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Context Analysis for Situation Assessment in Automotive Applications

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1. Introduction

In the last few years, the application of ICT technologies in automotive field has taken an increasing role in improving both the safety and the driving comfort. In this context, systems capable of determining the traffic situation and/or driver behaviour through the analysis of signals from multiple sensors (e.g. radar, cameras, etc...) are the subject of active research in both industrial and academic sectors (Trivedi et al., 2007); (Yu et al., 2009); (Schneider et al., 2008). These systems, unlike autonomous vehicles or automated control systems are more acceptable for near future real applications since they try to improve driver's sensing capabilities and to help the decision process in a non-intrusive way. According to this statement, car manufacturers are starting to introduce driving support systems in luxury vehicles as, for instance, parking sensors.

The extraction of contextual information through the analysis of video streams captured by cameras can therefore have implications in many applications focused both on prevention of incidents and on provision of useful messages to drivers as traffic flows analysis, dangerous behaviour detection, traffic laws infringements (e.g. speed limits), etc…. For these applications the analysis of what happens inside and outside a car is a relevant source of information.

A framework is proposed, integrating a dual camera network and a set of heterogeneous sensors communicating through a *CAN-bus* for the extraction of context data from on-board cameras mounted on vehicles and of other data as steering angle, speed, brakes, etc…. A camera is oriented so as to frame the portion of road in front of the vehicle while the other one is positioned inside the vehicle and pointed on the driver. As a matter of fact, the joint analysis of on board/off board car context can be used to derive considerations on driver's behaviour and then to detect possible dangerous situations (sleep, dangerous lane changes, etc.) or a driving style which does not respect traffic regulation.

Three blocks are considered: a) internal processing, b) external processing and c) vehicle status data coming from the *CAN-bus*. The most significant data that can be extracted from a camera monitoring the driver are the gaze direction, the position of face, frequency of blinking eyes and mouth movement. As well, the camera looking outside the vehicle allows detecting the position of the vehicle on the road and the lane changes. Moreover, the analysis of the road type (highway, urban road, etc.) and of traffic can provide relevant information to evaluate the possible risks of the driving behaviour. Finally, the data

collected through the *CAN-bus* allow a more robust interpretation of internal context providing information concerning the steering angle, the speed of the vehicle, etc… which can be considered in order to evaluate the behaviour of the driver and consequently of the vehicle with respect to the surrounding environment.
In this work, the architecture of the proposed system will be introduced, then the different blocks will be discussed in detail as well the impact of the proposed solutions on driver's behaviour. Moreover, promising results will be presented concerning the single processing frameworks and the integrated framework where data alignment and data association techniques will be applied to provide a comprehensive description of the driving context towards situation assessment. Finally, the impact of potential improvements of the proposed system and the introduction of a statistical representation of interactions among the driver, the vehicle and the surrounding environment will be discussed.

2. System architecture

2.1 Physical architecture

The physical architecture of the system (see Fig. 1) is composed as follows:

- A processing unit directly mounted on the vehicle allowing real time storing and processing of the acquired signals;
  - A standard camera looking outside the vehicle and positioned as to frame the portion of the road in front of the vehicle. Such sensor allows, for instance, capturing video sequences concerning other vehicles which are occupying the lanes;

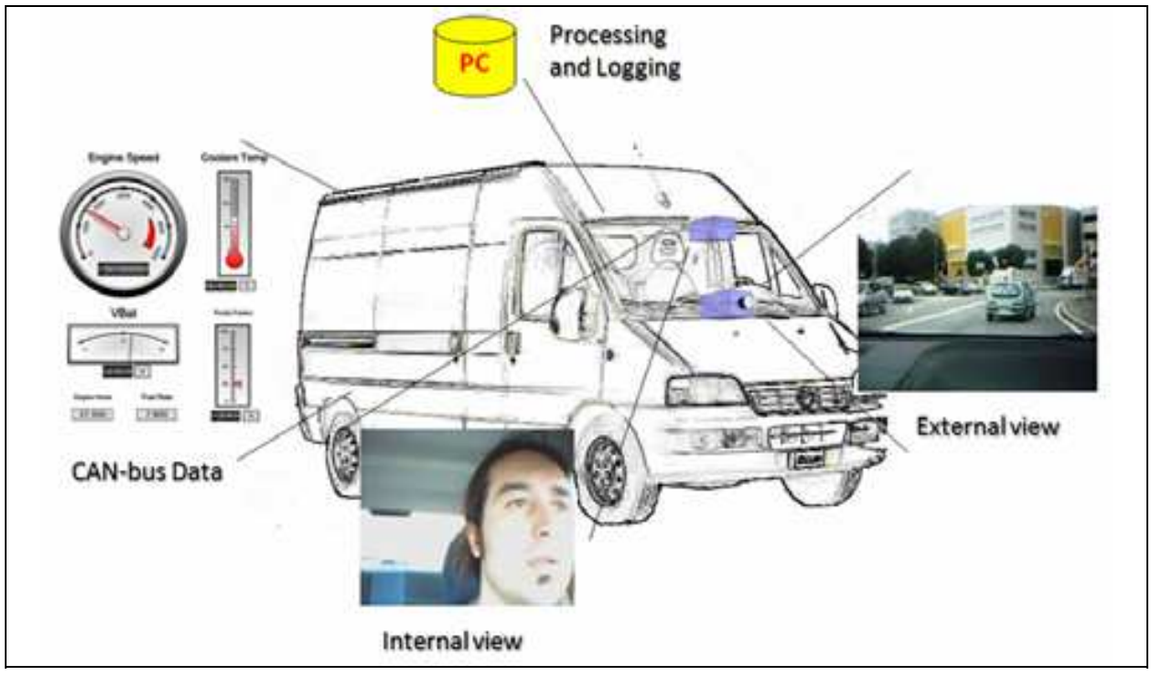


Fig. 1. System physical architecture

- A standard camera looking inside the vehicle and positioned as to frame the face of the driver. Such sensor allows, for instance, capturing video sequences in order to analyze the level of attention of the driver through the analysis of the facial traits;

- A Controller Area Network (CAN-bus) which communicates data concerning the internal state of the car (e.g. steering angle, acceleration) to the processing unit. Data are sent over an Ethernet network in an asynchronous mode as UDP datagram.

2.2 Logical architecture

The logical architecture of the system is presented in Fig. 2.

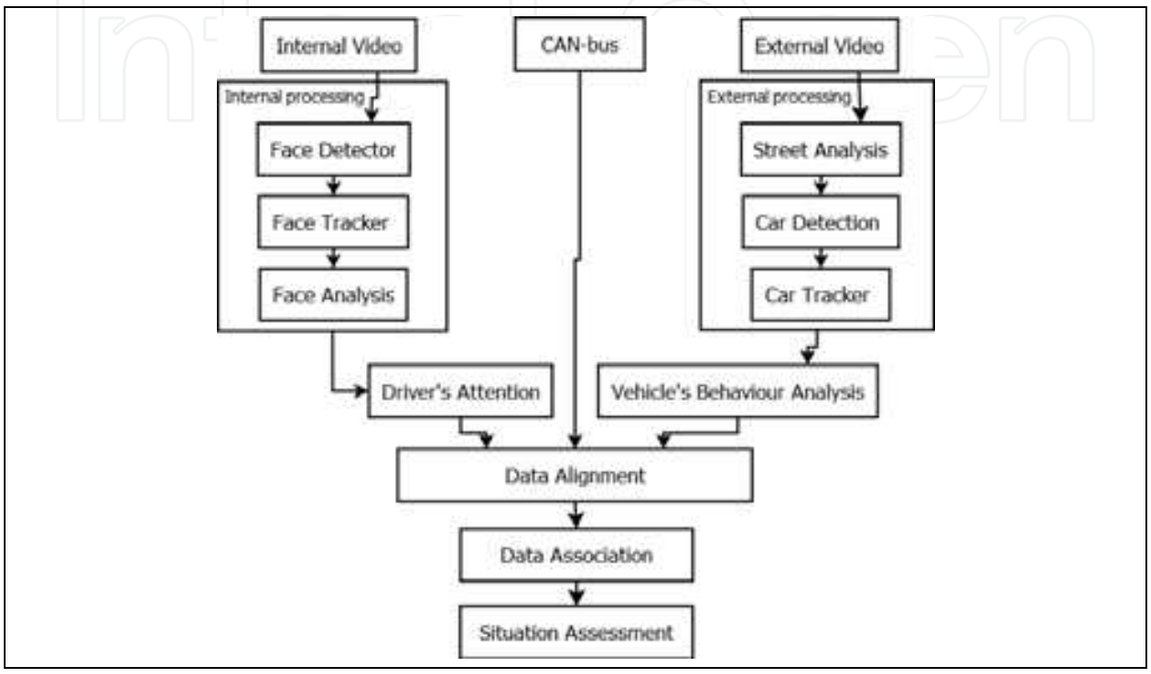


Fig. 2. System logical architecture

Three blocks have been considered, as described previously in the introduction, for the processing of the data coming from the camera looking inside the vehicle, the camera looking outside the vehicle and the CAN-bus (such blocks will be discussed in detail in the following paragraphs).

Then, the output of each block provides different information as the level of attention of the driver, the safe/not safe behaviour of the vehicle with respect to the correct driving patterns (also taking into account what happens in the surrounding environment) and the parameters related to the internal state of the car (speed, status of the lights, etc…).

Finally, data fusion techniques allow aligning and associating the collected data towards the assessment of potentially dangerous situations/behaviours which could affect not only the "intelligent vehicle" but also other cars. The preliminary studies concerning the application of bio-inspired data fusion models for understanding and, eventually, predicting anomalous events will be discussed in the following.

3. Internal video processing and driver's attention analysis

3.1 Related work

The most significant data that can be extracted from a camera monitoring the driver are the gaze direction, the position of the face, the eyes' blinking frequency and the mouth state.

In the state of art several works can be found regarding face pose estimation that is the feature we will mainly focus on for the purposes of the internal processing block. Such feature has been considered particularly relevant in the context of Human-Computer Interaction (HCI) or automotive applications.
A significant body of research has been carried out in the last few years. Various approaches can be categorized, according to the different proposed methodologies, by pointing out the condition of usage, the assumptions and the obtainable performances.
In (Asteriadis et al., 2009) gaze is estimated by analyzing the motion of some relevant features in the eyes and mouth area. This last method, however, does not take into account possible illumination changes since it is designed for indoor Human-Computer Interaction applications.
(Whitehill & Movellan, 2008) describe a method based on frame by frame head pose tracking robust to illumination changes and different facial appearance. Two classifier trained with the GentleBoost (Friedman et al., 2000) approach are used and the output are integrated using linear regression to estimate pose angles.
Other works try to cope with the difficult environmental conditions of the automotive applications (i.e. frequent and relevant illumination changes) by detecting eyes using infrared cameras (Bergasa et al., 2006).
These approaches are usually more robust and they can operate also with very low illumination even if not cost-effective (the cost of an infrared camera is much higher than a standard camera).
Recently, researchers (Yang et al., 2002); (Murphy-Chutorian & Trivedi, 2009) have presented a complete and up-to date survey of head pose estimation algorithms in order to fix the most common issues and to provide adequate solutions.
More in detail, head pose estimation methods can be not exhaustively classified as follows:

- Appearance Template Methods: a comparison among an image of the head and a set of models is performed in order to find the most similar;
- Detector Array Methods: a set of detector, each one specific for a pose discrete value, is trained;
- Non-linear Regression Methods: non linear regression tools are exploited to map the images and the related features as head pose values;
- Geometric Methods: Eyes, nose and mouth positions are exploited to determine the pose;
- Tracking Methods: the pose is evaluated according to the movement observed over consecutive frames;
- Hybrid Methods: two or more of the previously cited methods are combined to overcome drawbacks and limitations of each single method;

3.2 Face detection, tracking and analysis

The proposed internal processing system exploits a tracking based approach for driver's gaze detection to the aim of obtaining a better ratio between accuracy of the method and computational speed. The aim of this work is not to present in deep the technical details of the algorithms but to provide a general description of the method applied for the internal processing block. A more detailed description of the proposed algorithm can be found in (Ciardelli et al., 2010).
In particular, three processing steps have been considered:

- Face detection (face, eyes, mouth and nose);
- Face tracking;
- Face analysis and angle of view calculation.

Firstly, an initialization step is performed for face detection. For each trait the Viola-Jones detector is applied. Secondly, the tracking algorithm enables localizing the position of the face in the video frame and evaluating the relative position of every facial trait like the nose, the mouth and the eyes. For each trait, an instance of Kanade-Lucas-Tomasi (KLT) feature tracker algorithm has been used. Lastly, for each video frame the pose of the face is evaluated in order to extract the angle of view and other relevant information (see Fig. 3).

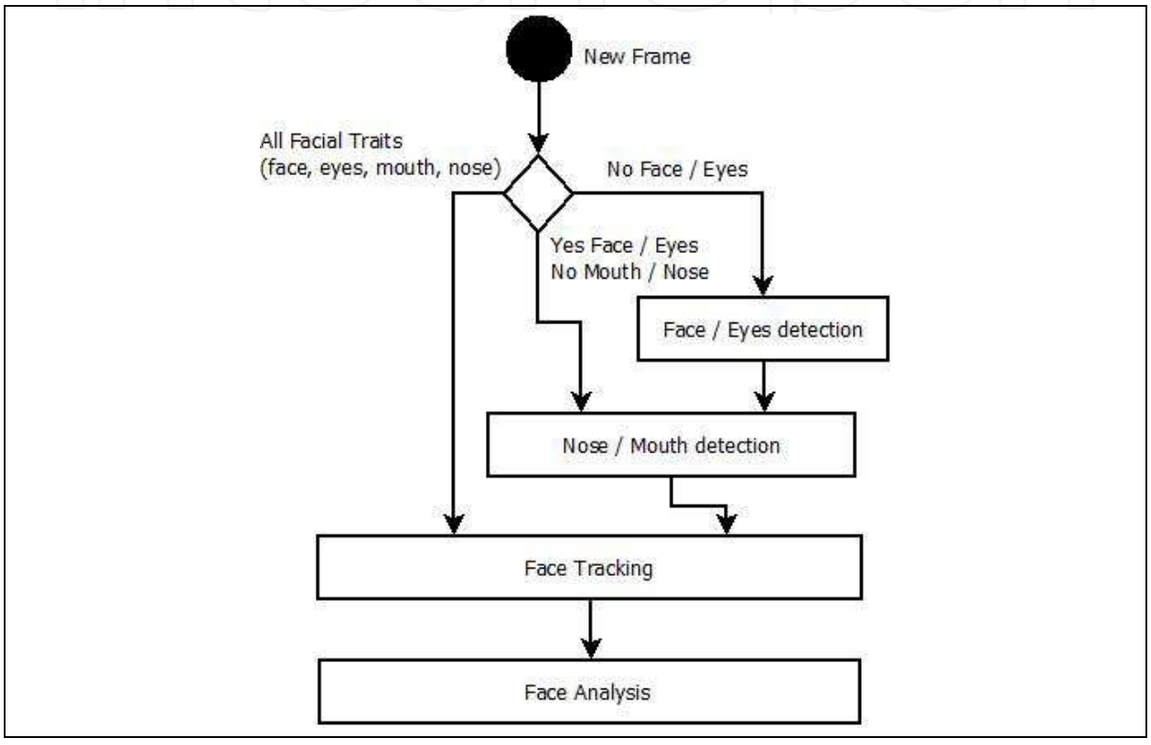


Fig. 3. Internal processing algorithm structure

Face analysis has been focused on the evaluation of the driver's view angle which is one of the most important information that is needed to assess his/her state. The information concerning the angle of view can be disassembled in yaw (rotation with respect to horizontal plane), roll (longitudinal rotation related to movement) and pitch (vertical rotation) angles as shown in Fig. 4.

As a general rule, we have assumed (having been demonstrated in a large testing phase) that the information obtained by the analysis of the yaw component can provide sufficient knowledge about the direction of the driver's gaze. More in detail, we can consider that values of the yaw angle near to 0 correspond to the situation of driver looking straight ahead (i.e. driver is looking at the street and his/her level of attention is adequate) while values far from 0 correspond to the case of driver looking in other directions rather than street one (i.e. a possible dangerous situation can happen because the driver is absent-minded).

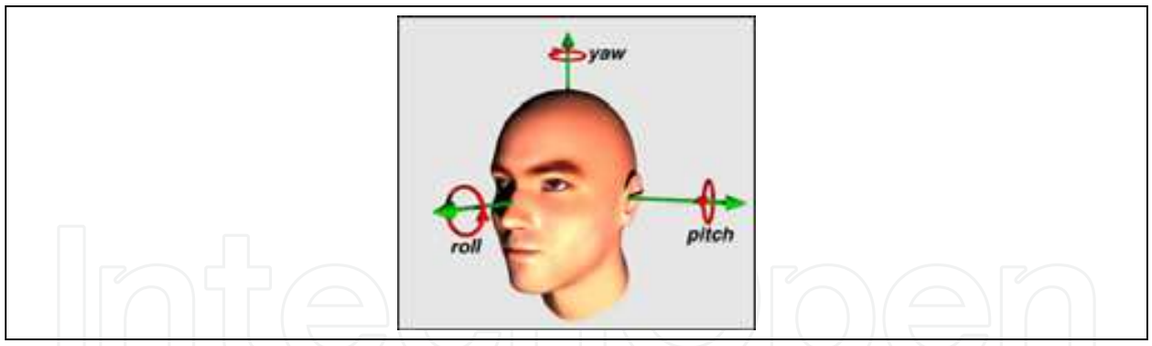


Fig. 4. Yaw, roll and pitch angles

3.3 Driver's attention and experimental results

The aim of the proposed experiments is not to demonstrate the effectiveness of the proposed face detection, tracking and analysis method which has been already proven in other works but to discuss the capability of the proposed system to properly assess the driver's attention in order to provide information useful for the analysis of the driving context.

According to this statement, to calculate the driver's attention, we decided to analyze the angle of yaw extracted from the camera framing the internal context of the car. A time interval μ has been fixed and the follwing formula has been applied:

$$\mathrm{att} = \sum_{t=i}^{i+\mu} w(d_t) + q(|y|) \tag{1}$$

where d_t can take values 0 or 1 depending on whether or not there is the face detection (0 if there is detection), $w(x)$ is the weight function for the non-detection event, $|y|$ is the modulus of the yaw angle and $q(x)$ the corresponding weight function. For each frame, the value of attention att thus obtained is compared with two thresholds η_0 and η_1 in order to assess the level of attention (low, medium, high).

A lot of experiments have been performed using a standard camera at 320x240 of resolution. The standard camera, installed on the vehicle as described in the previous paragraphs, has been used to analyze a driver during a thirty minutes drive aiming at identifying the level of attention.

In Fig. 5 some shots are presented showing the capability of the system of correctly recognizing the attention of the driver.

In the top left sub-figure, the exceeding rotation of the head with respect to the camera axis leads to a blank frame (due to a malfunctioning of the detection and tracking algorithms) which corresponds to a "low attention" message.

In the top right one, as well as in the previous frame, the system recognizes a "low attention" situation according to the value of the att factor which is lower than threshold η_0.

Finally, bottom left and bottom right images show respectively an average and a high attention situation being the values of att respectively within η_0 and η_1 and over η_1.

Table 1 shows the experimental result obtained by the driver's attention analysis. The percentage of frame with errors is obtained comparing algorithm results with observations.

Actually, a more significant percentage of errors occur in the case of low attention because it is more difficult according to the proposed method to correctly detect this case. However, such performance could be improved modifying the thresholds. In this case (i.e. increase of

the threshold) the capability of correctly recognize a low attention situation should improve even if the percentage of false alarms (i.e. of incorrectly detected low attention situations) should increase reducing the capability of preventing dangerous events which usually happen while the driver's level of attention is not adequate.



Fig. 5. Examples of driver's attention assessment

Low attention	7,1%
Average attention	5,3%
High attention	4,1%

Table 1. Percentage of frames with errors

4. External processing

4.1 Related work

The analysis of the road type (highway, urban road, etc.) and of traffic represent an important task to provide relevant information to evaluate the possible risks of the driving behavior.

In the literature, several works can be found addressing the problem of lane detection and vehicle's tracking. Concerning the first problem, in (McCall & Trivedi, 2006), a survey of lane detection algorithms is proposed where the key element of these algorithms are outlined. In (Nieto et al., 2008) a geometric model derived from perspective distortion is used to construct a road model and filter out extracted lines that are not consistent. Another widely used technique to postprocess of the output of the road marking extraction is the Hough transform as shown for example in (Voisin et al., 2005).

Among the different potential applications of vehicle's tracking, in (Chen) a security system for detection and tracking of stolen vehicles is discussed. A 360 degrees single PAL camera-based system is presented in (Yu et al., 2009), where authors provide both the driver's face pose and eye status and the driver's viewing scene basing on a machine learning algorithm for object tracking.
In (Wang et al., 2008) a road detection and tracking method based on a condensation particle filter for real-time video-based navigation applications is presented. The problem is also addressed using different approaches in other works. A real-time traffic surveillance system for the detection, recognition, and tracking of multiple vehicles in roadway images is shown in (Taj & Song, 2010). In this approach, moving vehicles can be automatically separated from the image sequences by a moving object segmentation method. Finally, in (Chung-Cheng et al., 2010) a contour initialization and tracking algorithm is presented to track multiple motorcycles and vehicles at any position on the roadway being not constrained by lane boundaries or vehicle size. Such method exploits dynamic models to predict the horizontal and vertical positions of vehicle contours.

4.2 Lane detection and vehicle(s)'s tracking

The logical framework of the lane detection module is presented in Fig. 6. A detailed description of the steps that have been implemented in order to detect the number of traffic lanes and the position of the vehicle with respect to the road is out of the scope of this work and has been already discussed in (Beoldo et al., 2009).

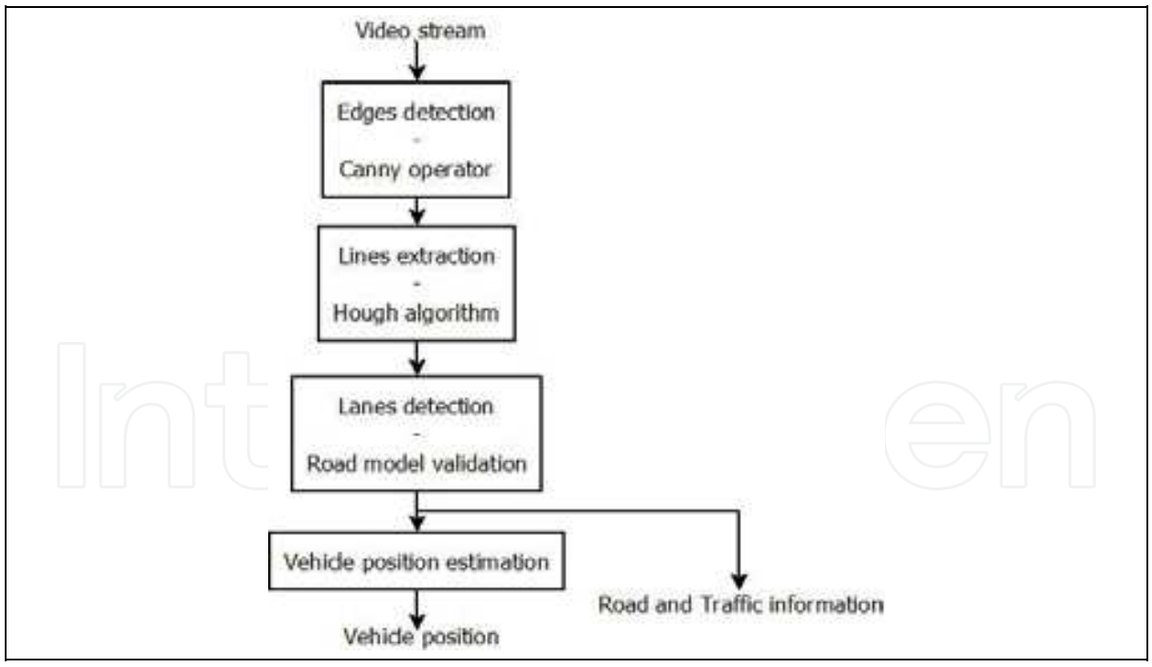


Fig. 6. Lane detection module logical framework

According to the proposed framework, the following steps have been applied to extract road context information from a video sequence:

1. Edges extraction using Canny operator (Fig. 7 - top left);
2. Lines detection using Hough algorithm (Fig. 7 – top right)

3. Lanes detection and road model validation:
   a. The two lines that belong to the lane where the vehicle is driving on are located;
   b. Attention is focused on an area within the triangle formed by the extracted lines. A frame per frame statistical analysis of the pixels belonging to the road is performed to create a model of the road.
   c. All pixels in the image below the point of intersection between the two lines identified at step 3 are considered and each pixel is compared with the model of the road looking for those that are more similar to the model (Fig. 7 – bottom left).
4. Evaluation of whether the road has one or two lanes and which is the position of the vehicle with respect to them (Fig. 7 – bottom right).

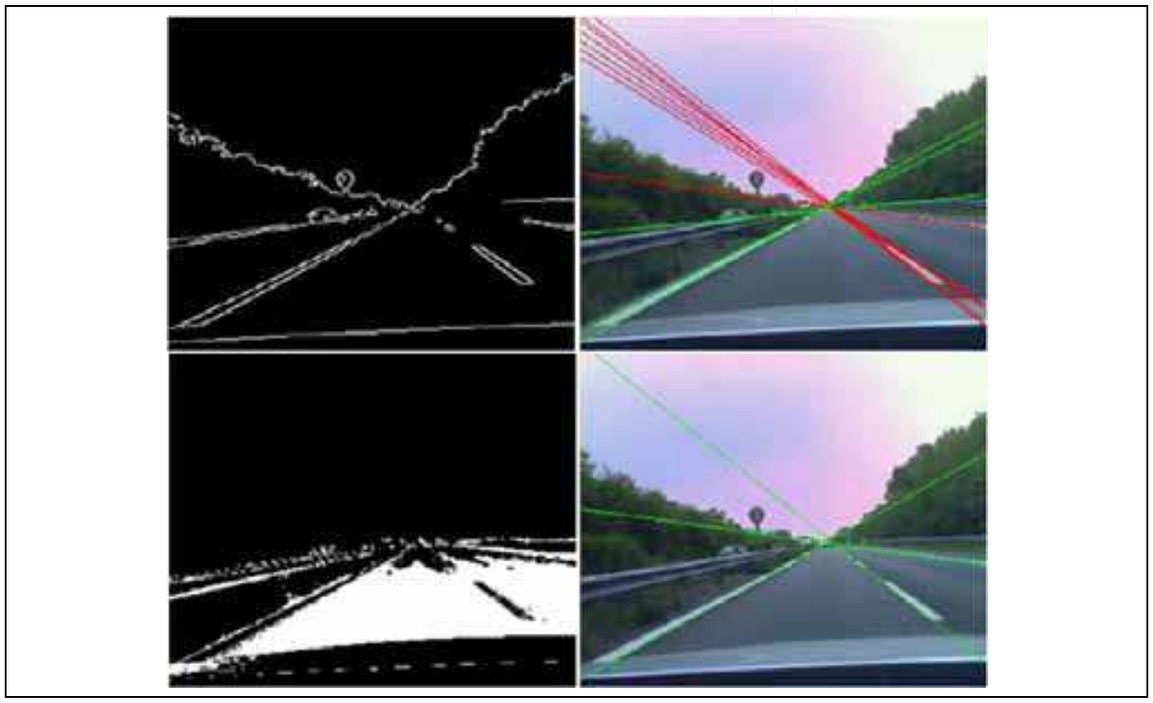


Fig. 7. Lanes detection and vehicle's position estimation: an example

Towards the development on an efficient intelligent system that enables improvements in the cars' safety, the extraction of the most accurate information concerning the space around the vehicle is needed. In such space, the targets to be considered are represented by fixed objects as buildings and trees and/or moving objects, mainly represented by all other vehicles (motorcycles, cars, trucks, etc…).

The main focus of the proposed system is represented by the detection and tracking of vehicles acting in the smart vehicle's surrounding space with particular regard to vehicles in front.

The two main consecutive steps which characterize such a detection and tracking system are:

- Generation of hypotheses (where the vehicle/object to be detected and tracked could be placed in the image);
- Hypotheses testing (previous hypotheses verification concerning the presence of vehicles/objects within the image).

As a matter of fact, the implementation of a solution robust enough to deal with the strict requirements of the proposed application is not easy. In particular, such a system must guarantee, at the same time, a few missed alarms (i.e. the number of missed vehicle/object detections) and a few false alarms (i.e. the number of wrongly detected vehicles/objects).
To this aim a feature-based tracking method is proposed where a Kanade-Lucas-Tomasi (KLT) feature tracking is used in a particle filter framework to predict local object motion (Dore et al., 2009). In particular, such a multitarget tracking algorithm exploits a sparse distributed shape model to handle partial occlusions where the state vector is composed by a set of points of interest (i.e. corners) enabling to jointly describe position and shape of the target.
An instance of the results obtained with the cited algorthm is presented in Fig. 8



Fig. 8. Vehicle's tracking algorithm: an example

4.3 CAN-bus

The Controller Area Network, also known as CAN-bus, is a vehicle bus standard designed to allow microcontrollers and devices to communicate with each other within a vehicle without a host computer. The CAN-bus interface allows extracting context data related to the vehicle's internal state. The data are sent asynchronously via an internal Ethernet network as UDP packets. A not exhaustive list of the data made available by the CAN-bus is provided in the following:

- Light: it indicates activation of the lights of the vehicle;
- Lateral acceleration (positive value corresponds to the left);
- Longitudinal acceleration;
- Parking brake;
- Speed;
- Steering angle (positive value corresponds to the left).

These and other data are made available and properly used according to the different type of application.
Fig. 9 shows an example where the video stream coming from the camera positioned in order to frame the external context and the temporal evolution (graph) of three different data coming from the CAN-bus are considered. The data shown in this example are the speed in metres per second, the acceleration in metres per square second and the steering angle in degrees. For each video frame, the displayed graphs are instantly updated according to the new available data.

In the proposed example the vehicle is moving straight ahead (steering angle equal to zero as shown in the bottom left part of the figure) and is approaching a turn. According to this, the vehicle is in a deceleration phase (see speed Module in the top right of the figure) and the graph of the longitudinal acceleration is negative (see bottom right part of the figure).



Fig. 9. Video/CAN-bus data visualization

It is important to note that, in our experiments, the video data are stored at 25 frames per second and that each video sequence lasts 5 minutes. Moreover, the video capturing-recording application works also as UDP receiver for the CAN-bus data so that the current frame is used as a reference for the synchronization of video and CAN-bus data. However, the CAN-bus data are sent asynchronously so it may also happen to not receive data for a few frames.

4.4 Vehicle(s)'s behaviour analysis and experimental results

The analysis of all the available information concerning the vehicle and the environment allows to generate alarms when a potentially dangerous situation happens. In particular, we have focused the attention on the analysis of the correlation between the distance with respect to the vehicle in front of the smart car (provided by the further processing of the information obtained from the detection and tracking modules) and the speed and the acceleration obtained via the CAN-bus. After a careful analysis it has been decided to define the following formula in order to establish whether or not to report an alarm:

$$\text{danger} = \begin{cases} \text{true} & \text{if } \text{dist}(x_t) < \varepsilon_n, \text{dist}(x_{t-1}) > \text{dist}(x_t) \text{ and } a(t) > 0 \\ \text{false} & \text{otherwise} \end{cases} \quad (2)$$

where $dist(x_t)$ is the function that calculates the distance between the camera and the vehicle which is in the forn of the smart car, ε_n is the threshold below which there may be danger and $a(t)$ is the value of the longitudinal acceleration at frame t.

Figure 10 shows the experimental results obtained applying the proposed method. Three different distances have been considered: a) near (distance below the ε_n threshold), b) average (distance within the ε_n and a ε_a threshold, properly fixed according to the different applications (i.e. highway, street, heavy traffic, etc...)) and c) far (distance over the ε_a threshold).

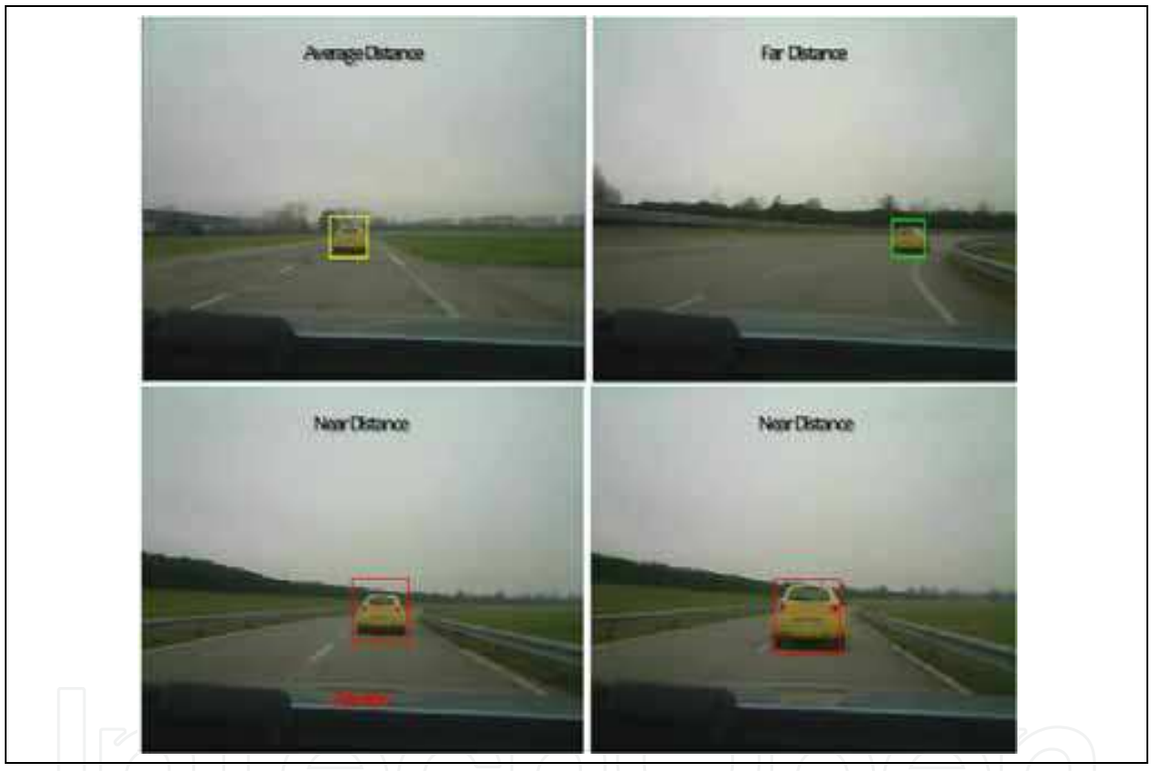


Fig. 10. Dangerous behaviour analysis: an example

In Fig. 10, the top right image shows a far distance situation. The green rectangle symbolizes the low level of danger. In the top left image an average distance situation is presented characterized by a yellow rectangle. Finally in the bottom images two different near distance situation are presented. In the left one, the system recognizes a near distance potentially dangerous situation and a message is displayed ("Attention"). In the right one, the system recognizes a near distance but not dangerous situation so that no message is displayed. The difference between the two cases resides in the data coming from the CAN-bus. In the first case, an increasing value of longitudinal acceleration is detected (potentially leading to a crash) while in the second one the value of longitudinal acceleration of the car is decreasing.

Future experiments will allow showing in the same GUI both the information coming from the video-sensors and from the CAN-bus.

5. Bio-inspired model for interaction analysis

Parallel activities have been carried out in order to study an approach based on a "bio-inspired" model for the analysis of driver's behavior and to detect possible dangerous situations. In (Dore et al., 2010) has been presented a general framework capable of predicting certain behaviors by studying interaction patterns between humans and the outside world. Such framework takes inspiration from the work of the neurophysiologist A. Damasio (Damasio, 2000).

According to Damasio, the common shared model for describing the behaviour of a bio-inspired (cognitive) system is the so-called Cognitive Cycle which is composed by four main characteristics:

- Sensing: the system has to continuously acquire knowledge about the interacting objects and about its own internal status, sensing is a passive interaction component;
- Analysis: the perceived raw data need an analysis phase to represent them and extract interesting filtered information;
- Decision: the intelligence of the system is expressed by the ability to decide for the proper action, given a basic knowledge, experience and sensed data;
- Action: the system tries to influence its interacting entities to maximize the functional of its objective; action is an active interaction component in relation to decision.

The learning phase is continuous and involves all the stages (within certain limits) of the cognitive cycle. According to the cognitive paradigm for the representation, organization, learning from experience and usage of knowledge, a bio-inspired system allows an entity predicting the near future and reacting in a proactive manner to interacting users' actions.

Damasio states that the brain representation of objects or feelings, both internal and external to the body, can be defined as *proto-self* and *core self*. *Proto-self* and *core self* are respectively voted for the self-monitoring and the control of the internal state of a person and for the relationship with the external world.

Thus, we can define as *proto* state $X_p(t)$ the vector of values acquired by "sensors" related to the internal state of a system and as *core* state $X_c(t)$ the vector of values acquired by "sensors" related to the external world. As well, a change in the *proto* state is defined as *proto* event while a change in the *core* state is defined as *core* event. To learn interactions between the internal and external context, the Autobiographical Memory (AM) algorithm, has been exploited (Dore et. al, 2010). In the proposed model, AM is the structure responsible for the representation of cause/effect relationships between state changes (events) occurring in the external world and in the internal system.

Such relationships are stored in the AM as triplets of events $\{ \varepsilon_{P^-}, \varepsilon_C, \varepsilon_{P^+} \}$ or $\{ \varepsilon_{C^-}, \varepsilon_P, \varepsilon_{C^+} \}$. This collection of relations between an entity (e.g. the system, a human subject, etc...) and the environment can be used to obtain a non-parametric estimation of the probability density functions (PDFs) $p(\varepsilon_{P^-}, \varepsilon_C, \varepsilon_{P^+})$ and $p(\varepsilon_{C^-}, \varepsilon_P, \varepsilon_{C^+})$. The PDFs describe the cause-effect relationships between the *proto* and the *core* events and allow to obtain a prediction of the future behavior of the interacting entities given a couple of *proto* and *core* events.

In the proposed automotive application, preliminary studies have been carried out focusing on the vehicle's behaviour analysis. In such a context, we have considered as *core* events all the data acquired from the sensor framing the external context (i.e. the position of vehicle with respect to the traffic lanes, the position of other vehicles, etc...) and as *proto* events the data collected via the CAN-bus.

Fig. 11 shows the logical architecture of the system based on the above described cognitive approach and designed to analyze the behavior of the driver.

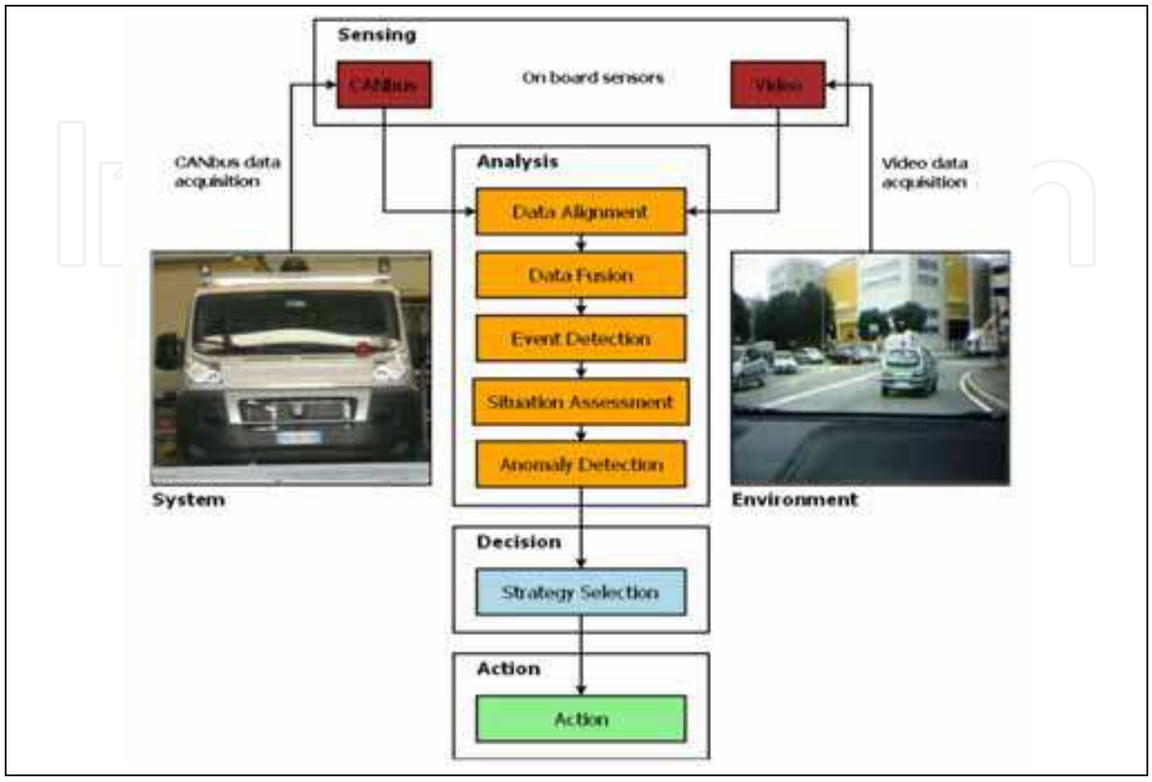


Fig. 11. Cognitive-based logical architecture of the system

Such framework can be divided into a sensing phase corresponding to sensor data (video and CAN-bus) acquisition an analysis phase corresponding to the processing of the available data according to the AM algorithm in order to define causal relationship between internal/external events and to identify abnormal situations. Then, in the decision stage the most suitable strategy to be applied in the incoming situation is selected according to previously acquired experience (properly stored in the AM). Finally, in the action phase, the system interacts with the outside world according to the strategy identified in the previous module.

It is important to highlight that the effectiveness of the proposed approach is strictly related to the amount of data available in the AM. According to this statement, the development of a simulator capable of resembling the behaviours observed in a real scenario is crucial. Actually, first steps have been performed in order to setup a simulation platform capable of providing a large set of training data resembling the scenario (a track) where a lot of real tests have been performed.

6. Conclusions and future work

In this work, a video-based system for context analysis and situation assessment in automotive applications has been presented. Two different solutions have been analyzed involving the internal and the external context of a vehicle. Promising results have been

shown concerning both the driver's attention evaluation and the vehicle's dangerous behaviour assessment.
Future steps will deal with the implementation of a cognitive based framework for the joint analysis of internal and external events towards the prediction of incoming dangerous situations and the definition of a proper proactive reaction strategy. A bio-inspired model will be applied to define causal relationship between internal and external events and a simulation platform will be developed to provide a large set of training data.

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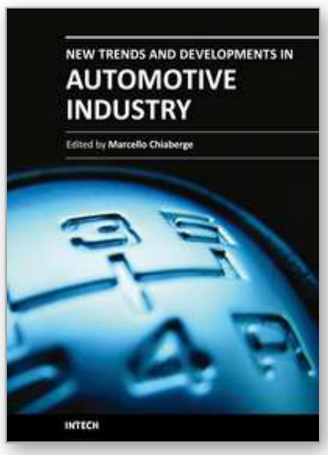
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