The VIAC Challenge: Setup of an Autonomous Vehicle for a 13,000 km Intercontinental Unmanned Drive

Massimo Bertozzi, Luca Bombini, Alberto Broggi, and Paolo Grisleri
VisLab, University of Parma, ITALY – `www.vislab.it`

***Abstract*— Autonomous vehicles have been demonstrated able to reach the end of a 220 miles off-road trail (in the DARPA Grand Challenge), and1 negotiate traffic and obey traffic rules (in the DARPA Urban Challenge), but no one ever tested their capabilities on a long, intercontinental trip and stressed their systems for 3 months in a row on extreme conditions.**

This invited paper presents the vehicles that will run the *VisLab Intercontinental Autonomous Challenge* and the design issues that are the base for the equipment of an autonomous vehicle that will have to drive itself without any human intervention on an intercontinental route for more than 13,000 km.

The challenge will take place from July 10, 2010 to Oct 10, 2010, therefore being currently under preparation, this paper focuses on the preparation issues and describes some important design choices.

I. INTRODUCTION

The World Expo 2010 will be held in Shanghai, China, May 1-Oct 31, 2010. It is the third most relevant worldwide event after the FIFA World Cup and the Olympic Games. The 2010 Expo theme is *better cities, better life*; therefore issues related to sustainable mobility are indeed central to the Expo, which will be a display of new ideas developed worldwide in this field.

The Expo will constitute a great opportunity to showcase new and innovative technologies in the field of intelligent mobility, especially urban mobility.

VisLab has been working for more than 15 years in the field of intelligent vehicles and participated in many worldwide events, like the DARPA Challenges. Many of VisLab's results are considered as worldwide milestones in the field of vehicular robotics, like the ARGO project (a passenger car that in 1998 drove for 2000+ km on Italian highways in automatic mode; 94% of the event was performed without human intervention), or the TerraMax vehicle.

TerraMax is an Oshkosh MTVR truck that VisLab equipped with sensing systems (primarily artificial vision) and that was able to reach the end of the DARPA Grand Challenge in 2005 (220 miles of off-road driving with no human intervention) and was qualified for the DARPA Urban Challenge in 2007 (6 hours of urban driving).

VisLab wants to set a new milestone in the domain of intelligent vehicles with a new initiative, completely conceived and sustained by VisLab: the idea is to demonstrate, through an extensive and impressive test, that the current technology is mature enough for the deployment of non-polluting and no-oil based autonomous vehicles in real conditions.

Fig. 1. The VisLab Intercontinental Autonomous Challenge route.

II. THE CHALLENGE

The challenge, named *VisLab Intercontinental Autonomous Challenge* (VIAC), has a unique final goal: to design vehicles able to drive autonomously along a 13,000 km trip, with no human intervention. Although this goal is definitely very complex, VisLab is approaching this exciting endeavor together with additional innovative ideas. The vehicles will be electric and power to the electronic pilot will be delivered by solar panels. These additional requirements will help demonstrate that it is possible –although in a prototype version– to move goods between two continents with non-polluting vehicles powered by green energy and with virtually no human intervention. Some goods will be packed in Rome, some collected throughout the trip, and finally taken to Shanghai with virtually no impact on world's pollution.

Fig. 2. The VisLab autonomous vehicles before equipping them with sensors.

The work described in this paper has been partially funded by the Open intelligent systems for Future Autonomous Vehicles (OFAV) Project, by the European Research Council (ERC) within an Advanced Investigator Grant.

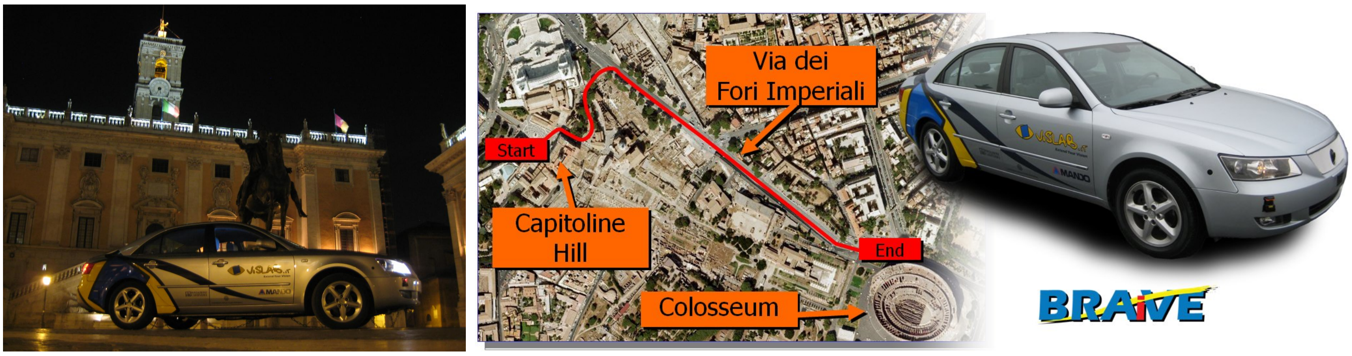

Fig. 3. BRAiVE (VisLab's latest driverless vehicle) in Rome, and the route of the demo.

A. *The Route*

The route will pass through different countries both in Europe and in Asia as depicted in figure 1. The main countries that will be traversed, besides few European countries, are Russia, Kazakhstan, and China, where the vehicles will spend much of the 3 months trip. Different roads and traffic conditions will be faced and the vehicles will have to deal with unexpected situations, providing ground for an excellent improvement of VisLab current ADAS systems.

B. *Scientific Outcome*

The Intercontinental Autonomous Challenge will be the first demonstration of autonomous driving on a route that is:

- Long: more than 13,000 km. This extensive test will allow a thorough test of the developed technologies;
- Extreme: different environments will be crossed to validate and stress the system in several different conditions.

C. *The Expedition*

The expedition will be composed of 4 autonomous vehicles plus support vehicles (4 Overland trucks including mechanic shop, storage, accommodation. . .). Other vehicles will also follow, mainly for live satellite broadcasting of the event. The complete trip will last three months.

III. AUTONOMOUS DRIVING

During the challenge two autonomous vehicles will be driving. Although the two vehicles will be exactly identical (same sensor suite and identical control system) they will have different goals:

- the first one will use the whole sensor suite (including expensive sensors) and will face a completely unknown environment;
- the second one will use a subset of sensors (only cheap ones) and will demonstrate 100% autonomy when coarse route information will be provided by the first vehicle.

A. *The First Vehicle*

The first vehicle will drive autonomously for most of the trip; it will conduct experimental tests on sensing, decision, and control subsystems, and will collect data throughout the whole trip. Although limited, human interventions will be needed to define the route and intervene in critical situations.

B. *The Second Vehicle*

The second vehicle will automatically follow the route defined by the preceding vehicle, requiring no human intervention (100% autonomous). It will be regarded as a readily exploitable vehicle, able to move on loosely predefined routes. At the end of the trip, its technology will be transferred to a set of vehicles to move in the inner part of Rome in the close future.

C. *Technology Demonstration*

During the trip, demonstrations will be performed in specific hot spots: autonomous vehicles will follow given routes, negotiating traffic, avoiding obstacles, and stopping when required. A first demonstration was given in Rome between the Campidoglio and the Colosseum in late October, which demonstrated autonomous driving in narrow roads, with pedestrians and traffic. The BRAiVE vehicle was used, which incorporates much of the technology installed on the electric vehicles that will on the road to China.

The Intercontinental Autonomous Challenge was officially announced by the Major of Rome in a press conference in Rome on October 29, 2009; after the presentation, the Major of Rome left the meeting on BRAiVE, VisLab's latest driverless car (www.braive.vislab.it).

IV. VEHICLE SETUP

The 4 electric vehicles are all equipped with the very same sensing and actuation technologies to optimize development time and help in case of failures.

A. *The Sensing System*

The vehicle sensing system is based on cameras and laserscanners. 7 cameras are installed on the vehicle (5 forward and 2 backward looking), while 6 laserscanners with different characteristics and orientations are placed around the vehicle.

Figure 4 shows the vision sensors' placement and describe their use.

Each camera is connected at 400 Mbps to its specific processing unit in the trunk through a Firewire hub. Laserscanners are connected to the 100 Mbps ethernet switch. Each camera is capable of transmitting the Bayer/Raw image captured from the Micron MT9V022, 752 × 480 sensor through the IEEE 1394A bus; in this way all the color information available is transmitted at 1/3 of the bandwidth of a full RGB, 8 bit per channel image. Appropriate color reconstruction is needed on-board the processing unit. The shutter of each camera belonging to the same system is started by a 10Hz software generated common trigger signal, to ensure the images are taken at the very same time: error between the starting capture times is below a tenth of microseconds. The stitching system and the stereo system have separate triggers. A software plugin performs a very fast analysis of the incoming images from a camera and finds the best exposure parameters, like shutter and gain, to be applied to the camera to improve recognition rates. Another custom software plugin ensures the synchronization of the main exposure properties between the cameras to ensure that images feeding the same system are consistent and similar to each other. Other camera parameters like white balance and gamma are tuned at the camera boot time to be consistent.

The optical system has been tuned selecting a focal length of 4.5 mm for the Stereo Front cameras, and 3.5 mm for the Stereo Back and Stich. The forward and backward stereo vision systems locate obstacles and lane markings, while the 3-camera frontal system stitches the 3 images together to form a single panoramic view of the 180 degrees in front of the vehicle in order to locate the leader vehicle. The laserscanners are used to locate obstacles, the vehicle in front, and other traffic.

One multi-beam laserscanner unit is mounted in the center of the front bumper. This laser has four planes, a horizontal aperture of 85 degrees, a vertical aperture of 3.2 degrees, and measures distances in the range 0,3–80 m. It is set to produce data in free run mode (not triggered) at 12.5 Hz. It is positioned at 54 cm from the ground plane and the pitch orientation is a few degrees downward. Three mono-beam laserscanners create a perception plane all around the vehicle at a height of about 60 cm. This allows to detect most of the commercially available vehicles. These lasers are placed at about 60 cm from the ground plane, with the scanning plane parallel to the ground plane and with an orientation appropriate to cover the maximum area around the vehicle. Other two mono-beam laserscanners are placed at 173 cm from the ground plane, over the cabin with a pitch angle of 45 degrees downward to detect ditches and curbs in the forward looking direction. All lasers are set up to send raw data at a selected rate. Since most of them do not have a trigger input, the synchronization is obtained via software by selecting the last captured scan before a given captured set of images. The laserscanners are visible from all the computers connected to the network; in this way their data can be used for several processings at a time. All the laser sensors have an IP67 waterproof grade.

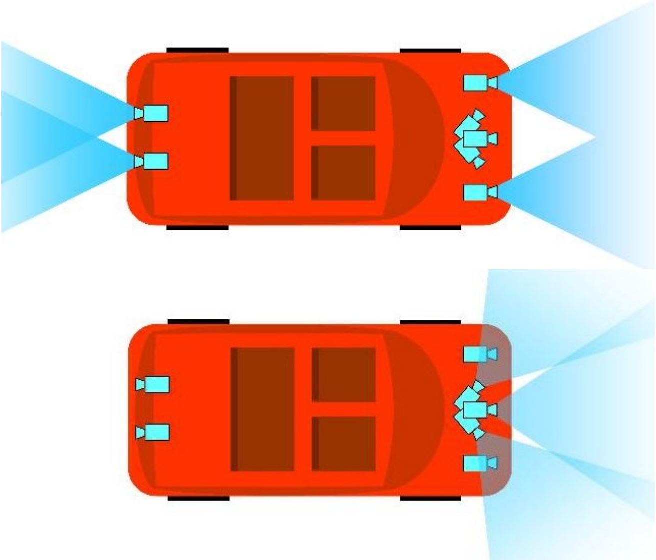

Fig. 4. The vehicle's vision sensing. Top: frontal and backward stereo vision systems able to detect lane markings and obstacles; bottom: frontal panoramic vision system, used to locate the leader vehicle.

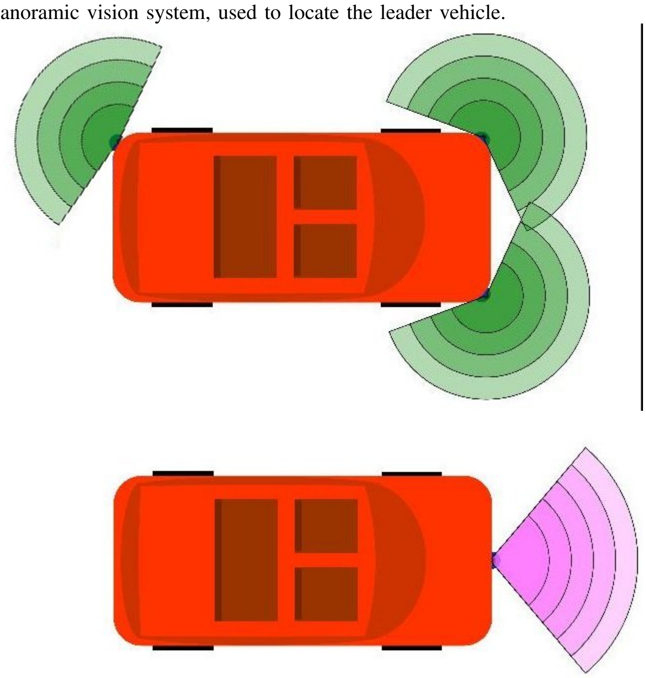

Fig. 5. The laserscanner system. Top: monobeam laserscanners covering the front and the back of the vehicle; bottom: multibeam (4) frontal laserscanner.

Figure 5 shows the laserscanner sensing systems and their use.

The vehicle also features GPS, IMU, and intervehicle communication systems. The AGI3 GPS/IMU unit, provided by TopCon, is mounted on top of the roof and provides both GPS and inertial data through a 115200 bps RS232 serial port and through a CAN port. GPS Transmitted data are provided in NMEA format, while INS data are available on a proprietary protocol. The inertial unit provides

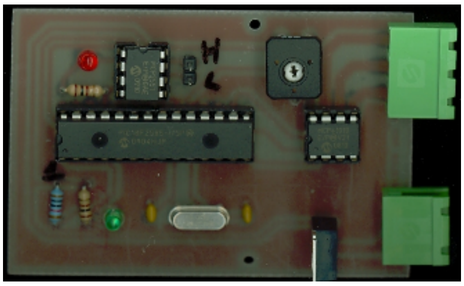

Fig. 7. The simple gas control board.

linear acceleration on three axes as well; the three angular accelerations are measured using the internal gyroscope; an additional magnetometer provides the bearing information and finally a thermometer provides the temperature of the unit.

Other data are available on the vehicle CAN bus. Among these: odometry, obtained from an incremental encoder, and the steering wheel status, which are used by the control algorithms.

Two technologies (vision and laser) are used together and their data fused in order to achieve a more robust detection in all scenarios like mountain, urban, off-road, and in all weather situations like dust, heavy rain, sunshine…

Two 240 W solar panels are mounted externally on top of the roof and provide the power to run the complete autonomous driving system. All the additional devices mounted on the vehicles for the autonomous challenge rely on an electrical system which is completely decoupled from the original vehicle power system.

B. The X-by-Wire System

The vehicles are equipped with full x-by-wire to control acceleration, braking, and steering.

In a number of vehicles, the CAN bus is used to control different on-board systems and even gas or brakes. Altough directly acting on CAN messages may seem a straightforward solution, this procedure hides complex issues, since car manufacturers generally use proprietary interfaces and protocols.

In this case we selected a vehicle on which we can completely master the CAN bus and protocol. On the Porter Piaggio we developed specific control mechanisms onterfaced with the CAN bus for the control of:

- gas,
- brake, and
- steering

1) Gas: The Porter Piaggio is an electric vehicle and its engine is controlled using pulse-width modulation (PWM). The PWM signal is generated by a mechanical potentiometer (6539S-1-502) directly connected to the gas pedal. The pot resistance varies from 0 to 5 kΩ while the current intensity ranges from 0.1 to 0.4 mA.

Therefore, a good solution for controlling the gas is the replacement of the mechanical pot using a digital one and a DIP packaged microchip PIC device has been selected. This digital pot can be controlled using the standard SPI protocol. Since the gas pedal has to be controlled using a CAN bus, an additional device is used to for CAN I/O and to generate the SPI signals: the PIC18F2585.

Fig. 8. The AES-25 installed on the Porter.

The PIC18F2585 is an 8 bits microcontroller that can work up to 40 MHz; it is equipped with a 4 MBytes flash memory, and can be programmed using the C language. An MCP2551 driver is used to interface the microcontroller to the CAN bus.

The digital potentiometer is a Microchip MCP41010 able to vary the resistance in the range 0–10 kΩ in 256 steps (in order to fit the resistance range in the required one, the pot is connected in parallel to a 10 kΩ resistor).

Figure 7 shows the resulting board.

The electric vehicle is not equipped with a complex gearbox and therefore it has only been necessary to automate the switch between forward and reverse gears: a separate circuit is again used to control a relay inside the electric engine.

2) Steering: Off-the-shelf components can be easily adapted to act on the steering wheel. In fact, in the agricultural environment, semi-automated or remotely driven tractors are widely exploited and the devices used to act on the tractors steering wheels can be transferred to the Porter Piaggio.

Specifically, a TopCon Accurate Electric Steering-25 has

Fig. 9. The linear actuator installed on-board of the vehicle.

Fig. 6. The first vehicle equipped with sensing technology and the on-board PCs.

been selected. This device is an electronic steering wheel that can be controlled via CAN bus through a proprietary protocol. The AES-25 can reach 30 RPM, features a 0.5 degrees resolution, and reached a 5 N m torque.

Figure 8 shows the installation of AES-25 on the Porter.

The AES-25 features the possibility of overriding the steering. If a sufficiently high external torque is applied to the steering wheel (namely, the driver tries to override the AE-25 behavior), it stops working and allows the driver to steer. This feature is mandatory for the development phase, since it is possible to safely test new control or perception strategies and to take the vehicle control in case of errors or danger.

3) Brake: The Porter is equipped with a mechanical brake and therefore it is not possible to intervene at electronic or idraulic level. Also in this case, it is mandatory to allow the driver to override the system behavior, namely to be able to brake even when the system is not braking.

Therefore, it has been selected to directly intervene on the brake pedal using a linear actuator. The main requirements for this actuator are a reduced size and to feature a really short latency. For these reasons, the use of an idraulic actuator was discarded and the use of an electric one was preferred.

In order to precisely define the actuator, a usage percentage ($Fu[\%]$) has to be considered:

$$Fu[\%] = \frac{t_{work}}{t_{tot}} \times 100$$

When $Fu[\%] < 30\%$ the use of a linear actuator based on trapezoidal spindle is suggested, while for $Fu[\%] > 50\%$ the use of ball screw technology is preferred.

For safety reasons, it has been decided to over-estimate the $Fu[\%]$ and therefore a ball screw based actuator has been selected: the Setec ISOMOVE 32.

This actuator is able to reach a 1500 N axial dynamic force at 200 mm/s and can be easily controlled thanks to a CAN interface.

C. The Software Architecture

The current system is depicted in figure 10.

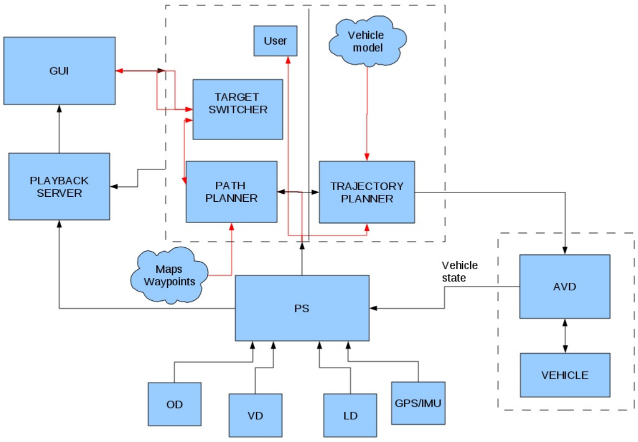

Fig. 10. The vehicles software architecture.

The solution adopted, and currently being tested, is based on 4 blocks: the Perception Server (PS), the Automated Vehicle Driver (AVD), the Graphical User Interface (GUI), and the central part which is the union of trajectory planner and path planner. In a further paper a more detailed definition of the software architecture will be given, together with an analysis of the achieved performance during the testing phase.

V. CONCLUSIONS

The 4 electric vehicles will leave Italy on July 10, 2010, and currently the VisLab team is still working on the prototypes.

Anyway, the equipment of these prototypes attracted the interest of other players and, in accordance to our ERC-funded project, VisLab is going to share the internal architecture, as wll as also replicas of these vehicles, with interested research centers.