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Sensing Requirements for a 13,000 km Intercontinental Autonomous Drive

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***Abstract*—This paper presents the design issues that were considered for the equipment of 4 identical autonomous vehicles that will drive themselves without human intervention on an intercontinental route for more than 13,000 km.**

Autonomous vehicles have been demonstrated able to reach the end of a 220 miles off-road trail (in the DARPA Grand Challenge), to 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. This paper presents the technological challenge of a set of vehicles that will run the *VisLab Intercontinental Autonomous Challenge (VIAC)*.

The challenge is scheduled to take place during the 2010 World Expo in Shanghai, China (and precisely from July 10, 2010 to Oct 10, 2010). Being currently under preparation, this paper focuses on the development, the vehicles' technical details, and the challenge itself. Other following papers will describe the outcome of the challenge and its results.

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.

The Expo will thus constitute a great opportunity to showcase new and innovative technologies in the domain of intelligent mobility, especially if focused on the urban areas.

VisLab has been working for more than 15 years in the field of intelligent vehicles and participated to important international 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[1] (a passenger car that in 1998 drove for 2000+ km on Italian highways in automatic mode) or the TerraMax vehicle[2] (an Oshkosh MTVR truck that VisLab equipped with sensing systems, primarily artificial vision).

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Whereas ARGO driving test was performed without human intervention for 94% of the route, in year 2005 TerraMax drove 100% autonomously for 220 miles of off-road paths, reaching the finishing post of the first DARPA Grand Challenge. In year 2007 TerraMax qualified for the DARPA Urban Challenge[3] (6 hours of urban driving with no human intervention) confirming itself as one between the very few first autonomous vehicles in the history of robotics. Team Caltech's Alice, Stanford's Stanley[4], Carnegie Mellon's Boss[5] and MIT's Talos are other examples of state-of-art of autonomous driving in real environments (both off-road and urban). Although performed in unfriendly environments, the previous vehicles were fielded and operated during challenges defined by precise rules and in predefined scenarios. The VIAC experiment instead will be held along a route where no a priori knowledge of the world is available.

The underlying idea is to demonstrate, through an extensive and impressive test entirely conceived by VisLab, that the current technology is mature enough for the deployment of non-polluting and no-oil based autonomous vehicles for people and goods transportation in real environment conditions, thus setting a new milestone in the domain of intelligent vehicles.

II. Challenge Presentation

The challenge, named *VisLab Intercontinental Autonomous Challenge*, has a unique final goal: to design vehicles able to drive autonomously along a 13,000 km trip, with no human intervention. Although already a very complex goal, VisLab is approaching this exciting endeavor together with additional innovative ideas. In fact all the vehicles are electric and power will be delivered to each autonomous driving system by solar panels. So, if successfully concluded, VIAC will contribute to demonstrate that it is possible –although in a prototype version– to shift goods between two continents with non-polluting vehicles powered by green energy and with virtually no human intervention. During the expedition some goods will be collected in Parma whereas others throughout the trip, all to be taken to Shanghai with virtually no environment impact.

Together with the intrinsic complexity of the test, high

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temperature range, lack of route maps, great variety of environment scenarios and traffic situations, absence of road code in some areas are just a few of the many unknown variables that shall be encountered during the trip.

A. The Organizing Partners

VIAC is organized by two Italian partners, VisLab and Overland (www.overland.org) a format/brand with a 15 years experience in the organization of worldwide expeditions on a caravan of trucks and other vehicles. VisLab manages all the autonomous vehicles technical equipment and driving system whereas Overland will support the expedition organizing the logistics and giving mechanical aid plus accommodation to the team on its trucks.

B. The Route

The 13,000 km route will cross different countries both in Europe and Asia as depicted in Fig. 1. Vehicles will travel from Italy to China through Slovenia, Croatia, Serbia, Hungary, Ukraine, Russia, and Kazakhstan.

Fig. 1. VIAC's 13,000 km route from Italy to China.

C. Scientific Outcome

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

Long: more than 13,000 km. This extensive test will allow a thorough test of the developed technology, including the robustness of the hardware solutions such as processing systems (PCs and DSPs) and sensors.

Extreme: different environments will be crossed to validate the system in several different conditions. The software part of the autonomous driver will be stressed and its performance assessed in unknown and unexpected road and off-road situations.

Differently from the DARPA Challenges, VIAC will be a manned challenge, more similar to the ARGO test "Millemiglia in Automatico"[1] or to the Navlab 5 USA tour "No Hands Across America"[5]. Other challenges will be held in not a far future to explore the possibility of driving for thousands of miles with really nobody onboard.

Throughout the trip all data coming from the whole set of sensors and from the vehicles themselves will be collected and stored. Such a huge amount of data coming from all sorts of light, paths, environment, traffic situations will be of extraordinary importance for further research in the automotive field. It will in fact allow offline analysis together with tuning and improvement of the algorithms developed.

D. 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 late October 2009, starting from Michelangelo's Piazza del Campidoglio (Fig. 2) and ending in front of the Colosseum, demonstrating autonomous driving in narrow roads, with pedestrians and traffic.

Fig. 2. BRAiVE at night in Rome's Piazza del Campidoglio after the October 2009 demo.

The Intercontinental Autonomous Challenge was officially announced during a press conference, held in Rome on October 29th 2009, by the Major of Rome Mr. Gianni Alemanno who eventually left the meeting on BRAiVE (www.braive.vislab.it) VisLab's latest driverless car. The Municipality of Rome, Italy, already showed its interest in using these vehicles downtown to deliver goods to shops, collect trash, and manage mobility in the last mile.

E. The Expedition

Taking part to the expedition will be 4 autonomous vehicles (2 travelling, 2 as backups) plus other support vehicles (4 Overland trucks including mechanic shop, storage, accommodation, etc.). In order to guarantee all the necessary safety measures, policemen and patrol cars will escort the convoy in some areas and help during the scheduled public demos that will be held in the main cities crossed during the route.

III. THE AUTONOMOUS DRIVING SCHEME

During the challenge the autonomous vehicles will be operating 2 at a time while the other 2 will be recovered on one of Overland's trucks. Although identical in their setups - same sensor suite, same control system - they will be driven by different goals.

The first vehicle will use the whole sensor suite (including expensive sensors) and will face a completely unknown environment. A driver and a passenger will sit in the vehicle, which 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 react to unexpected route changes. The first vehicle will not reach 100% autonomous driving.

The second vehicle will use a subset of sensors (only cheap ones) and will demonstrate full autonomy at a low cost when route info is available (via maps or thanks to info provided by a first probe vehicle): it will be unmanned and 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. Static info can be provided by a leader vehicle (or from a map, if available) while dynamic info are collected by onboard sensors.

IV. VEHICLES SETUP

Vehicle design and sensors selection are generally driven by the knowledge on expected scenarios; in case of the DARPA Challenges a great help in this phase was provided by the race rules, which specified at least the scenarios that the vehicles had to face and the behavior when facing other traffic or other road participants. In this case, on the other hand, we have no expectations on scenarios and we cannot make any assumption on other vehicles behaving according to rules. During the DARPA Urban Challenge, the road was populated by other vehicles together with robots, but they were driven by stuntmen respecting very specific rules. In this case the vehicles will have to face extremely congested areas crowded of vehicles, some of them disrespectful of traffic rules.

The sensing technology installed on the vehicles, stems from the findings and the experience gained thanks to the use of BRAiVE; the only difference being the need for cross-country driving skills, which are not included in BRAiVE's portfolio of possible driving behaviors. Therefore, specific sensors and algorithms have been included to handle off-road paths, although there is no possibility to use some a-priori knowledge on the characteristics of such scenarios, being them completely unknown. The algorithms, sensors, and their positioning has been defined based on VisLab's experience with other vehicles and other projects.

The design and layout of the architectural components of these vehicles is completely different from what was decided for BRAiVE: in this case the sensors and all equipment must be kept handy for maintenance even in remote locations and in extreme conditions (desert, mountains, remote areas). Therefore all sensors are placed in an easily reachable position; cables and wires are also easily identifiable; and PCs have been positioned on an internal layer which allows fast access from both the booth and the internal back seats. 'Ease of use' was the key consideration guiding the vehicles design. On the other hand BRAiVE was equipped with a completely different criterion in mind: all sensors and cabling were hidden, all actuation devices were moved below the hood, and special care was taken to provide the car with a clean and tidy look. In the case of these new vehicles, the aesthetical aspect was taken into account from a different perspective, i.e. by keeping the sensors and the hardware well visible and accessible.

The 4 electric vehicles are all equipped with the very same sensing, processing, and actuation technologies to optimize development time and usability. Although the 4 vehicles will be used in different configurations (e.g. a leader, or a follower, or a standalone car), their setup with identical hardware and software equipment meant putting an additional burden on development time (each vehicle must be kept as standard as possible to include all possible usage patterns). Nonetheless, the possibility of swapping the vehicles in operation provides additional flexibility in case of failures or when there will be the need for additional driving shifts, since the autonomy of the batteries is limited.

A. *The Sensing System*

Although primarily based on vision like the TerraMax vehicle, which concluded the DARPA Grand Challenge with 3 front cameras and 3 laserscanners, the vehicles sensing system is based on both cameras and laserscanners to take advantage of complementary technologies. Vision and laser technologies 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.

Special emphasis has been given to vision technology since it provides a cost-effective way of sensing the environment. No particularly expensive sensor has been considered in the design as well as no sensor with special needs in terms of physical installation has been included. Expensive 3D lasers spinning at high frequencies on top of the vehicle have been deliberately avoided; they would have fit perfectly on the first vehicle, which is a test vehicle used as a probe for new technologies, but their cost would have been prohibitive on the second vehicle, which has been designed to be readily exploitable as an unmanned city vehicle.

Vision has another great advantage over laserscanners: cameras have many candidate installation positions within the vehicle (in the cabin, outside the vehicle, hidden by a cover on the roof, or installed into the headlights), but laserscanners used for mid-long term sensing need to be placed in front of the vehicle, in the most prominent position. This is a drawback that will become more and more evident as the technology advances and car manufacturers integrate such devices on the mass market vehicles: the frontal position is one of the few positions in the car that gets hit by rocks and debris on the road, and it is the area which is generally bumped when parking the car. Even if the sensor is physically very robust and will not brake, it might get miscalibrated, therefore reducing its performance.

Seven cameras are installed on the vehicle (5 forward and 2 backward looking), while four laserscanners with different characteristics are placed around the vehicle.

Fig. 3 shows the vision sensors' placement and describes their use. The forward and backward 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.

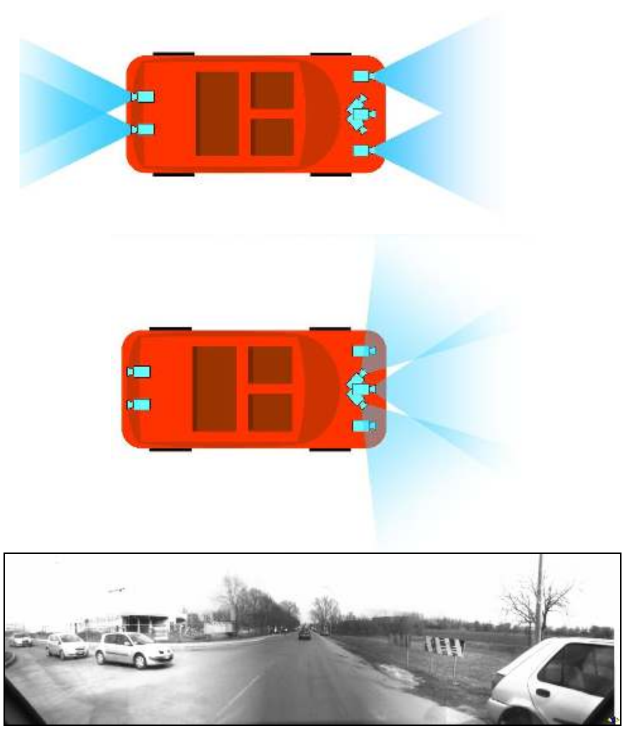

Fig. 3. The vehicle's vision sensing. Top: frontal and backward stereo vision systems able to detect lane markings, obstacles, and other road participants like pedestrians and vehicles; middle: frontal panoramic vision system, used to locate the leader vehicle in the far range and under very tight curves or abrupt mountain cliffs; bottom: an example of 180 degrees view in front of the vehicle.

Fig. 4 shows the positioning of the laserscanner sensing systems and their coverage. The laserscanners are used to locate obstacles, the vehicle in front, and other traffic.

The sensing system is therefore divided into partly overlapping devices in the following way.

- **Stereo systems** (front and back): short and medium range coverage aimed at the detection of obstacles, lane markings, pedestrians, and vehicles; it also provides 3D data for terrain mapping when driving off-road.
- **180 degrees front panoramic vision**: medium and long range coverage with very wide field of view to detect the vehicle in front even in challenging conditions like on winding or hilly roads.
- **Two front laserscanners**: short and medium range coverage with partly overlapping monitored areas to detect obstacles and vehicles.
- **Multibeam laserscanner**: short, medium, and long range coverage to detect obstacles and vehicles; the advantage of deep penetration is mitigated by the reduced field of view, which makes its usage worth when driving on smooth areas and fairly straight roads only.
- **Tilted monobeam laserscanner**: short range coverage, aimed at detecting the traversable path when driving off-road; it locates curbs, ditches, and berms; this is the only sensor different from BRAiVE's setup.

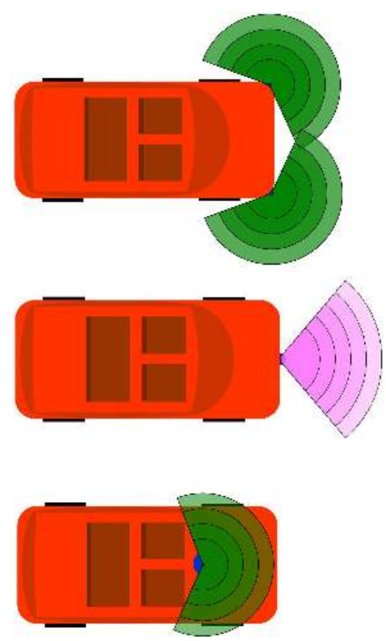

Fig. 4. The laserscanner sensing system. Top: monobeam laserscanners covering the front of the vehicle; middle: multibeam frontal laserscanner; bottom: monobeam laserscanner mounted tilted over the roof to cover the immediate proximity of the vehicle.

The vehicle also features GPS, IMU, and V2V communication systems.

B. The Processing System

The onboard sensor suite is managed by a processing system of 3 PCs (Fig. 5), all featuring off-the-shelf boards and components. PC1 manages the GPS, IMU, x-by-wire and V2V communication systems; PC2 the 3 stitch cameras and the 4 laserscanners; finally PC3 manages the stereo camera systems and again the 2 lower front lasescanners.

Fig. 5. The 3 onboard PCs installed into the booth of the first test vehicle.

C. The x-by-wire System

The vehicle is equipped with full x-by-wire, allowing to control speed and steering via CAN messages. Specific control mechanisms have been designed and realized to control the steering wheel, the brake pedal, and the gas setpoint. In particular, a TopCon steering wheel including an electrical servo motor interfaced to the CAN bus has been installed on the steering column; it receives setpoints and torque requests via CAN and moves accordingly. The torque it can deliver is sufficient to move the servo-steering system available on the vehicle even on the halt. The control of speed is made easier by the fact that the vehicle is electric and speed is controlled via a special board developed by VisLab which interfaces to the electric motor. Finally braking has been realized by a simple coupling of a cable with the braking pedal: by pulling the cable, braking is obtained and carefully modulated.

D. Other equipment

Other devices have been installed to complement the sensing system and add further functions. A *solar panel* is used to recharge an additional car battery, which in turn powers all sensors, processing systems, and actuators. An *E-Stop function* is available via RF signal to stop the vehicles in dangerous situations. Additionally, a *joystick controller* is also available inside the driving cabin to help make small trajectory corrections in the testing phase.
A *satellite communication equipment* is installed on the vehicle roof to broadcast live info from the vehicle to the VisLab website.

E. Autonomous driving

A *leader-follower* approach is used to manage the whole trip: due to the lack of digital maps, the first vehicle defines the route and the second follows. Two situations are possible, according to the visibility of the leader. If the leader is in line of sight and the follower can see its shape, then the follower will use its position to determine its trajectory; local sensing is used to refine its position on the road. Figure 6 shows this situation.

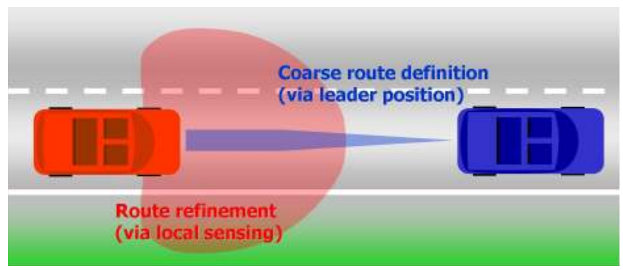

Fig. 6. The driving pattern when the leader is in line of sight: the second vehicle follows the route described by the first vehicle and uses local sensing to refine its position on the road.

On the other hand, when the leader is not visible by the follower (for example it is behind a curve or a third vehicle is in-between), the second vehicle follows the coarse GPS waypoints broadcasted via radio connection by the first vehicle, and –again- local sensing is used to refine the vehicle's position on the road. Figure 7 sketches this behavior.

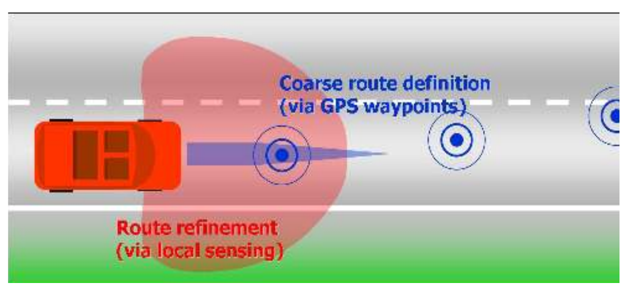

Fig. 7. The driving pattern when the leader is not visible by the follower: the second vehicle follows the route described by GPS waypoints; local sensing refines its position on the road.

V. CONCLUSIONS

This papers presented the hardware architecture and setup choices for the equipment of 4 electric vehicles that will undergo a unique test of automatic driving for 13,000 km in

3 months. The design followed a special guideline of avoiding expensive sensors and sensors whose integration on a possible production vehicle would not be feasible. Special emphasis was given to the definition of the driving pattern, which –in some sense– replaces the rules of other challenges like this. Being maps not available for many regions of the trip, a way to define the route without intervening on the autonomous vehicle has to be defined: therefore a leader vehicle is used to create a temporary map and send it to the autonomous vehicle which follows.

Further papers will describe the perception algorithms, the autonomous driver including the trajectory planner, and finally the results of this extreme test.

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