impact and consumption, but these behaviors usually also lead to improvements in safety and comfort (Jimenez and Aparicio, 2008; Kompfner and Reinhardt, 2008).

However, the implementation degree of this new generation of ADAS is still very limited (Federal Highway Administration, 2006), mostly derived from classical systems which were limited to acting on a single vehicle, that installed sensors, control units, actuators and user interfaces. This philosophy changes when we add to the vehicle communications system that allows to interexchange information with other vehicles, with their surroundings and, in general, ubiquitous sources of information. They are called cooperative systems, which allow providing solutions to the problems of mobility in road transport, increasing safety and efficiency, using information provided by the internal sensors of the vehicles as they come through systems communications. Additionally, cooperative systems is not only restricted to a single vehicle but include the development of ADAS involving interaction between several vehicles and even transport users, through the use of personal devices (National Highway Traffic Safety Administration, 2005). These cooperative systems tend toward autonomous driving, where cars automatically take control of their own actuators for maneuvering with the other vehicles in the road, to improve safety and efficiency (European Road Transport Research Advisory Council, 2008; Verma and del Vecchio, 2011; Travis et al., 2006; Naranjo et al., 2006). Therefore, an assistance system that integrates information from short and long ranges should
take into account both an adequate system of perception of the environment as a wireless communications system that allows the fusion of information available on the vehicle

1.1. Environment perception

Sensing systems are essential in the design of systems for driver assistance, as they are responsible for providing information to decision-making units. The reliability of obstacles detection systems based on laser and radar technologies has to be present in commercial technologies. On the other hand, systems of computer vision have begun to incorporate intelligent systems due to their lower cost and the variety and amount of information in its various versions are able to provide, although their detections have certain limitations, mainly due to the dependence of light or atmospheric conditions. Manufacturers such as Lexus, BMW and Opel, already presented these systems.

The detection and classification of road lanes is the first task to undertake, to assist in the location of both the own vehicle, and the other users and thus allow evaluating their behavior. Despite being a recurrent theme in recent years (Gern et al., 2002), important challenges remain looking to improve their efficiency and robustness, mainly on intercity environments (Liu et al., 2013; Han et al., 2012; Hilario et al., 2005).

Once detected road markings, it is possible to study the interaction between the different elements of the road, and it is essential a proper classification of different road users (cars, motorcyclists, cyclists and pedestrians) (García et al., 2012; Cho et al., 2011).

Current sensor technologies, despite having made progress in recent years, are still far from meeting the demanding requirements of safety applications at a price that allows its use in commercial systems. To alleviate this problem they were designed systems that merge information from different sources, creating a more complex and robust data set that allows more reliable and efficient detections and classifications Broggi et al., 2008; García et al., 2012).

The decision-making units associated with the development of ADAS are responsible for maintaining control, stability and maneuverability of the vehicle during danger situations. Their development and validation is challenging due to its complexity and dependency of other vehicles, environmental conditions and type, etc. The development of virtual simulation allows to analyze the dynamic behavior of the vehicle and study the interaction between the various elements involved in driving, perception and communication systems (Bassems et al., 2013), with the ultimate aim of collaborating in the design stage and in the later stages of validation (Gietelink et al., 2006).

Configuration problems depending on the environment, ADAS type, etc. have represented a limitation for such systems (Doniéca et al., 2008). Nowadays, research has the aim of identifying and characterizing the most significant variables in order to include more efficient systems that must operate in real-time conditions (Bifulcoa et al., 2013) and the impact that these devices have on driver behavior (Maag, 2012).

1.2. Communications systems

Vehicular Ad-Hoc Network (VANET) is an ad-hoc network where the nodes are vehicles (cars, trucks, buses, etc.). In the context of this project it is interesting because it will allow the interconnection of nodes that move arbitrarily and exchanging information between them (Marfia et al., 2007), and these nodes can dynamically create a network.

The VANETs are an important research topic within the intelligent transport systems. Some of the most representative consortia are: Vehicle Safety Communications (USA), Car to Car Communication Consortium (Europe), Internet ITS (Japan), etc. It should be included IEEE itself which, together with the European C2CCC, is developing the IEEE 802.11p protocol.

One of the main difficulties facing this technology is the communications efficiency. This problem arises because the standard way of transmitting information is by multicast (all users) that, when implemented to large-scale scenarios, saturates the network (Hiller et al., 2007; Gordillo et al., 2009). Thus the development of new solutions need specifically tailored solutions to such areas to increase efficiency (Taleb et al., 2007).

The implementation of this type of vehicular networks, supported by GeoNetworking, is still at a fairly early stage of development, with limitations in their stability and efficiency (De La Fortelle et al., 2007; Sandonis et al., 2013).
1.3. Pre-collision systems

To give an early response to situations of risk, and adapt safety measures to occupants of the vehicle and the characteristics of the collision, pre-collision systems arise. These systems seek to reduce the number of accidents and their severity (European Road Transport Research Advisory Council, 2008).

A key aspect in these systems is the decision of whether or not the collision is avoidable because it determines the type of action the vehicle should automatically take (reversible or irreversible steps). To do this, the real-time analysis of the situation should be calculated and TTC (Time-To-Collision) compared with TTA (Time-To-Avoidance) (Jiménez et al., 2013). Other information of interest is the relative impact speed, the impact probability, its location, the characteristics of mass and stiffness of the obstacle (Jiménez et al., 2012). Finally, in this type of system it is essential to act on the control of the vehicle, to carry out maneuvers mitigation.

1.4. Autonomous maneuvering

The intelligent control of vehicles is one of the current challenges of intelligent transport systems. The application of Artificial Intelligence techniques to vehicle systems, enables driving assistance systems to interact with the environment (Verma and del Vecchio, 2011; Naranjo et al., 2006). In this context, a few years ago systems that take control of the vehicle were introduced in the market, although partially. Some examples are Adaptive Cruise Control (ACC) with brake management (Naranjo et al., 2006), parking assistant (Endo et al., 2003), imminent collision emergency stopping (Choe et al., 2008), collision avoidance assistant (Eidehall et al., 2007), automatic intersection manager (Naranjo et al., 2007), automatic lane change (Hessburg and Tomizuka, 1995) or lane keeping systems (Wu et al., 2008). However, more advanced systems require higher levels of detail and accuracy in detecting the environment, in order to assess whether the maneuvers they will perform are safe enough. These systems involve complex perception and sensor fusion.

Nowadays, fully automated driving is a very important research topic, and there are well known developments made by Google, DARPA Challenge competitors (Travis et al., 2006; Trapagier et al., 2006; Thrun et al., 2006), groups as VisLab research group at the University of Parma (Broggi et al., 1999) or within the California PATH program (Hessburg and Tomizuka, 1994).

Regardless of social or legal issues which arise with this novel technologies, it is clear that there can be a breakthrough for improving safety if the systems are able to act fast and effectively. However, it should be noted that, the high complexity involved in these scenarios, these systems demands a high amount of reliable information of the vehicle and the surroundings.

2. Driver assistance system proposal

Intelligent systems can provide solutions to the problems of road mobility, increasing safety and efficiency. As an additional step, both objectives could be integrated. The main objective of this project is to develop an integrated driving assistance system for inter-urban environments, mainly single carriage-ways roads given their special problems, aimed at improving both safety and efficiency through the development of a number of specific applications that meet with this integrated approach. These applications will be considered as cooperative systems, and are based on multisensory perception and communication between vehicles and with the infrastructure, to provide additional information in order to promote actions involving several vehicles. Thus, the system takes advantage of merging information from two sources: onboard perception systems and communication systems between vehicles and infrastructure (Fig 1). Hence, the first one offers immediate environment information, regardless of obstacle type or the fact that other vehicles equip communications systems. That is, they provide information autonomously and independently, providing obstacle detection which, by their nature, could hardly be located through communications technologies. Moreover, communication systems can provide information where perception systems may have difficulties, increasing the action scope. Thus, both sources are complementary, and the integration significantly increases the potential in terms of improving safety and efficiency. The system also includes vehicle automation which is capable of autonomously maneuver if a dangerous situation is detected and the driver does not act properly.
This integrated application for road safety and efficiency ADAS is based on the development of four applications that combine safety and energy efficiency, supported by Information Technology (Fig 2):

- Cooperative adaptive cruise control for fuel efficiency, considering other vehicles and road vertical profile and characteristics.
- Overtaking assistance system in single-carriageways roads that takes into account appropriate speed evolution and identifies most suitable road stretches for the maneuver.
- Assistance system in intersections with speed control during approaching maneuvers.
- Collision avoidance system with the possibility of evasive maneuvers, including pedestrians, cyclist and motorists.

Specifically, the system has the ability to analyze especially complex critical maneuvers such as overtaking, entrances to the path of other vehicles and detect the presence of pedestrians, cyclists and motorcyclists, alerting the driver of these situations and scenarios and, if accident is imminent, to take control of the vehicle automatically in order to slow and/or change its trajectory according to the analysis of the environment and act on the deployment of protection systems.

3. Obstacles detection

Obstacle detection system was developed based on a fusion system consisting on computer vision and laser scanner. The laser scanner used is a Sick LDMRS 4-layer Laser and a stereo camera. The laser provides a point Cloud (PC) from which the system extracts the obstacles (clusters of points). These clusters are used both for ROI generation for computer vision and as information for obstacle classification, based on machine learning.
3.1. Point Cloud Clustering

The first step is the obstacle detection using laser generated PCs. Obstacles are located as local concentrations of points in the PC which are mathematically categorized as clusters. Most of the clustering strategies available in literature are designed for highly populated PC, obtained from high definition multilayer laser scanners and stereo cameras. They do not adapt to outdoor, sparse PCs offering limited performance. In order to solve this limitation, a novel clustering strategy was created, based on a classical Euclidean distance, modulated by several parameters in order to modify the clustering behavior, such as distance from the sensor to the obstacle, geometrical constraints, allowed number of points in every cluster, etc.

After cluster extraction, the resulting clusters are checked against cluster constraints, such as ClusterTolerance for maximum width of cluster in meters, and minClusterSize and maxClusterSize for minimum and maximum number of points. These parameters are also dependant on the distance to the obstacle.

The strategy is addressed to obtain the most populated clusters possible, taking into account that we are using a low resolution multilayer laser. The threshold distance must be adapted to the distance $x$ from the laser sensor to the obstacle, as the distance between consecutive laser points grows with $x$. Due to laser construction limitations, the minimum distance detected in $y$ and $z$ in consecutive points will be greater than the initial threshold if not adapted following Eq. (1).

\[
\begin{align*}
\text{ClusterTh} &= \text{BaseTh} + \text{DistCorr}(x) \\
\text{DistCorr}(x) &= \sqrt{(x \tan(\alpha_y))^2 + (x \tan(\alpha_z))^2} \\
\text{if } |\arctan \left( \frac{y}{x} \right)| &< 2\pi \frac{10}{360} \text{ then } \alpha_y = 2\pi \frac{0.125}{360} \\
\text{if } 2\pi \frac{10}{360} \leq |\arctan \left( \frac{y}{x} \right)| &< 2\pi \frac{30}{360} \text{ then } \alpha_y = 2\pi \frac{0.25}{360} \\
\text{if } 2\pi \frac{30}{360} \leq |\arctan \left( \frac{y}{x} \right)| &< 2\pi \frac{60}{360} \text{ then } \alpha_y = 2\pi \frac{0.5}{360}
\end{align*}
\]

$x, y, z$ are point’s coordinates.

Due to laser scanner restrictions, $\alpha_y$ is always 0.8º

After cluster generation, it is necessary a coordinate alignment in order to align the camera and the laser scanner, this is performed based on the detection of the plane corresponding to the road surface (Rodríguez-Garavito et al., 2014).

Once all the calibration parameters (rotation and translation) between sensors have been computed, the system is able to translate from laser coordinates into camera coordinates in the allowing identification based on both sensors.

3.2. Obstacle classification

Obstacle classification is performed based on SVM approach, based on features of both sensors. Clusters are converted into a mesh structure by Delaunay triangulation in order to reconstruct the shape of the obstacles. For the computer vision approach, Histogram of Oriented Gradients (HOG) are the features used for every obstacle. Based on these two sensors, SVM training is performed.

4. Vehicle-to-vehicle and vehicle-to-infrastructure communications

Vehicular communications are considered the basis of cooperative systems, which can be defined as those safety and energy efficiency applications in transport based on the sharing of information among all the vehicles in nearby areas and road infrastructure. Thus, wireless communications give support to the flow of information between different users of the road and the road itself, allowing efficient, robust and real-time data transmission. These
communication systems can be divided into three types: vehicle to vehicle communication (V2V) vehicle to infrastructure communications (V2I) and vehicle to person communications (V2P). Generally are considered communications vehicle to X (V2X). The objective to be achieved is that each vehicle, infrastructure item and road user equip one vehicular communications module, which service the Dedicated Short Range Communications (DSRC). For these DSRC units to be interoperable and manufacturer independent, the data transmission is managed by a tower of ISO standardized protocols as shown in Table 1:

| ISO Layer                  | Protocol                     |
|----------------------------|------------------------------|
| Application                | Application Message Set      |
| TCP                        | ETSI EN 302 636-5-1         |
| Basic Transport Sublayer   | ETSI EN 302 636-4-1         |
| GeoNetworking Layer        | IEEE 802.2                   |
| Logical Link Layer         | IEEE 802.11                  |
| MAC Layer                  | IEEE 802.11p                 |
| Physical Layer             |                              |

The basis of these systems is the communications protocol IEEE 801.11p, which supports data transmission at the physical layer. This protocol is a protocol extension of WiFi wireless data transmission, adapted to transport. Both at the link and MAC layers use standard protocols inherited from classical wired communications. One of the basic characteristics of vehicular communications is that all data packets that are generated will be associated with a geographic location, represented by its GPS coordinates. This implies two facts: first, all DSRC units must equip a GPS receiver; on the other hand, the GPS coordinates of the location of the packet source must be added in the data packet. This will be done in the networking layer where the standard has been adapted to add the GPS position (among other data) into the headers of data packets. This layer supports also the most characteristic feature of transport communications: always be carried out in broadcast mode, i.e. all packets will be sent to all users in range, but its use will be restricted to a geographic location specified in the data packet itself. This behavior is called geobroadcast. Moreover, multihop behavior of the data packets will be enabled, meaning that all communication modules behave as routers, receiving and forwarding data packets received. Thus, it is possible to extend the range of the data packets beyond the coverage of one DSRC unit itself.

The transport and TCP layers are joint, allowing TCP communications with a basic transport protocol that allows packet routing and enables the GeoNetworking function of the next layer.

Based on these specifications, in this paper it will be used INSIA-ITS communications modules to support vehicular communications, which implement the protocol stack specified to ensure interoperability with communication modules from other manufacturers. In addition, these modules are equipped with multiple interfaces to allow interconnection with other devices via WiFi, Bluetooth or CAN Bus.

Finally, at the application level 4 different applications are defined that will run within the module itself and generate standard data packets each with its own user data field as shown in Table 2.

| Application                | Data packet                          | Required Frequency |
|----------------------------|--------------------------------------|--------------------|
| Cooperative ACC            | Application ID                        | 1 Hz               |
| Overtaking Assistance      | Kind of vehicle/user (car, truck, motorcycle, pedestrian,….) |                      |
| Intersections Assistance   | GPS Position (Lat, Lon) (Degrees)     |                    |
| Collision Avoidance        | Speed (m/s)                           |                    |
|                            | Timestamp (sec)                       |                    |
|                            | Heading (Degrees)                     |                    |
5. Tests

Partial tests of the different components of the system have been performed. More specifically, tests of the perception system and the communication module have been done.

Perception system was tested over 4 different scenarios, in order to provide vehicle detection techniques in real time.

- Test 1: Test 1 is performed with raw learning process, no bootstrapping techniques were applied and the images presented different sizes and dimensions.
- Test 2: In this case, bootstrapping techniques were presented which helped to identify the features in the SVM. Images still presented different sizes and dimensions.
- Test 3: Similar to test 1, no bootstrapping technique was used, however, in this test; the images were resized to a common size.
- Test 4: On this test, images were resized as test 3, and bootstrapping technique helped to increase the success rate.

Training and test image sets are presented in table 3. The results indicators are the following ones and final results registered form tests are shown in Table 4.

\[
\begin{align*}
\text{Accuracy} & = \frac{\sum \text{True positives} + \sum \text{True positives}}{\sum \text{Total population}} \\
\text{Precision} & = \frac{\sum \text{True positives}}{\sum \text{False positives} + \sum \text{True positives}} \\
\text{Recall} & = \frac{\sum \text{True positives}}{\sum \text{False negatives} + \sum \text{True positives}} \\
\text{Specificity} & = \frac{\sum \text{True negatives}}{\sum \text{False positives} + \sum \text{True negatives}}
\end{align*}
\]

Table 3. Test performed with sets used for training and validation.

| Test   | Training images | Positive training images | Negative training images | Test set |
|--------|-----------------|--------------------------|--------------------------|---------|
| Test 1 | 5999            | 35352                    | 2247                     | 864     |
| Test 2 | 5999            | 35352                    | 2247                     | 864     |
| Test 3 | 3554            | 2317                     | 1237                     | 844     |
| Test 4 | 3554            | 2317                     | 1237                     | 844     |

Table 4. Results for the 4 test performed.

| Test   | Accuracy | Precision | Recall | Specificity | True positive rate | False positive rate |
|--------|----------|-----------|--------|-------------|--------------------|---------------------|
| Test 1 | 0.852    | 0.865     | 0.914  | 0.737       | 0.914              | 0.990               |
| Test 2 | 0.918    | 0.912     | 0.967  | 0.829       | 0.967              | 0.171               |
| Test 3 | 0.926    | 0.920     | 0.965  | 0.864       | 0.965              | 0.136               |
| Test 4 | 0.970    | 0.961     | 0.990  | 0.935       | 0.990              | 0.065               |

Figure 3 shows the behavior of overtaking warning system of a motorcycle that overtakes a car in a test with real vehicles on road. Here, the communications system is tested. During the test, the motorcycle is traveling at a maximum speed of 50 km/h, the car is traveling at an average speed of 25 km/h and the test duration is 35 seconds. The two vehicles are continuously connected, while the warning system only begins to generate warnings of vulnerable road users in the proximities when the distance between the bike and the car is less than 20 meters, circulating both vehicles in the same direction. At that time, the safety application starts issuing warnings to the
driver of the car, informing him that there is a motorcycle circulating in the vicinity as well as the relative position to which the car is. During these 35 seconds, the bike surpasses the car and continues its path, stopping the warnings when the distance is greater than 20 meters.

Fig. 3. Overtaking maneuver test.

6. Conclusions

This paper presents an integrated collision avoidance system including obstacles detection systems using artificial vision and 3D-laser scanner, and wireless communications modules. By this technique, it is possible to retrieve more information than with a single system, extending the digital horizon and anticipating further risks that may arise on the road. Four fundamental operating scenarios were planned, oriented to single carriageways roads, based on their higher dangerousness and the higher cost of deploying infrastructure based safety measures. Moreover, the system suggests more efficient behaviors under normal driving conditions, and provides warnings to the driver if it detects any danger, furthermore, the system can also take control of the vehicle (both the steering wheel and the speed) for performing evasive maneuvers or stops automatically.

Several tests of the system modules separately have been performed, verifying proper operation. Likewise, tests are being completed in controlled scenarios of the complete assistance system. The results have been quite satisfactory.

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