When space technologies enable services for the Autonomous and driverless Transportation of persons

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BIOGRAPHY

Damien SALLÉ, PhD and Msc in Robotics, Mcs in Mechanical Engineering. He did his PhD research at the Paris Robotics Laboratory (LRP). His research focused on methodologies for the optimal design of redundant robotic manipulators. As an application of this research, he designed a robotic instrument, optimal for minimally invasive heart surgery.
He joined Robosoft in 2005 where he was in charge of the management of the European R&D project.
He is now the Head of the Software Developments department, which focuses on R&D, and more specifically the development of the robuBOX^{TM}: Robosoft's software product for robot controllers' development.

INTRODUCTION

ROBOSOFT, established in 1985 by INRIA researchers, is recognized as a leading supplier of advanced robotics solutions throughout Europe and beyond. ROBOSOFT is a profitable and independent SME of 25 persons with a turnover of 3.5 M€.
ROBOSOFT has been building a unique expertise in service activities automation. Its experience in robotics, more precisely in subsets integration and automatic control, allows providing operational robotic solutions in 5 areas: education and research in robotics, transport (automatic transport of goods and people, automatic gas refueling), cleanliness (automatic floor and windows cleaning), security (remotely operated mobile robots) and health (assistive mobile robots for elderly and handicapped people).

Robosoft thus supplies advanced mobile robotics solutions to drastically reduce the cost of services in transport. Many cybercars have been developed and sold in different versions (Cycab, RobuCAB, robuRide) both as research platforms and as vehicles for touristic sites exploitation (Simserhoff, Vulcania).

Space technologies have enabled a new era in the context of robotics and autonomous systems, thanks to GPS, RTK-DGPS localization and soon to come Galileo. These technological improvements allow unleashing the potential of cybercars and considering them as serious competitors for the automatic transportation of people, as they require very low infrastructure costs.

This paper thus introduces one of the services that can now be provided in the field of ground transportation: the autonomous transportation of persons by cybercars.
It gives technological insights of the control of such systems using Robosoft's robuBOX^{TM} which allows to easily transform any vehicle into a cybercar.
This paper also shows the step-by-step developments required for the exploitation of such cybercars, using the example of the Vulcania theme park, the first commercial exploitation of GPS based fully automated people transportation system.

1 INTRODUCTION TO CYBERCARS

Cybercars are driverless autonomous vehicles that can provide point-to-point and on-demand transportation services and can be operated in fleets to optimize the quality of service. They can also be used in a more traditional way as automated shuttles. They rely on GNSS information for the precise localization of the vehicles, combined with hybridization techniques to improve availability and quality of the localization as well as redundancy for improved safety.

Fig1 : Cybercars in a campus environment

Fig2 : Cybercars as automatic shuttles for parking servicing in touristic or pedestrian area

This new approach of shared public transport can be applied to all the protected sites receiving a high concentration of people having to move on relatively short distances (few kms) in indoor or outdoor environments. Among the protected places being able to receive cybercars one can quote: Inner city centers, Industrials or academicals campuses, Public parks and resorts, Airports, Fairs, etc…

Robosoft is designing, manufacturing and producing all the cybercars in its catalogue, proving the efficiency of the robuBOX™, its software solution for the control of such vehicles.

2 ROBUBOX™ SOFTWARE TRANSFORMS ANY VEHICLE IN AN AUTONOMOUS ROBOTIC SYSTEM

ROBOSOFT provides the robuBOX, a generic and advanced robotics controller design software, developed with Microsoft® Robotics Studio and implementing high-level mobile robotic functions like path generation and following, obstacle avoidance, localization and navigation... It aims at quickly robotizing any type of mobile platforms and vehicles.

The robuBOX main target is to provide integrators and manufacturers with an off-the-shelf solution to quickly and easily build standalone or fleets of service robots, such as AGV (Automatic Guided Vehicles), scrubbing machines, cybercars, and so on. Based on reference designs for both the hardware platforms and control software, it becomes really easy and fast to transform any machine into a professional service robot.
On the other hand, the Robosoft's internal development tools are also made available to highly competent robotics professionals and researchers to allow them to develop any control architecture, using provided hardware and algorithm services, or using their own developments.

So the robuBOX software is made of different solutions, depending on the level of qualification of its user: from highly integrated for specific industrial applications to fully open for researchers.
This set of software solutions, described in the following sub-sections, includes the robuBOX services architecture templates and generic interfaces, as well as efficient robotic algorithms services, implemented for real operations.
Finally, the robuBOX enhances the realistic simulation environment provided by the MSRS, as it provides easy integration of existing robots or machines, and last but not least, the capability to use exactly the same control architecture for the simulated robot than for the real robot. This allows of course, a drastic gain in time and development effort for the prototyping and implementation of robotic control architectures.

2.1 RobuBOX services architecture and generic interfaces

The robuBOX is based on the Microsoft Robotics Studio. It thus uses all the mechanisms available for communication and synchronization between the services.
RobuBOX however greatly simplifies the controller design as it enhances the MSRS intrinsic capabilities for re-use of services, generic interfaces, fast development and prototyping of robotic control architectures. This is achieved through numerous functionalities:

2.1.1 Definition of generic interfaces between the services:

ROBOSOFT, using its 20 years of experience as an advanced service robotics designer and manufacturer, has proposed definitions for standardized interfaces between robotic components and algorithms: how is defined a localization data, a laser scan data, a trajectory data, a differential or a car-like drive, a map of the environment, a landmark extractor etc… They correspond to standardized abstract contracts in the MSRS vocabulary.

2.1.2 Enhanced dynamic interfacing capabilities:

Using these generic interfaces, ROBOSOFT has developed software to be able to dynamically replace a running control component by another of the same type.

2.1.3 Enhanced security and errors management:

robuBOX includes 3 levels of management of the services:

- Node manager that launches the required services on each of the DSS nodes of the possibly distributed application, using a safe-launch procedure,
- Device manager that ensures all-time coherence and integrity of the services architecture through heart-beat listening, thus improving the reliability and safety of the application,
- Application manager that includes the 2 previous managers and is used to deal with application level services, providing alarms and application integrity status.

2.1.4 Enhanced debugging and monitoring capabilities:

Powerful debugging features are already included in the MSRS such as the capability to access each service status in a web browser, an integrated console for logging info distributed in the application, and of course the

debugging environment of Microsoft Visual Studio. However, our experience has shown that these features needed to be enhanced in order to perform really efficient and rapid development of robotic applications.
The robuBOX thus integrates services to collect the data for all the running services and providing direct access to the data, through graphical visualization: 2D laser scans, trajectory plotting, detected landmarks, generated metric map etc…

The robuBOX architecture and standardized interfaces thus allow generating powerful services architectures for robotic systems. For example, figure 3 illustrates the robuBOX services architecture for a mobile robot that needs to repeat pre-learnt trajectories.

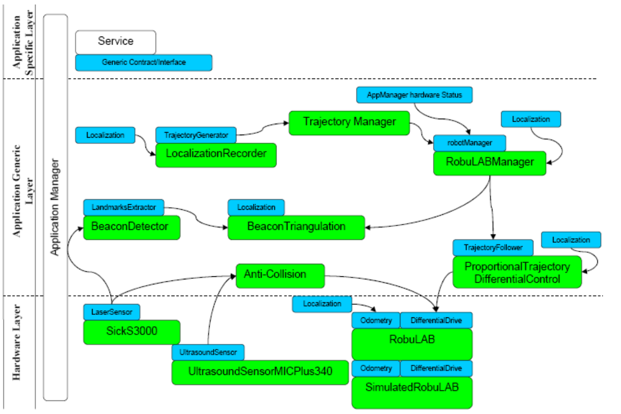


Fig. 3. RobuBOX services architecture example for a trajectory following mobile robot.

Using most of the services of this architecture and adding just a few additional algorithms services, one can very rapidly define a robot performing an explorer task while constructing is own metric map of the environment using a SLAM algorithm, as illustrated in figure 4.

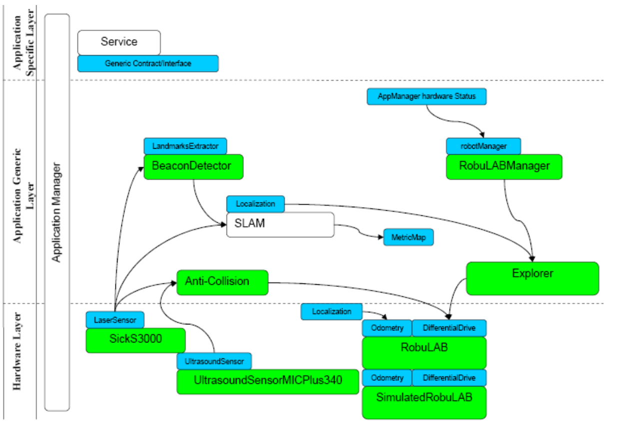


Fig 4: RobuBOX services architecture example for an explorer robot creating a metric map of its environment

2.2 *RobuBOX rapid prototyping through realistic simulations*

The Microsoft Robotics Studio embeds in its core a physical engine used to perform dynamic simulations of robots. The robuBOX extends its capabilities as it allows using the exact same control law: the hardware components services are replaced by the simulation services exhibiting the same standardized interfaces.

The extension of the MSRS simulation is made through an appropriate use of the entities and the generic contracts defined by ROBOSOFT. This enhancement of the simulations allows to very simply simulating the behavior of the robot. Once debugged and triggered, the exact same architecture is implemented on the real robot.

The figure 5 shows the robuCAB vehicle in a simulated urban city environment where it can be controlled to follow pre-learnt routes, perform platooning avoid obstacles etc…

Fig. 5. RobuBOX services architecture example for a trajectory following mobile robot.

3 CONTROL OF THE CYBERCARS USING GPS AND ROBUBOX

In order to perform the servicing missions that are given to cybercars or automated people transportation systems, control algorithms must be developed and implemented in the vehicles.

3.1 *Localization and navigation:*

In most of the applications involving cybercars, the vehicle autonomous navigation tasks focus on replaying precisely pre-learnt routes (trajectories) while detecting obstacles and avoiding collision. These trajectories are then linked together to define a network.

During the exploitation, a centralized supervision system uses this network graph to compute the optimal path to destination for each of the vehicles, such as shown in figure 6 for the simulation environment presented in figure 5.

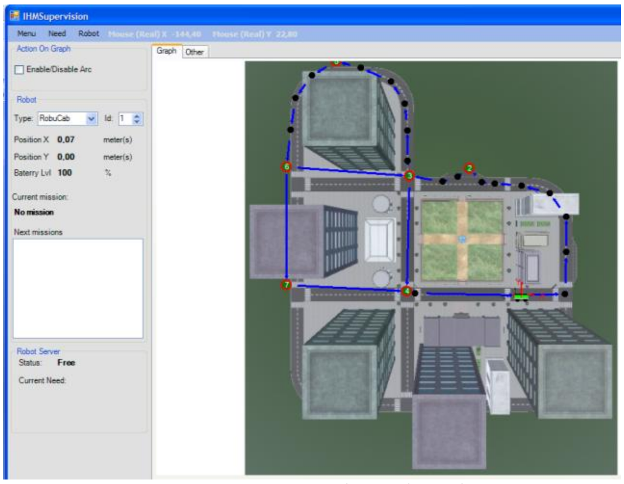


Fig. 6. Centralized supervision system for the fleet of cybercars.

The trajectories can be automatically processed and generated offline if precise maps exist for the exploitation site.
But most often they are learnt by the system using teach by showing techniques: while an operator drives manually the vehicle, it records the positions and learns the route, as illustrated in fig7.

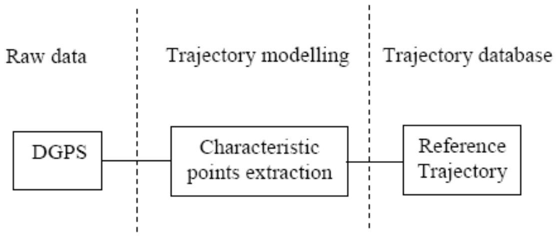


Fig. 7. Teach by showing trajectories recording.

This navigation system is divided in 2 parts (see fig 8).

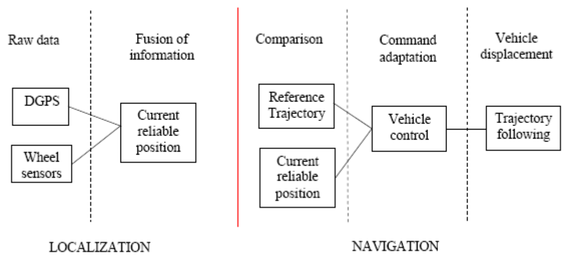


Fig. 8. The autonomous navigation process.

- Localization: of course, one of the most critical issue is the capacity of the vehicle to localize itself precisely in the environment. This is where GNSS and GPS come into the field: as they provide infrastructure-less positioning they are very suitable to the cybercars applications. However due to their know limitations such as availability (especially in urban environment) they should be combined with proprioceptive sensors such as odometry, gyroscope or Inertial measurement unit.

- Control law: current position from localization is compared to the reference trajectory. This comparison allows to generate the speed and steering control of the vehicle to follow the reference.

The robuCAB navigation is made using a control which combines orientation error and lateral error with respect to a reference trajectory (see figure 9).

$$SteeringAngle = D \times K_{pp} \times ErrorSteer \times K_e \times \frac{180}{\Pi} + OffsetSteer$$

D: lateral error (orthogonal projection on the followed line)
$ErrorSteer$: steering error
$OffsetSteer$: mechanical offset
K_{pp}: proportional gain on lateral error
K_e: proportional gain on steering error

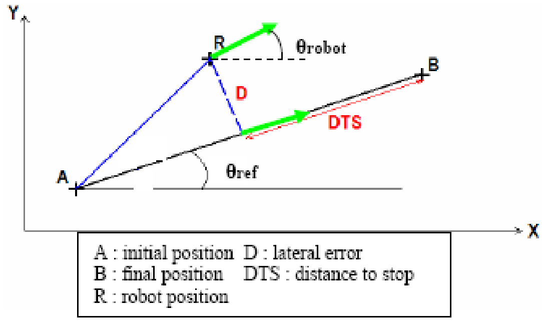
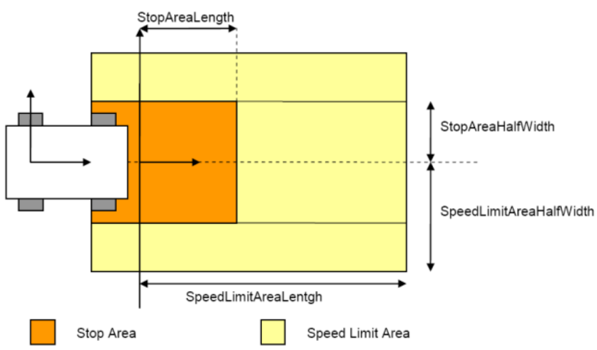


Fig. 9. robuCAB control law

3.2 *Obstacle avoidance*

During the autonomous displacement, the vehicle and passengers protection is made autonomously using ultrasound sensors and a laser range finder.

The protection is made through a division of the space in front of the vehicle, taking also into account the current steering angle of the vehicle to deform the obstacle detection zones. Each zone is attached to risk value, this value being dependant on the presence of an obstacle. The speed of the vehicle is then managed directly by these risk zones and their values (see figure 10). When an obstacle is detected in front of the vehicle, the vehicle reduces its speed and emits a bipping sound.
The vehicles are also equipped with emergency stop button located inside and outside the vehicles.



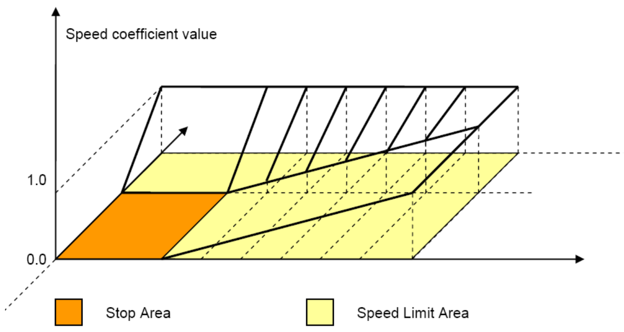


Fig. 10. Obstacles detection and vehicles speed adjustment.

3.3 Platooning

Another useful feature of cybercars is there capability to follow each other and form a small train, called a platoon. In such configuration, the first vehicle can be driven manually and all the remaining vehicles are autonomously following it. Or another scenario is the high-speed dedicated highways, where vehicles are following each other to reduce distances and increase the throughput of the traffic lane.

Such platooning functionalities is also available on Robosoft's cybercars using robuBOX, as illustrated on figure 11 with 3 cycab vehicles.

Fig. 11. Platooning of cybercars.

The control law for platooning is using first a feature extraction algorithm to detect in our case a segment (but could a reflective landmark or a circle or whatever characteristic feature).

Once a segment is extracted, as illustrated in figure 12, a position control law is applied to control both the steering in order to align the segment with the longitudinal axis of the vehicle, and the speed in order to maintain a constant distance with the previous vehicle.

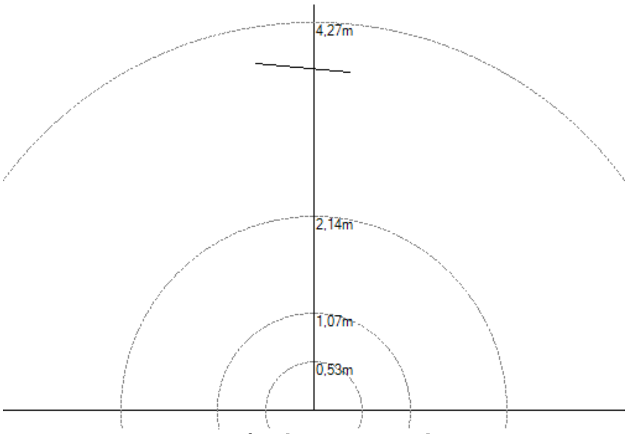


Fig. 12. Segment extraction for platooning control

Platooning with segment extraction has been experimentally tested and validated on robuCAB driving 18 km/h.

4 HOW GNSS TECHNOLOGIES UNLEASH THE POTENTIAL OF CYBERCARS

What has been discussed and shown up to now is how to control cybercars to perform different service application such as platooning or driverless point to point and on-demand transportation of people.

These functionalities are coming from the robotics technology field and require a robust and accurate localization of the vehicle in order to guarantee performance and safety.

These service applications are only able to give their full power since the GPS and more precisely RTK-GPS is available at acceptable costs.

Indeed the following sub-sections will show the evolution of the cybercars applications in the last 5 years.

4.1 Simserhof fort

The first commercial application of such cybercars fleet has been for Robosoft in 2003 the robuRIDE experience in the Simserhof fort entertainment park, in the French section of the 2nd world war defensive Magineau line. 5 vehicles are in exploitation and have transported more than 150000 people since the opening (fig 13.).


Fig. 13. Simserhof Entertainment park. Cybercars using embedded wires.

For this site, the vehicles are not GPS driven but uses embedded inductive wires to control the steering. This technology has proved its robustness and safety but requires a bit of infrastructure preparation as the wire must be precisely embedded.
The other limitation is the limited flexibility left for future extensions or reconfigurations of the paths.

Nevertheless, this commercial application paved the way of driverless automated cybercars transporting people in an every-day exploitation configuration.

4.2 Mobivip project and Anglet city experiment

In the scope of a French national funded research project, a one month experiment has been conducted in the city of Anglet in 2006. The technical goal was to validate in real conditions the control and safety systems of the cybercars.
The commercial and societal goal was to validate that the public was ready to accept such driverless vehicles.

The experiment has been conducted during a full month, 8 hours a day, transporting people on demand in a pedestrian area along the Atlantic Ocean (fig 14). The only action users had to perform was to select on a tactile screen their destination, all the rest being autonomous.
The vehicle was equipped with a RTK-GPS that was fused with odometry of the vehicle, proving that such technology was viable for a robust and safe commercial exploitation. Public acceptance was also very high and strong expectations were raised.

Fig. 14. Anglet experiment: using the robuCAB in a pedestrian area, and tactile interface to select destination.

4.3 Vulcania Entertainment park

Located in the French mountains of the Massif Central in Auvergne, Vulcania is a theme park dedicated to volcanoes.

Their latest attraction, the volcanBUL experience, opened in March 2008 and consists of 3 robuRIDE transporting 28 persons each at 8 km/h in a scenographic experience of the surrounding volcanoes and geyser attractions, as illustrated in figure 15.

Fig. 15. The VolcanBUL experience at Vulcania theme park

For this world first commercial exploitation of GPS driven automatic transportation of people, the vehicles are equipped with a L1/L2 RTK-GPS hybridized with a 6-axis inertial measurement unit and a wheel odometer (OXTS Inertial+ product), allowing for centimetric localization at 20Hz, even in difficult areas where the vehicles are driving under trees.

The vehicles are following pre-learnt trajectories as described in section 3.1. Security is ensured by a bumper and a laser range finder combined with obstacle detection algorithms described in section 3.2.

Thanks to the already existing software modules within robuBOX, the development of this application, from the vehicle definition and hardware low level control up to

the vehicle's navigation and scenography definition has been achieved in less than 3 months.
The next sub-sections illustrate the different steps that were necessary to complete this project and deliver a thrilling application to the Vulcania theme park, for the pleasure of its visitors.

4.3.1 Reconnaissance of the site for GPS covering evaluation

In December 2007, a reconnaissance vehicle has been equipped with a L1/L2 RTK GPS in order to evaluate the quality, precision and availability of GPS signals on the Vulcania site (fig 16.).

Fig. 16: Vulcania site reconnaissance using RTK GPS

4.3.2 Control architecture definition

The following step is to define how the vehicle will be controlled. Using the robuBOX and MSRS, software services are just like Lego bricks that can be assembled together to define control architecture. So you just need to select the existing bricks you want to use for hardware management, signal processing, control and application/ scenography definition. Then only have to develop whatever functionalities are missing.

The final control architecture for the Vulcania, presented in fig 17, is thus defining all the services that will be used, as well as the interactions between them.

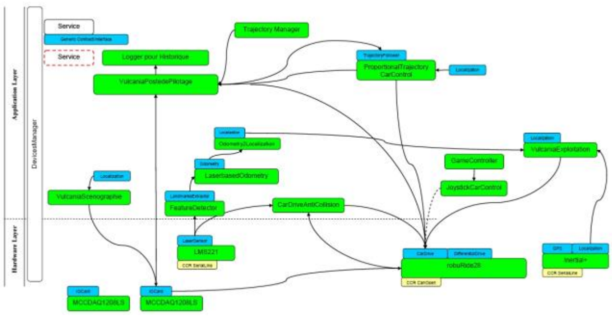


Fig. 17: Vulcania robuBOX control architecture

Once the architecture is defined, one could just try it directly on the 5 tons vehicle… but should watch out for inaccurate tuning! So trying it and tuning it in simulation is just a very useful step!

4.3.3 Control law tuning thanks to dynamics simulation of vehicle and environment.

One of the outputs of the site reconnaissance is a set a recorded trajectories of the future routes of the cybercars, the main one being a loop as shown on figure 18. It is 1.2 km long and supports slopes of up to 10%.
The GPS data collected are NMEA GGA, projected in Lambert93 planar frame and then relocated with respect to the base station.

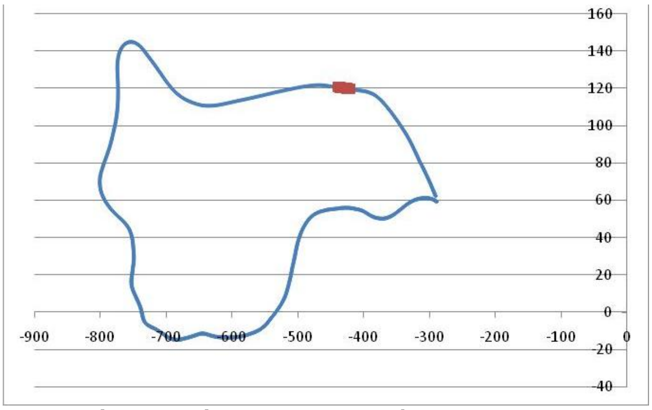


Fig. 18: Vulcania main loop trajectory, in Lambert93 projection.

Using these projected localization as input of a robuBOX service, 3D models of the site environment and routes are generated for the Microsoft Robotics Studio simulation environment, as shown in figure 19.

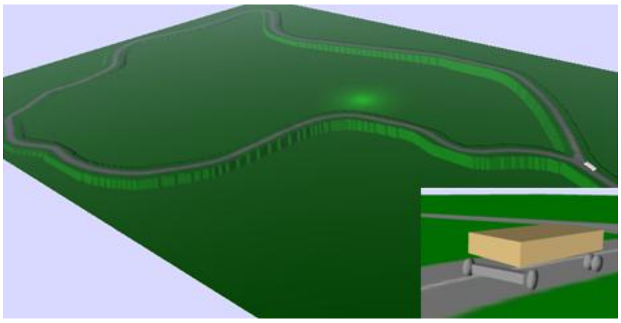


Fig. 19: 3D model automatic generation using recorded GPS trajectories

The robuRIDE vehicle has also been modeled in the dynamic simulation environment, using the real vehicle dynamics parameters such as its 5 tons mass, acceleration range maximum wheel speed etc…
This simulation allowed tuning of the vehicle's control laws while the real robots were not finished to be produced, allowing a drastic saving of time. The other benefit of the simulation is that you don't care if the control law is badly tuned and the vehicle crashes… it's only in simulation!

4.3.4 Deployment on the real vehicles, fine tuning of the control and inauguration

Once the control law has been tuned, and the whole exploitation process, including fleet management rules, has been validated in simulation. It is time to deploy the software on the vehicle. For he robuRIDE vehicles, a 1.6GHz PC104 running Windows XPembedded is used. All the tight critical control loops for the motors servo control are performed using intelligent CAN-Open drives.

The first step in the deployment is to test all the hardware layer management on a lab setup. Then when hardware is validated, the control architecture is deployed on the embedded PC and the vehicle can be started.

The only thing remaining is fine tuning of the control laws, exploitation strategies and speed regulation on the path to ensure comfort and nice experience to the passengers!
Then you're ready for the attraction Grand Opening, illustrated in figure 20, just 3 month after you started developments.

Fig. 20: Vulcania volcanBUL Grand Opening, using the GPS-controlled driverless robuRIDE transporting 28 persons at 8km/h.

5 CONCLUSION

This paper has introduced how GPS and GNSS have allowed unleashing promising applications for autonomous transportation of people.
The robuBOX software has been introduced and shown to be an off-the shelf solution for quickly and easily transforming any vehicle into an efficient cybercar or autonomous robot.

Robosoft's experience and history in designing and providing commercial exploitation of autonomous transportation of people, starting from infrastructure limited solutions to fully reconfigurable and expandable solutions based on RTK-GPS.

The next step to reach the goal of massively deploying cybercars based applications would be a cost reduction: indeed localization techniques based on RTK-GPS hybridized with 6axis inertial units is really costly.

To go one more step into providing cost-effective solutions, Robosoft is working in different French national or European funded projects such as CTS-SAT, Cybercars2 or Citymobil. In these projects, most of the technological locks are been studied to provide enabling solutions.

And as the robuBOX is available to manufacturers and integrators in order to transform any vehicle in an autonomous robotic system or cybercar, the soon future should see the emergence of more traditional cars moving autonomously and transporting people without any drivers!