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VIAC: an Out of Ordinary Experiment

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***Abstract*— This paper presents the preliminary results of VIAC, the VisLab Intercontinental Autonomous Challenge, a test of autonomous driving along an unknown route from Italy to China. It took 3 months to run the entire test; all data have been logged, including all data generated by the sensors, vehicle data, and GPS info. This huge amount of information has been packed during the trip, compressed, and transferred back to Parma for further processing. This data is now ready for a deep analysis of the various systems performance, with the aim of virtually running the whole trip multiple times with improved versions of the software.**

This paper discusses some preliminary figures obtained by the analysis of the data collected during the test. More information will be generated by a deeper analysis, which will take additional time, being the data about 40 terabyte in size.

Fig. 1. The 4 Piaggio Porter Electric vans.

I. INTRODUCTION

VisLab has been developing Advanced Driver Assistance Systems for many years [1], [2], [3], all of them based on the perception of the road environment using artificial vision and other sensors. Many of these systems have been fused together to implement a comlpete perception of the environment in which the vehicle is moving in order to reach full automation of the driving task. Such prototype vehicles include ARGO [4], TerraMax [5], [6], and BRAiVE [7], [8]. BRAiVE is the latest vehicle prototype which is now integrating all systems that VisLab has develpoed so far. BRAiVE has been testd autonomously in many occasions: both on-campus in Parma, and off-campus in other cities, the most famous being Rome where in October 2009 BRAiVE drove from the Capitoline hill to the Colosseum in autonomous mode.

BRAiVE's performance has been satisfactory in the tests that were performed so far, but all of them were organized in very well structured scenarios and in predictable environmental conditions. Further tests in the same conditions would have brought limited advantages since the main factor that has to be tested is the system's ability to cope with a plethora of different scenarios.

Therefore, instead of waiting for the next DARPA Challenge, if any, VisLab decided to take the lead on the testing phase and organized a huge experiment, never conceived before. The test had to be extensive (more then one month of continuous testing), hit different scenarios (including road infrastructures, weather conditions, illumination conditions, road and off-road, rural and urban traffic patterns), and involve driving on real roads.

The systems that had to be tested were a subset of the systems available on BRAiVE, and the technology used on the new vehicle prototypes explicitly developed for this test was taken from BRAiVE: similar sensors and similar location on the vehicle. The possibility to record all data coming from the sensors would have allowed to test other systems, this time off-line, once the trip was finished.

This paper discusses results and figures obtained from the data collected during the VisLab Intercontinental Autonomous Challenge test: 4 vehicles traveled autonomously from Italy to China, driving along unknown roads.

A. Vehicles Selection

Different vehicles were considered as candidates for the challenge, until the final idea emerged: to choose an electric vehicle and test its capabilities on such a long and diverse route. The use of non-polluting transportation means is ever increasing, especially within busy city downtowns, and many institutions are actively developing autonomous vehicles targeted at very specific goals, such as [9] and [10]. VIAC would become the first extensive test of such kind of technologies. The original vehicles are produced by Piaggio, an Italian company very well known worldwide for fashionable scooters and also specialized in commercial vehicles. The base vehicle is an Electric Porter Piaggio (see Fig. 1), featuring electric propulsion.

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Fig. 3. The route covered by VIAC: more than 13,000 km from Italy to China.

B. Systems under testing

VIAC represented a unique chance to test a number of algorithms and their implementations on the field, thus assessing their performance in terms of detection rate, robustness against unexpected scenarios, and stability after hours of continuous operation.

The onboard perception systems can detect obstacles, lane markings, ditches, berms and indentify the presence and position of a preceding vehicle, as illustrated in Fig. 2. The information on the environment produced by the sensing suite is used to perform different tasks, such as leader-following, stop & go, and waypoint following, depending on the situation. Two different path planners were implemented: 1) global path planner, that determines a route between the current position and a distant goal, regardless of the presence of obstacles; 2) a local path planner, which effectively drives the vehicle, implementing the optimal trajectory and obstacles avoidance policies.

Since no maps were available to cover the whole trip, the global path planner was never used and vehicles drove autonomously in lane-keeping, waypoints following or leader-follower mode.

C. Dates and Route

The test was carried out across several countries with advanced technology and human effort. The trip began on July 20, took over three months and the total distance covered was more than 13,000 km. Vehicles travelled from Italy to China through Slovenia, Croatia, Serbia, Hungary, Ukraine, Russia, and Kazakhstan (as depicted in Fig. 3).

To display VisLab technologies developed during the past years, press conferences and live demos were organized in major cities along the route.

D. Data Collecting

Throughout the trip, all data coming from the whole set of sensors and from the vehicles themselves has been collected, tagged, and stored: this allows offline testing, tuning, and improvement of another whole set of algorithms which were not used during VIAC, such as terrain mapping and slope estimation, zebra crossings and pedestrians detection, tunnel detection and visibility estimation.

(a) (b)

Fig. 4. Front (a) and back (b) views of the vehicles

II. Vehicles Setup

A. Sensors Selection

Most of the sensing technologies installed on the vehicles is directly derived from the perception suite of BRAiVE [7]; however, BRAiVE was not designed to drive autonomously in off-road environments, hence it misses all the crosscountry driving skills needed during an intercontinental trip like VIAC. The sensors layout was therefore revisited and a new set of algorithms was developed to handle offroad scenarios. Another key difference with the BRAiVE sensing suite is the physical sensors placement and wiring: on BRAiVE 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. Instead, VIAC vehicles were equipped keeping sensors, actuators, and processing units accessible, in order to optimize development time, usability, and ease maintenance in remote locations (see Fig. 4).

Special emphasis was given to computer 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. As shown in Fig. 4 most of the sensors have been mounted outside the vehicle, exposed to any kind of weather conditions.

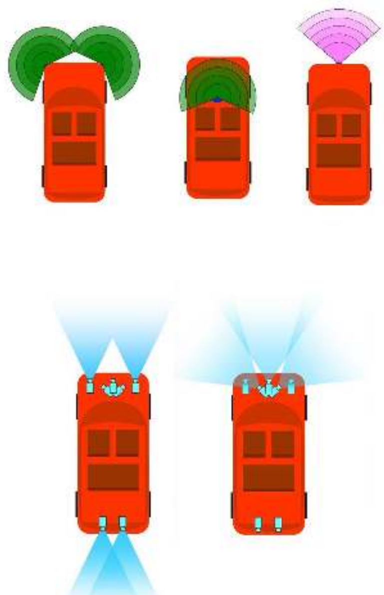
Vision has another great advantage over laserscanners: cameras can be installed *in a variety of positions* on the vehicle (inside the cabin, on the roof, or within the headlights), while laserscanners used for mid-long term sensing need to be placed in front of the vehicle, usually behind the front bumper. This constraint means also that laserscanners are easily hit by rocks, debris, and other objects.

A total of seven cameras (5 forward and 2 backward looking), and four laserscanners with different characteristics have been installed on each vehicle, as shown in Fig. 5. In particular, on the front part each vehicle was equipped with the following sensors:

- *Panoramic Vision System*: it provides a 180 degrees view of the frontal part of the vehicle by switching

(a) (b) (c) (d)

Fig. 2. Output from some of the systems installed on the vehicles: (a) lane detection, (b) preceding vehicle detection, (c) stereo obstacle detection, (d) ditch detection



(a) (b)

Fig. 5. Laserscanner (a) and vision (b) based sensors' placements. From left to right: Lateral laserscanners, Off-road laserscanner, Central laserscanner, Front ad Rear Stereo Cameras, Panoramic Vision System.

3 images coming from 3 synchronized cameras. The resulting image is a high resolution frontal view, that is used to detect and track the leader vehicle even when approaching a tight curve or a steep hill;

- *Front Stereo cameras*: the frontal stereo system is used to locate obstacles, determine the terrain slope and locate lane markings. The baseline is about 80cm; it is used for medium to short range sensing;
- *Off-road laserscanner*: this mono beam laserscanner is pitched down so that the beam hits the ground in front of the vehicle; it provides information about the presence of ditches, bumps, and obstacles right in front of the vehicle, especially whe driving off-road;
- *Lateral laserscanners*: two single beam laserscanners are mounted right on the corners of the frontal the bumper; they are used to detect obstacles, pedestrians, and vehicles in the immediate surroundings. Each laserscanner has an aperture of about 270 degrees, while the perception depth is about 30 meters;
- *Central laserscanner*: this laserscanner is basd on a 4-planes laser beam which is used to detect vehicles, obstacles, and pedestrians in front of the vehicle. Its four planes allow to partially overcome a common problem of laserscanners: when the vehicle is pitching down or up, the laser beams hits the ground, or points to the sky, acquiring no useful data. Its perception depth is about 80 meters and its aperture about 100 degrees.

The back of the vehicle is equipped with:

- *Rear Stereo cameras*: the rear stereo system is used to locate obstacles in short ranges.

III. The Expedition

A. Preliminary Tests

During development several preliminary tests were performed, involving a number of kilometers of autonomous driving in different weather and environmental conditions. The First test area was inside the 2 Km long loop of the Parma University Campus and in its surroundings, both in urban and rural scenarios.

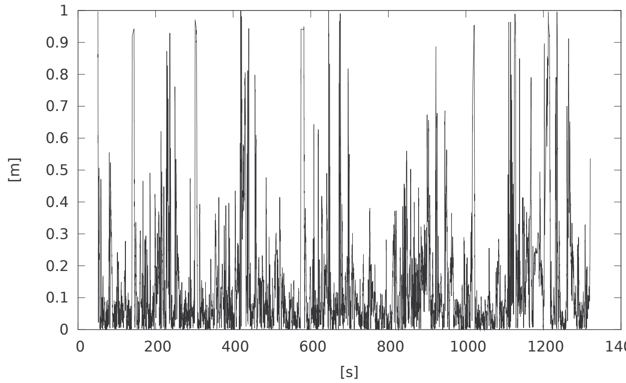
In Fig. 6(a) and 6(b) the results of WayPoint Following autonomous tests (6 laps performed inside the university campus) are presented: the mean crosstrack error reported by this experiment was of 0.13 m, and its standard deviation was of 0.15 m. The average speed on this test was 26 km/h and the maximum speed reached was 46 km/h.

Autonomous driving performance in leader follower mode, both in urban and extraurban areas are shown in Fig. 7(a) and 7(b): the mean crosstrack error is 0.17 m, and its standard deviation is 18 m. The average speed on this test was 28 km/h (maximum 50 km/h).

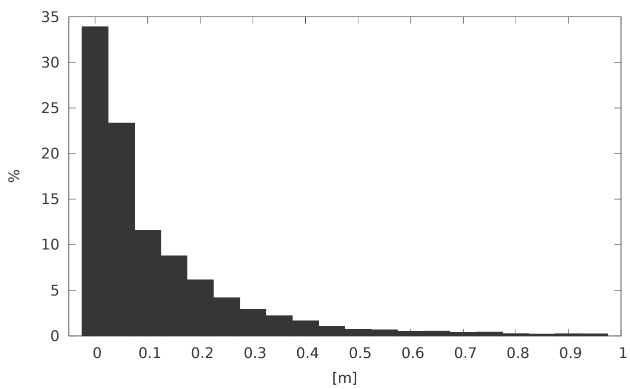
The significant increase in the lateral crosstrack error is explained by the presence of obstacles along the road which influence the trajectory of the vehicle as it replans to avoid them, moving it away from the original WayPoints.

B. Expedition Scenarios

Throughout the journey the expedition travelled across a plurality of scenarios completely different from each other. Crossing a large part of the Eurasian continent all sorts of situations, environments, roads, and weather conditions were met: mountains, planes, unpaved, and dusty roads.

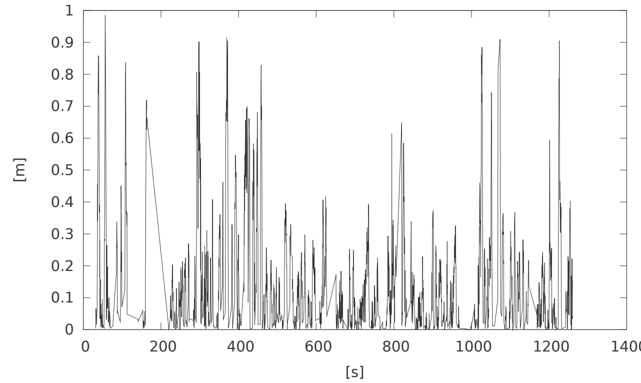


(a)

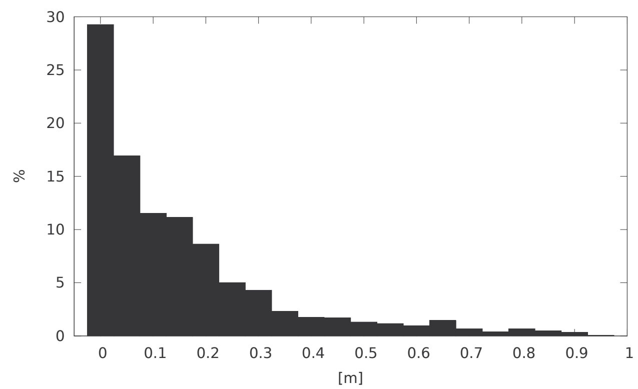


(b)

Fig. 6. Plot of lateral crosstrack error *(a)* and relative histogram *(b)* during the experiment of 22 minutes of autonomous operations on campus with autonomous GPS Waypoint following.



(a)



(b)

Fig. 7. Plot of lateral crosstrack error *(a)* and relative histogram *(b)* during the experiment of 21 minutes of autonomous operations in urban and rural environments with vehicle in autonomous Leader Vehicle following.

In Europe and in the first part of the Russian Federation the convoy travelled for many kilometres on highways and drove into the heavy urban traffic of many great eastern Europe cities like Belgrade, Budapest, Kiev, Moscow, then went across Siberia, the flat steppes of Kazakhstan, up the Tien Shan Mountains and finally all the way across China towards its destination, Shanghai.

The elevation map in Fig. 8 shows the heights recorded in the whole journey by the GPS sensors. In Europe the highest point passed was only 280 m above sea level, in the outskirts of Budapest while in Russia it was up the Ural Mountains, natural boundary between Europe and Asia, with a peak of 713 m. In Kazakhstan the expedition did not encounter mountain passes but a big plateau all the way until Almaty.

Nothing compared with the two chinese mountain passes. Heights recorded start to rise again immediately after, at the Korghos pass near the border between Kazakhstan and China, where the vehicles had to climb a very hard uphill road to reach the summit of that part of the Tien Shan Mountains (2.100 m), and then again at the Lanquan pass encountered after a desert zone and the Turpan depression (50 m under sea level), at almost 3000 m, the highest point reached during the whole trip.

In this track the autonomous vision systems were heavily tested as due to a lot of road construction with long stretches of off-road tracks, road conditions were too bad for many kilometers (no asphalt, huge and frequent holes in the ground, see Fig. 10-(a)) so the electric vans had to avoid large potholes and to drive in dusty situations with very low visibility.

The chart in Fig. 9 shows the temperatures collected throughout the entire expedition. Red, green, and blue lines show respectively each day maximum, average, and minimum temperatures. Data were acquired by a sensor inside the GPS antenna positioned on the vehicle rooftop so values are affected by bias: the highest temperature was increased by sun exposure while the minimum was altered by the heat given off by the sensor motherboard.

Nonetheless data trend remains correct, with a maximum temperature of about 50 °C recorded in Europe during summer months and a minimum one of nearly 0 °C registered in Siberia where the expedition faced cold wheatear with a little snowfall as well.

The expedition last run was taken when accessing Shanghai city from one of its main entrances, the great Nanpu Bridge. The vehicles made the last tracks of the trip followed by several groups of journalists while facing Shanghai downtown heavy traffic. This run was done fully autonomously for both the leading and the following van. The day after two vans drove around the city in leader-follower configuration

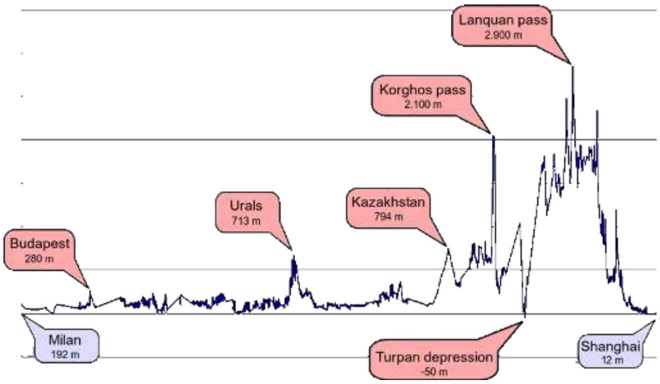


Fig. 8. Elevation map: the most significant altitudes recorded.

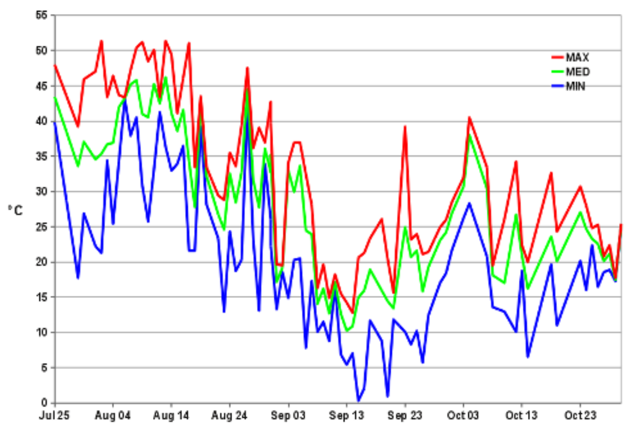


Fig. 9. Temperatures recorded during the trip.

and reached one of Shanghai's most popular sites (see Fig. 10-(b))

VIAC had is official conclusive event on October the 28th 2010 at the Belgium-EU pavilion inside Shanghai's 2010 World Expo.

The final part of the event was a demonstration of the leader-following system with two automatic vehicles which took part in a choreographic parade with carnival floats passing through the exposition pavilions, as shown in Fig. 10-(c).

C. Vehicles Autonomy Performance

The series Piaggio Porter Electric vehicles have been equipped with sensing systems, processing units, and actuators to allow autonomous navigation, focusing on minimizing the impact on the already limited maximum travelling distance. To achieve this goal the traction and custom VisLab electric circuits have been kept separated, with the latter being powered by a solar panel mounted on the roof, thus leaving the capacity of the 16 traction batteries intact. The only potential performance penalty left was the additional weight of the custom hardware, which is in fact neglectable if compared to that of the vehicle itself.

(a) *(b)* *(c)*

Fig. 10. Off-road driving on a chinese road*(a)*; the vans in Shanghai's downtown renowned Bund area *(b)*; the Expo parade GPS path *(c)*.

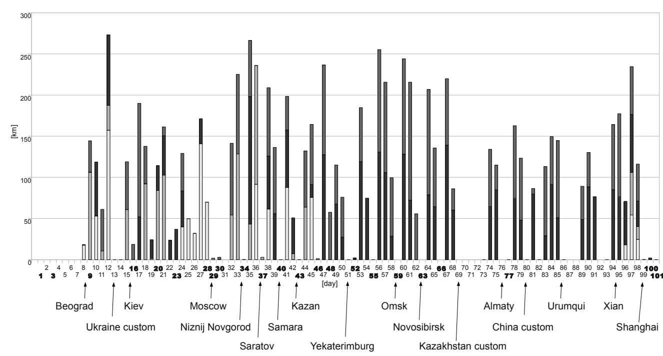


Fig. 11. Travelled distance in autonomous mode per day. Different gray levels are used to indicate the distance performed by each of four different vehicles. The expedition was involved in demonstrations on days marked with boldface.

D. Statistics

In this section some preliminary performance of the four electric vehicles driving in autonomous mode throughout the expedition are presented.

The data collected refer to the effective 61 days of autonomous driving on an overall 90 days journey: 191 runs for a total of 214 hours in autonomous mode were completed. Usually the runs ended when no battery power was left, but sometimes logistic needs mandated a stop, such as when crossing a state border. The maximum distance traveled in autonomous mode per run was 96.7 km, with an average of 77.0 km. A detailed chart of travelled distance per day is shown in Fig. 11. In this graph also it is possible to see which major cities have encountered, the states borders and the days when demonstrations were performed. No autonomous run were performed in some tracks due to technical or logistic problems. The sum of the tracks gives 8244 km in

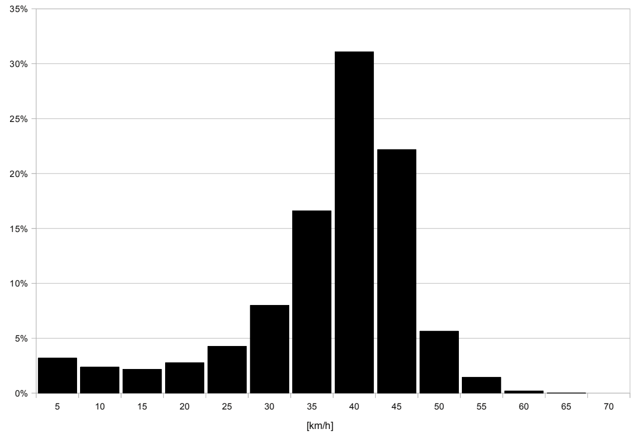


Fig. 12. Overall profile of the speeds performed by the electric vehicles during the journey.

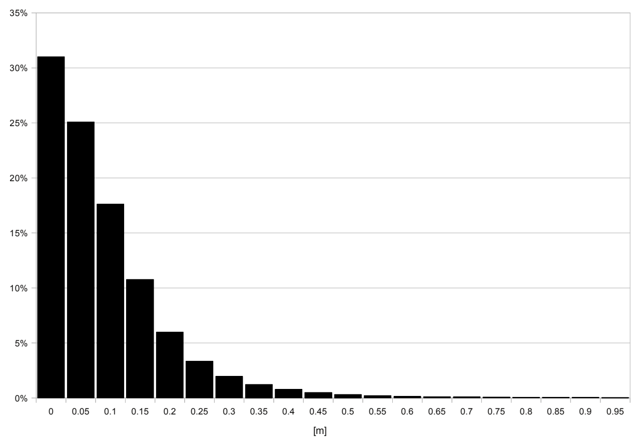


Fig. 13. Histograms of lateral cross-track errors in the autonomous driving configuration (Leader Vehicle Following).

autonomous mode covered at an average speed of 38.4 km/h and a maximum speed of 70.9 km/h. A detailed speed profile is reported in Fig. 12. Maximum distance covered in a single day was of 273 km and the maximum amount of time spent in a day driving in autonomous mode was of 6 h, 26 min.

In figure 13 a rough statistical path-planner error graph using as ground-truth the route performed by the leader vehicle is shown. In the histogram distribution of the differences between the path made by leader and follower are shown. Differences between the two paths are due to the fact that the follower vehicle used the leader's trajectory as an indicative path only and merged it with the sensors data to generate its own optimal trajectory.

IV. Conclusions

This effort, unique and fascinating, provided the testing patterns that were sought: different scenarios to test the various systems and sufficient data to effectively validate the perception systems.

VisLab also secured 20,000 processing hours on the largest Italian supercomputer to run the entire trip multiple times. This will provide sufficient processing density to quickly process the entire data set with different algorithms and parameters. At the end of the simulations, it is believed that the final perception systems will be much more robust than the ones available now and that were used during the cross-Asia trip.

For example a new Semi-Global-Match approach to Disparity Space Image computation is currently under testing, using the VIAC stereo images. Results will will be compared with the performances obtained with the previous SAD based algorithm and published soon. Path planner is also object of improvements: the huge amount of sensing data captured allows now to simulate almost every driving scenario, from urban to rural.

VisLab would also like that this very unique effort could bring forward the entire research community by sharing the whole data set with its partners. Being it quite large, it will be impossible to share it via FTP and new techniques are now being investigated, like the use of an image/data server or the availability of annotated segments of data.

V. Acknowledgments

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