Test-bed for Unified Perception & Decision Architecture

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Abstract

This paper presents the test-bed that will be developed for a Unified Perception & Decision Architecture (UPDA). Due to the increasing demand of ADAS systems to be mounted on cars, it is more and more important to develop a unified architecture that can communicate and share information between these systems. This is the aim of an ERC-founded project and to develop and test such architecture a car has been set up with many different sensors.

1 Introduction

VisLab is undertaking highly innovative research within its ERC-founded European project, whose topic is the development of an open standard for the perception and decision subsystems of intelligent vehicles. The subject, gathering the attention of car industries all over the world, was first outlined in 2006 by the German Research Foundation under the name of “Cognitive Automobiles” [1]. Currently, many commercial vehicles include sophisticated control devices like ABS, ESP, and others. These control equipments have been independently developed by car manufacturers and suppliers. Generally, they also act independently, and are singularly tuned. Nevertheless, new methods to improve overall performance are currently under development, exploiting communication and cooperation of these devices: the recently introduced Unified Chassis Control (UCC) is an example. The deployment of the UCC in the mass market, requires to adapt and rethink all control subsystems to provide communication, data fusion, and an overall tuning: namely to integrate all of them together. From the car manufacturers and suppliers point of view, the introduction of the UCC requires the redesign of each single block (ABS, ESP, ...) meaning an additional financial effort, besides the obvious delay in reaching the market. Had a complete UCC architecture been defined well in advance with respect to the development of each single block, its implementation would have been straightforward, less costly, and would have reached the market earlier. Perception and decision modules are in an earlier development stage than control ones: the advanced driver assistance systems that are currently available on the market are only basic ones (Lane Departure Warning, Blind Spot Monitoring, Automatic Cruise Control, Collision Mitigation), independently developed by different car manufacturers and suppliers. The state of the art of advanced driver assistance systems, in fact, has not yet defined a complete architecture that would allow fusion of all these basic blocks and benefit from their integration. The availability of such architecture would allow to define a standard module interface so that the following research efforts could be more focused in providing modular systems, already engineered to fit into this architecture.

In order to develop these concepts, VisLab is setting up BRAiVE, (Fig. 1) a prototype vehicle (three more are expected for 2009) integrating various sensing technologies. A new architecture (UPDA, Unified Perception & Decision Architecture) is meant to take as input all the data coming from the different perception modules, fuse them, and build a more sophisticated world model to be used in the following decision level. In doing this, a standard interface will be defined for each module, allowing different providers to integrate their own perception system into this standard architecture, which will also boost competition.

Fig. 1 BRAiVE, VisLab’s test-bed vehicle for the UPDA architecture

Providing a UPDA involves the understanding of what has to be perceived and classified by the vehicle. We make a list of the main items in the following:

- *pedestrians*: still or moving and, if moving, how fast;
- *vehicles*: and their speed;
- *other obstacles*: and their speed;
- *lanes*: any sort of roadways demarcation line –temporary or permanent, continuous or dashed;
- *stop lines*;
- *junctions*: crossings layout;
- *parking lots*: available parking areas delimited by horizontal demarcation lines;
- *tunnels and bridges*;
- *road signs*: danger, priority, prohibitory, mandatory and indication signs;
- *traffic lights*:
- *free space*: surrounding environment areas available for the vehicle to move and steer;
- *blind spots*: areas of the road that cannot be seen while looking forward or through either the rear-view or side mirrors;
- *light and visibility conditions*: daylight, nighttime, dazzle, rain, fog, snow, etc.;
- *road slope*: road plane inclination;
- *environment*: can be urban or extra-urban; if the latter, no lanes will be available for the vehicle to find its way.

The advanced driver assistance systems currently available on the market can be described in terms of the items just listed: Lane Departure Warning involves the detection of *lanes* and *free space*; Blind Spot Monitoring the detection of *vehicles*; the ACC functionality is allowed by detecting the preceding *vehicle* and Collision Mitigation involves the detection of *vehicles*, *other objects*, *tunnels and bridges*, *free space*.

BRAiVE will be provided with driver assistance systems similar to those already available on the market but with improved performances, plus other major capabilities, listed in the following:

- *Crossings Assistance*: lateral perception is important when facing an intersection, and as junctions may have very different layouts, the lateral system must be able to perceive traffic coming from different angular directions. During a traffic merging manoeuvre, the vehicle is allowed to pull into traffic only when oncoming traffic leaves a gap of a sufficient time interval (usually at least 10 seconds). Hence the vehicle, regardless of the junction layout, needs to perceive the oncoming traffic as well as estimate cars speed from long distance.
- *Overtaking Assistance*: when driving on a road with multiple lanes, the lane change manoeuvre is a common task in order to overtake slower traffic. Two rear cameras installed acquire images of the road behind and on the vehicle side. The cameras are installed so that they can frame the area close to the vehicle and extend their vision over the horizon. This system can overcome some LIDAR limitations, like its inability to provide useful results when moving along dusty roads, where the clouds produced by the vehicle itself negatively affect the laser beams. This is a problem mainly of the rear LIDAR since dust clouds are produced by the vehicle in motion; sometimes it affects also the front ones especially during sudden stops when dust clouds overtake the car. Despite this problem, LIDAR data have been used to refine the detected obstacles position measurement, thus reducing the errors introduced by vehicle pitching, since distance estimation is performed by a monocular system.
- *Lane Keeping*: navigation in a urban environment has to be very precise. The vehicle must be able to detect obstacles and lane markings with high confidence on the detection probability and

position accuracy; moreover the system must detect stop lines, to allow a precise positioning of the vehicle at intersections, and lane markings in sharp curves. The perception system must therefore cover a distance range useful for detections at driving at medium-to-high speeds. The vehicle includes two stereo systems (one on the front and one at the back) which provide precise sensing in its close proximity.

- *Parking Assistance*: the system aims at supporting the driver during parking manoeuvres.
- *ACC Stop-and-Go*: this functionality is to be used for speed adjustment in respect of the preceding vehicle. Stop-and-Go is for queue-driving, when the vehicle speed is lower than 15km/h in a urban-like environment (whereas ACC operates at higher speeds, like on highways). Once engaged, gas and brake control are handled by the system until some driver's action on the pedals disables the automatic speed control of the car.

To meet these requirements, a sensors belt has been set up around the vehicle. The choice to primarily use passive sensors is dictated by the will of producing a car suitable for mass production: active ones are likely to interfere with each other, thus potentially degrading the performance of multiple autonomous vehicles operating in close proximity. The vehicle is equipped with a variety of devices, including sensors for world perception, navigation and control systems, localizations devices, computers, displays, batteries, wiring. A lot of effort must be spent to obtain a high integration level, making the perception devices barely visible from outside the vehicle and the controls and displays integrated into the dash board, headrest and armrest. Fig. 2 shows the overall equipment schema.

BRAiVE will be used for testing both UPDA and ADAS applications.

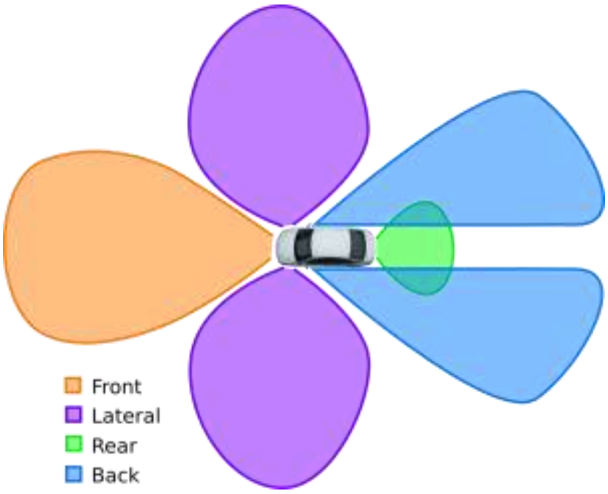

Fig. 2 BRAiVE's perception modules, sensing its surrounding areas

2 Hardware Architecture

As introduced in the previous section, the aim of the architecture proposed is to give BRAiVE an all-round view in order to let it perceive the environment and its evolution before taking any decision about its own movement. The vehicle must be able to sense its surroundings, understand situations and react quickly; a service-based system architecture coupled with efficient path planning, trajectory algorithms and behaviour modes ensures that sensor data are processed in a timely manner, while robust low level control and X-by-Wire components enable the vehicle to manage different situations.

The complete perception apparatus integrates 10 cameras, 3 laserscanners, a laser, a GPS unit connected to an Inertial Measurement Unit, and 4 PCs; the whole car has been set up for drive by wire, and can be controlled via CAN messages. The UDPA architecture to be implemented on BRAiVE receives, as input, information coming form laser, laserscanners, cameras, GPS antenna, inertial navigation system and vehicle state. All these information are gathered to create, and continuously update, a perception map of the environment where BRAiVE is called to move, on the basis of which the implemented driver assistance actions are evaluated and taken.

To get into the architecture details, in the following the description will be split in 4 subsections, each referring to a monitored area of Fig. 2 and describing a perception module: front, lateral, rear, and back. The items listed in section 1 will be associated with each monitored area and, to give an idea about what each module's output will look like, similar systems previously developed by VisLab and their respective outputs will be cited. Those systems will be the prototype vehicle TerraMax T2, which participated to the 2007 Urban Challenge [2], a market available Hyundai Grandeur, demonstrated at IV 2008 conference [3]., TerraMax, which was between the only 5 vehicles to have completed the 2005 Grand Challenge course [4], and a Volvo truck. In the following sections' images, devices involved in the different modules perception are highlighted with colored ovals: red to indicate cameras and green to indicate laserscanners.

2.1 Front

The vehicle frontal perception must cover the orange area in Fig. 2. Specifically, referring to the items listed in section 1, the head-on system must detect *pedestrian*s, *vehicles*, *other obstacles*, *lanes*, *stop lines*, *parking lots*, *tunnels and bridges*, *road signs*, *traffic lights*, *free space*, the *road slope* together with the kind of *environment* around and its *light and visibility conditions*.

For this purpose, BRAiVE head-on system includes 2 stereo pairs –of which one with 2 color cameras and the other with 2 b/w cameras– placed behind the windscreen, 2 single layer laserscanners with a 270 degrees scanning range and a sensing range from 0.1 to approximately 60 meters, another laserscanner with 4 parallel and simultaneous scanning layers, a scanning range of 100 degrees and a sensing range from 0.3 to 200 meters, and finally a laser with 16 beams, a 16 degrees scanning range and a sensing range up to 200 meters.

Some of VisLab's previously developed systems for frontal area monitoring are shown in Fig. 3, 4, 5.

Fig. 3 TerraMax T2 head-on area was equipped with a trinocular color cameras system and 2 laserscanners for obstacles and lane detection [2]: system output is shown in the right image

Fig. 4 The Hyundai Grandeur had a single b/w camera installed behind the windscreen and a laserscanner with a 90 degrees scanning range and an extended sensing range up to 80 meters to detect road signs [5] and pedestrians [3]; images on the right give some examples of its outputs: road signs detection and pedestrian detection during nighttime visibility conditions

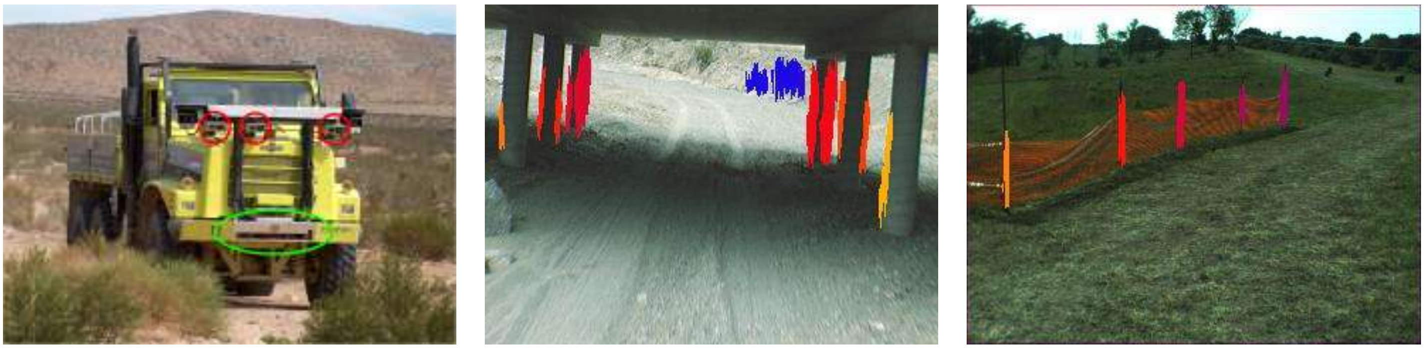

Fig. 5 On TerraMax was installed another trinocular color cameras system aided by a single laserscanner with 4 scanning layers, a scanning range of approximately 150 degrees and a sensing range of approximately 80 meters [4]; right images show some examples of its output: obstacle detection (bridge pillars and small poles) in extra-urban environments

2.2 Lateral

Perception on the vehicle's lateral sides must be able to detect *pedestrians*, *vehicles*, *other obstacles*, *junctions* and *free space*. BRAiVE lateral system, monitoring the violet areas in Fig. 2, includes 2 color cameras installed near the car's hood, above the tires and at the bumper's both ends.

Some of VisLab's previously developed systems for lateral areas monitoring are shown in Fig. 6, 7.

Fig. 6 TerraMax T2 was equipped with a lateral system made of 2 color cameras placed on a bar in front of the ventilation grid with the purpose of detecting cars approaching at traffic junctions [2]; right image shows an output example of T2 lateral system: cars driving towards the junction are framed by a red bounding box

Fig. 7 The Hyundai Grandeur had a single b/w camera installed near the wing mirrors for parking assistance purposes; both images on the right show examples of free space detections: green areas (red in the bird's eye vieew underneath) are suitable for parking the car

2.3 Rear

BRAiVE rear perception system, monitoring the green area in Fig. 2, is committed to the detection of *vehicles* and *other* obstacles, *parking lots*, *free space* and *blind spots*. For these purposes, 2 color cameras are placed in both wing mirrors lodgings besides the respective mirrors.

Some of VisLab’s previously developed systems for rear areas monitoring in Fig. 8, 9.

Fig. 8 TerraMax T2 rear view system consisted of 2 color cameras placed on top of the truck cabin, pointing backwards [2].; right images show some approaching cars detected by red U-shaped lines

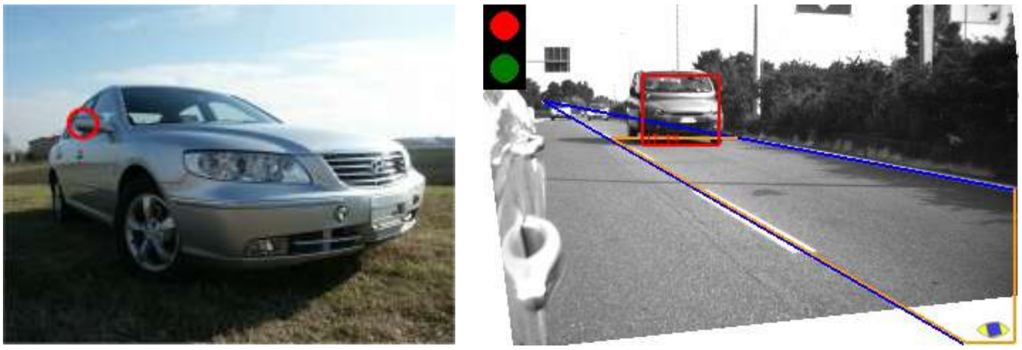

Fig. 9 The Hyundai Grandeur rear view system was made of 2 b/w cameras installed in the wing mirrors lodgings; right image shows an example of the system’s output: lanes with a blue stripe and an overcoming vehicle with a red bounding box, are correctly detected; the traffic lights image indicates if overtaking is permitted or not

2.4 Back

To monitor areas at the back, blue colored in Fig. 2, BRAiVE is equipped with a stereo pair of 2 color cameras and a laserscanner between rear bumper and number plate. Aim of the system is the detection of *pedestrians*, *vehicles*, *other objects*, *parking lots* and *free space*.

Some of VisLab’s previously developed systems for frontal area monitoring, but convertible for back areas, are shown in Fig. 10, 11.

Fig. 10 TerraMax T2 frontal system for near obstacles detection consisted of a color cameras stereo pair and 2 laserscanners (described in Fig. 2.1 caption) [2]; the right images roadway lanes and a preceding car being correctly detected

Fig. 11 Another color cameras stereo system installed by VisLab on the front of a Volvo truck cabin, for near obstacles detection [6]; examples oft he system's output are shown in the right image

3 Final Considerations

The project is aimed at the development of autonomous vehicles and supervised driving systems with the ultimate goal of defining a common open architecture which will be proposed as a standard to the automotive sector. Besides providing clear advantages on safety for road users, the availability of an open architecture will encourage and make possible the sharing of knowledge between public and private research communities (academic and automotive industry) and thus speed up the design of a standard platform for future vehicles. Further research steps will be eased -and therefore made more effective- thanks to the common and open architectural layer proposed. The project is divided into the following two main milestones:

1. the development of fully autonomous vehicles and,
2. extension towards driving assistance systems, namely systems able to supervise a driver and to intervene when necessary.

Fig. 12 shows the evolution of driving assistance systems leading to autonomous driving. The first 4 steps have a human being as vehicle main leader: starting from a set of independent warning systems (step 2) like lane departure warning, to independent active systems (step 3) like adaptive cruise control, collision avoidance, and finally a unified perception and decision architecture (step 4) devoted to perform an active cooperative driving. From step 5 onward the vehicle leader changes from the human being to the electronic pilot increasing the sensing capabilities. First with autonomous driving and then (step 6) with supervised driving, in which the human instructs and directs the manoeuvre while the main control is owned by the electronic pilot. Human contribution, in this case, is treated like one of the other sensing devices, and thus overridable. This project will reach step 3 and step 4, using the new concept architecture to make all the systems cooperate together.

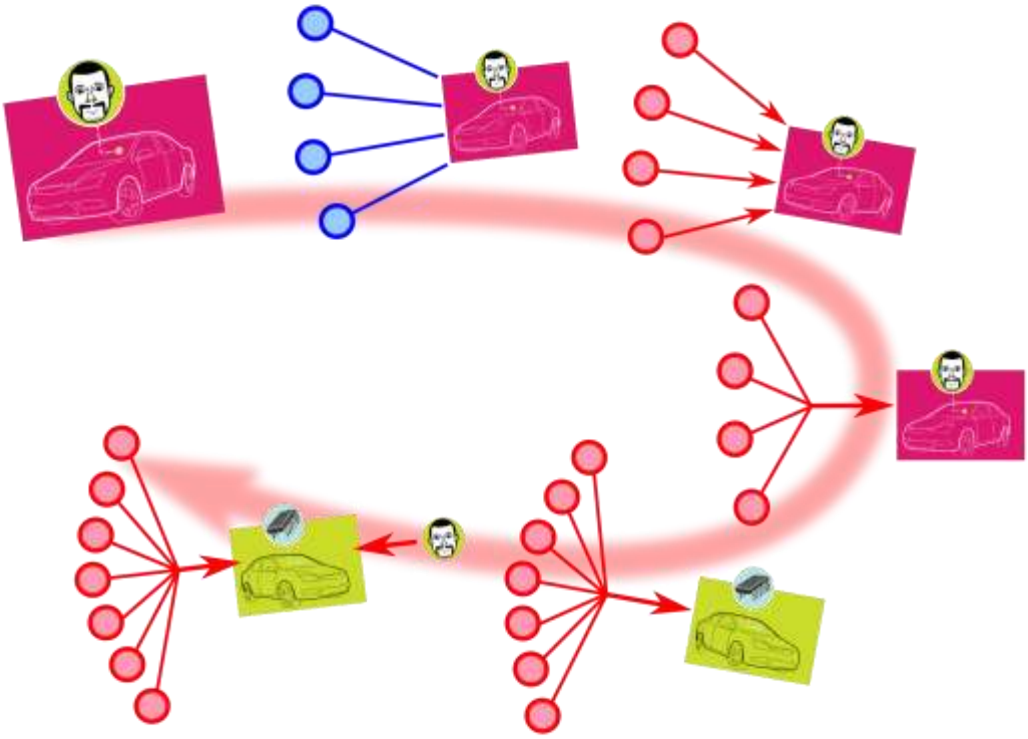

Fig. 12 Intelligent vehicles evolution

The first milestone will be a demonstration of fully autonomous vehicles able to cope with real scenarios and not only with controlled environments. This requires to develop both an extended perception system able to build an accurate world model and a sophisticated decision system. This part will be based on the work already developed by VisLab for other projects (like ARGO [2] and the DARPA Challenges [7]) and its experience as a primary player in this field.

In the second stage, leading to the second milestone, a perception module able to analyze the driver's intentions as well as a Human Machine Interface will be added in order to enable driving assistance features. As mentioned, this requires to extend both the perception and decision functionalities in order to integrate new inputs.

During both stages, the logical architecture of the vehicle (i) autonomous system and (ii) supervisory system will be designed, tested, and validated thanks to intermediate tests on its completeness, feasibility, and scalability by means of the test bed described.

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