Preprints of the 21st IFAC World Congress (Virtual)
Berlin, Germany, July 12-17, 2020

From a classic Renault Twizy towards a low cost autonomous car prototype: a proof of concept

Rodolfo Orjuela, Jean-Philippe Lauffenburger, Jonathan Ledy, Michel Basset, Joel Lambert, Didier Bresch, Jean-Jacques Bockstaller

IRIMAS UR7499 , Université de Haute-Alsace
12, rue des frères Lumière, F-68093 Mulhouse, France
(e-mail: firstname.lastname@uha.fr)

Abstract: This paper shows how a conventional electric car is modified into an autonomous vehicle. The starting point to the presented developments is the Renault Twizy® specially designed for urban mobility. The goal is to reuse the mechanical, electrical and electronic elements to customise this car in an autonomous electric vehicle. For that purpose, communication, actuators and sensors systems are added. The challenge here is double, on the one hand the integration challenge due to the small place offered by the Renault Twizy®, and on the other hand the proposed systems must associate low cost and good performances. The proof of concept of our autonomous prototype is given through some experimental validations.

Keywords: autonomous vehicle prototype, guidance and perception strategies, Renault Twizy®

1. INTRODUCTION

Autonomous, self-driving or driver-less vehicles are considered as an interesting option for intelligent transportation systems. This novel mobility solution can advantageously improve safety, reduce congestion, decrease pollution emissions and increase the mobility for all (Chan, 2017). However, despite of recent demonstrative operations of full autonomous vehicles given by automotive manufacturers and researchers, this topic remains subject to intense researches and several technical and scientific challenges in perception, planning, and control must be taken up to democratise this emergent technology.

The expected developments and solutions to cope with these challenges need open and low cost scalable experimental prototypes in order to test, validate, and improve driver-less strategies. An experimental autonomous vehicle, called ISRobotCar, is presented in Silva et al. (2012) from the re-instrumentation of a Yamaha electric AGV. The distributed software and hardware architecture is presented and a path following fuzzy control strategy is validated. A small-size prototype is developed in Shimchik et al. (2016) as a first step to propose a long term autonomous golf cars for passenger transportation. This prototype will be controlled by Robot Operating System (ROS) largely employed in mobile robotic applications and less employed in autonomous car applications. More recently, an electric go-kart was converted into a x-by-wire vehicle to test Advanced Driver Assistance Systems (ADAS) and autonomous driving (AD) using also ROS in Alzu'bi et al. (2018). In Lozoya Santos and Tudon-Martinez (2017), the work made to convert a fully functional combustion engine vehicle into an autonomous car is presented. The target vehicle is a three-wheeler made of aluminium built at the Universidad de Monterrey for the *SAE Supermileage Competition*. The main modifications are presented and can be a good starting point for similar transformations.

The already mentioned prototypes are very useful for researches in order to test and validate algorithms for the autonomous driving. However the democratisation of autonomous vehicles needs the development of prototypes based on more standard commercial vehicles integrating low cost sensors and actuators to evaluate the feasibility and the scalable concept by taken into consideration the industrial constraints. The already mentioned goals are the main motivations of the works presented in this paper which describes how a conventional electric car has been modified into an autonomous vehicle.

Among the commercialised available cars, the Renault Twizy® electric car is chosen here. This is a small two seater electric car specially designed for urban mobility with a low cost (prices start at 6,990 Euros up to 8,490 Euros). Initially designed as a concept car in 2009, the Renault Twizy® is marketed since March 2012 in France. With more than 21,874 units sold worldwide since its launch, the Renault Twizy® is also offered in 2017 as a Platform Open-Mind (POM) which is a Renault Twizy® stripped of its bodywork. The idea is to provide the mechanical basis to create new electric vehicle prototypes. Costumers can then reuse the mechanical, electrical, electronic elements. This opportunity largely ingresses the advantages of this car to imagine new possibilities for the mobility of tomorrow. For these reasons the Renault Twizy® seems an interesting starting point to develop an autonomous vehicle. Some projects to transform the Renault Twizy® into an autonomous car are started, for example by the Chalmers university [1] or by the StreetDrone company [2]. However, these two projects seem poorly documented.

The challenge here is double, on the one hand the equipment must be low cost in order to evaluate its performance, and due to the small size of the Twizy, this equipment must be taken up very little space on the other hand. The proposed prototype is equipped of low cost sensors including a front and back barrier of ultrasonic telemeters, a camera, Inertial Measurement Units (IMU), and GPS, etc. to gather information from its environment. Actuators acting on the steering and throttle to make the autonomous vehicle follow the planned path are also integrated in the proposed car. These news sensors and actuators communicate thanks to an additional Controller Area Network (CAN) bus to send information to the embedded computer. Finally, these informations are then processed using RTMaps (Real Time, Multisensor applications) software provided by *Intempora*.

This paper is organised as follows. In Section 2 a short introduction of the Renault Twizy® is given and the main ideas about our hierarchical guidance architecture for autonomous driving are exposed. The whole implemented architecture involving hardware, software and communication architectures is presented in Section 3. Finally, some preliminary experimental results of guidance by wire are shown in Section 4 and a short discussion is given in Section 5 to conclude this paper.

2. PROTOTYPE AND WHOLE ARCHITECTURE

As stated in the introduction, the starting point of the proposed developments is the Renault Twizy® 45. This small two seater electric car with safety standards (Airbags, ABS, etc.) is compatible with automatic driving urban applications due to its compact size characteristic and its interesting specifications as shown in Table 1. Some views of our prototype after modifications are given in Fig. 1.

Table 1. Renault Twizy® 45 main features

Electric motor	Power: 5 hp, Max. torque: 33 Nm
Maximum speed	45 km/h
Acceleration (0 to 45 km/h)	9.9 s
Autonomy	120 km
Batteries	Cap.: 6.1 kWh Type: Lithium-ion
Dimensions	L: 2.32 m W: 1.19 m H:1.46 m

Fig. 1. Views of the our Twizy 45 autonomous prototype

[1] https://www.chalmers.se/en/departments/e2/news/Pages/Students-make-electric-car-autonomous.aspx (accessed 07.10.2019)
[2] https://streetdrone.com/streetdrone-twizy/ (accessed 07.10.2019)

The autonomous driving needs the implementation of a whole control guidance architecture. Generally speaking, this latter is a hierarchical architecture involving three main levels, know as, perception level, reference generation level, and the control level (Attia et al., 2012; Pendleton et al., 2017; Laghmara et al., 2019). Fig. 2 shows a general view of the global control guidance architecture with the three main levels.

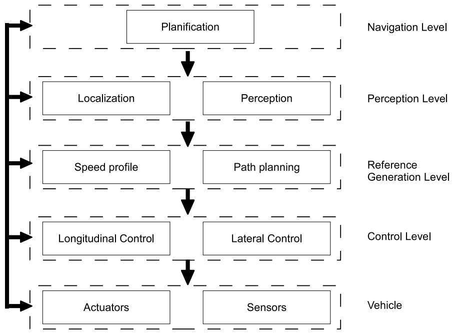

Fig. 2. Hierarchical autonomous driving architecture

The perception level employs the information provided by multiple heterogeneous sensors (camera, inertial central, Radars, Lidar, etc.) in order to modelling the surrounding vehicle environment and to localise the vehicle (Broggi et al., 2013). These informations feed the ***reference generation level*** which generates the speed profile and the path planning references (Attia et al., 2012). The path planning is generated using geometrical references (position, orientation, etc.), and the desired speed is determined according to the speed limitations, the driving situations, etc. Finally, ***the control level*** computes the appropriate actions to track the references given by the reference generation level. For that purpose, a lateral control generates the steering angle and the longitudinal control manages throttle and break (Attia et al., 2014).

3. IMPLEMENTED ARCHITECTURE

The transformation of the Renault Twizy® 45 into an autonomous vehicle needs the implementation of a control guidance architecture involving hardware and software modifications according to the previously guidance architecture. The proposed prototype has been equipped with an embedded computer, several sensors to obtain information from its environment, actuators to allow the autonomous vehicle to follow the planned path, and a CAN bus to link the devices. The schematic view of the proposed architecture is illustrated in Fig. 3.

The embedded computer (HP portable computer, windows 7, i5) is the core of the architecture. It carries out all calculations required by the perception, reference generation, and control levels. As it will be explained in section 3.1, a second CAN bus is implemented to link the new added sensors and the actuators with the embedded computer. Two main actuators acting on the throttle and the steering wheel are integrated and will be presented in section 3.2. The steering wheel is actuated by a servo motor and some mechanical adaptations are made to implement it. The throttle is controlled by wire through a developed electronic device which replicates the signals from the actual electronic acceleration pedal.

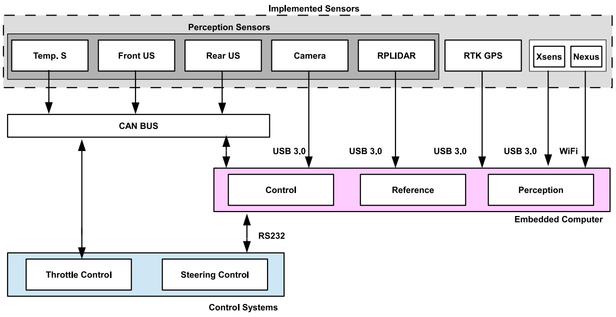

Fig. 3. Implemented architecture

For the surrounding environment perception, ultrasonic sensors on the front (Front US) and on the rear (Rear US), a Camera, two 2D-RPLIDARs, and a temperature sensor (Temp. S) are added. The vehicle position is obtained by a RTK (Real Time Kinematic) GPS, and two Inertial Measurements Units (IMU) are implemented to the vehicle dynamics measurements. The purpose of these sensors is to gather the minimum information required to manage the environment perception, the vehicle localisation, and the vehicle dynamics measurements as it will be explained in section 3.3.
As it can be remarked in Fig. 3, each device has its own update rate and its communication protocol (CAN, USB 3.0, WiFi, etc.), in order to make the asynchronous sensor information acquisition easier, the RTMaps software has been chosen. Indeed, this software is well adapted to manage asynchronous multi-sensor, multi-protocols communication in pseudo real-time acquisition as it will be presented in section 3.4.
Finally, the power supply for this additional devices is obtained by a set of additional 12 V DC laboratory batteries. The idea is to separate the initial and the added power supplies. The global current consumption estimation is of 1.7 A.
In the following sections a description of these developments is provided.

3.1 Implemented communication system

A communication network must be implemented to link the new added sensors as well as the actuators with the embedded computer. In the vehicle context, the CAN bus is largely used to this end. In its original configuration, the Renault Twizy® is equipped with a CAN bus. However, it is not easy to identify all the sent messages managed by the Twizy on-board computer. On the other hand, the modifications of these messages can have strong effects on the Twizy embedded software.

It has been then preferred to implement a second CAN bus mainly for safety reasons. In this way conflicts can be avoided, each CAN bus is dedicated for each configuration. The original CAN bus is employed for the standard configuration while the second bus is dedicated to the autonomous driving configuration. The CAN bus is added using Arduino boards coupled with CAN shields using a standard configuration. The CAN bus data messages are converted into physical readable data signals in the RTMaps software by defining appropriate .dbc files. As previously shown in Fig. 3, the throttle control and some sensors are linked to the new CAN bus. The communication between the new CAN bus and the embedded computer is made through a standard PCAN-USB from the Peak-system company.

3.2 Implemented control systems

Specific control systems acting on the steering, throttle, and brake must be implemented for the autonomous vehicle so it can follow the planned path with the desired speed. In this section, the proposed solutions to cope with the steering and throttle control are presented. It is worth noting that at this stage of transformation, the brake remains uncontrolled due to technological difficulties encountered.

The control architecture, illustrated in Fig. 4, proposes two main driving modes, the standard human driving and the autonomous driving. It is indeed convenient to allow the possibility to have both driving modes.

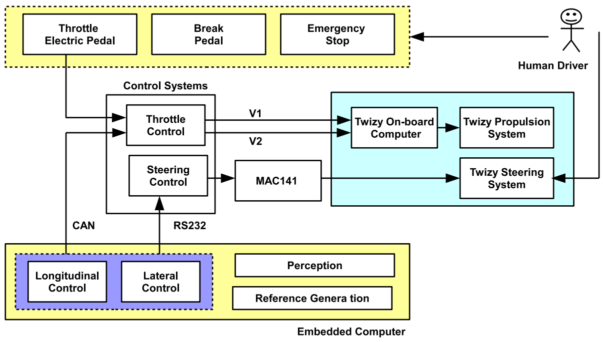

Fig. 4. Implemented control systems for steering and throttle control

The steering control system is given through a small steering electric motor directly coupled to the steering column. The main specifications of this motor are the torque and the angular speed. The expected angular speed for our use case is evaluated to 2 tr/s on the steering wheel and the estimation of the needed torque is obtained from experiments. As expected, the maximum torque to turn the wheel steering is obtained considering the following driving conditions, a stationary Twizy (or very slow speed) in a dry road. Several tests are conducted and the maximum torque measured using a torque wrench under different driving conditions is 25 Nm. This measurement is considered as the lower bound of steering motor specification.

Finally, the selected motor is the MAC 141 from the Transtechnik company (a brushless servo motor with integrated controller), 12 to 48 V DC, nominal torque 0.48 Nm, nominal speed 2700 to 4000 tr/min. A high precision planetary small gear box (AB060-060-S2-P2) is also used to theoretically obtain an output torque of 55 Nm, which is two times greater that the estimated torque for safety. This motor is controlled using a standard RS232 protocol and a specific RTMaps block developed for that purpose. From a mechanical point of view, a specific system is designed to integrate this electric motor on the vehicle. The developed CATIA 3D model of the whole mechatronic system is shown in Fig. 5. The steering column is belt driven by the electric motor. In this way the possibility to easily couple or uncouple the motor can be offered to provide classical or autonomous driving modes.

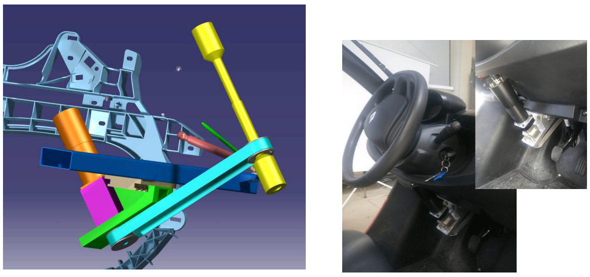

Fig. 5. Implemented electro-mechanical system for steering control

The throttle Control System acts as a software controlled electronic switch allowing control through the actual throttle pedal or the embedded computer for autonomous driving. The developed throttle control is mainly an electronic device placed between the actual throttle pedal of the Twizy and the Twizy on-board computer as previously shown in Fig. 4.
The control priority is always given to the human driver instead to the autonomous driver for safety reasons. Therefore, the actions provided by the longitudinal control are then replaced by the driver's actions when the throttle electric pedal, the break pedal or the emergency stop are activated by the human driver.

The actual electric acceleration pedal generates two different voltages (redundancy for safety) according to the pedal position. These DC voltage signals are then directly sent to the Twizy on-board computer to act on the Twizy propulsion. In the autonomous driving mode, the developed electronic device allows to generate by software the same DC voltage signals to be also sent to the Twizy on-board computer. Consequently, from the Twizy on-board computer point of view two voltages are always received (the electric pedal for human driving or the throttle control for autonomous driving) and our electronic system allows to change the source (human or autonomous) of the longitudinal control. 6.

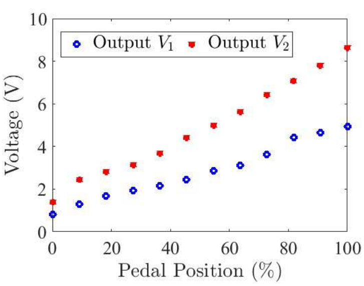

Fig. 6. Electric pedal measured voltages for each output

Some experiments are made to measure the DC voltage for both outputs according to the electric pedal position as illustrated in Fig. With a standard regression, the coefficients of both straight lines are easily computed and these equations are employed to compute the both voltages to control by wire the acceleration. The CAN communication between the embedded computer and the electronic system is established in order to physically generate both voltages to be sent to the on-board computer as previously illustrated in Fig. 4.

3.3 Implemented sensors

Specific sensors for environment perception, vehicle localization, and vehicle dynamics measurements must be implemented for an autonomous driving. A description of these sensors is given below and their locations are illustrated in Fig. 7.

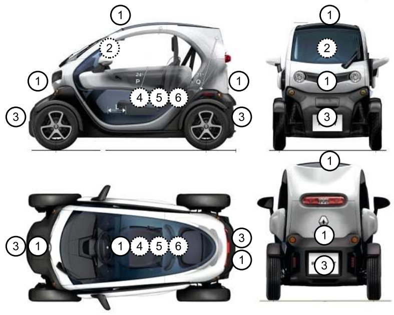

Fig. 7. Sensor locations: ① RPLIDAR, ② Camera IDS 3240LE-NIR USB3, ③ Barrier of US, ④ GPS RTK, ⑤ IMU xsens MTi 100-series, ⑥ IMU Nexus.

Environment perception sensors. For surrounding obstacle detection, two lines of three ultrasonic sensors are installed at the front and the rear of the vehicle. The idea is to detect very close obstacles (2.40 m) to avoid collisions. Another perception sensor is added to have more accurate information about the surrounding environment. The chosen sensor is a 2D and 360^o laser scanner, 2D-RPLIDAR commercialised by Slamtec, with a 25 meters range radius for indoor or outdoor applications. Its very compact size is compatible with our application and it is then possible to collect very accuracy information about the obstacle positions.
The front environment perception is finally completed with a camera IDS 3240LE-NIR USB3. This industrial camera, with a resolution of 2 Mpixels, provides 40 frames per second. The obtained images can be useful for the determination of static environment (road boundaries, traffic signs, etc.) and dynamic obstacles (vehicles, pedestrians, etc.) as will be shown in section in section 4.

Vehicle dynamics sensors. Inertial Measurement Units (IMU) provides informations about the vehicle dynamics, e.g. lateral and longitudinal accelerations, yaw rate, etc. Among the possible choice, we propose to evaluate the IMUs of the Nexus 6 Smartphone and of the professional Xsens MTi 100-series. A WiFi communication between the Smartphone and the embedded computer is used. A free Android application Sensor2nmea is employed to send the IMU measurements to the embedded computer. On the other hand, the Xsens MTi 100-series uses a standard serial port. A comparison is provided in section 4.

Vehicle localisation sensors. The vehicle localisation must be as accurate as possible. Standard GPS signal provides informations with a poor accuracy for autonomous vehicles application. The idea is to improve these measurements by considering the Real Time Kinematics (RTK) GPS technology which is based on a position correction from a base station. It is considered that the base position is perfectly known and that it sends correction data to the rover (here the vehicle). In this way the centimetric (less to 5 cm) vehicle positionning can be obtained. Notice however, that the communication between the base and the vehicle is often through radio waves with a communication range of few kilometers. For this application, we adopt the Ublox NEO-M8T GPS + LIS3MDL Magnetometer module (XL) commercialised by Drotek. Two RTK GPS must then be employed, one for the base station and the other for the vehicle positioning.

3.4 Software architecture

A screen-shot of the main RTMaps diagram with the IHM is presented in Fig. 8.

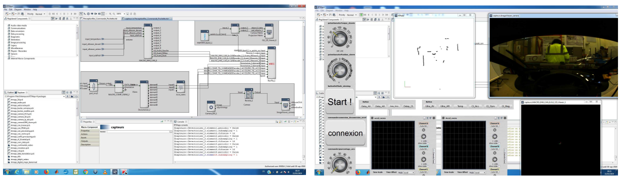

Fig. 8. RTMaps architecture and IHM

RTMaps software provides several blocks in its standard library. The user can pick-up blocks to easily built RTMaps models. However, for specific sensors or actuators blocks must be developed using C++. For instance, a RTMaps block has been developed to control the steering motor. Moreover, RTMaps blocks for CAN communication are already proposed but an appropriate .dbc file containing definitions of CAN messages and signal must be also written to ensure the communication. The software architecture is mainly composed of RTMaps macro-components and RTMaps blocks for communication (CAN, RS232), sensors, and control devices (throttle and steering control).

3.5 Cost estimation

Finally, the list of the added devices with their cost is summarized in Table 2.

4. EXPERIMENTAL TESTS

Experiments are proposed in this section in order to show the effectiveness of the proposed vehicle transformations.

4.1 Guidance by wire test

A guidance by wire test is realized. The steering wheel and the throttle are controlled by wire using the embedded computer. The obtained Cartesian trajectory is obtained from the RTK GPS measurements and shown in Fig. 9.

The lateral and longitudinal accelerations provided by the IMUs (xsens MTi 100-series and Nexus 6) are then

Table 2. List of added devices with the approximative cost

Device	Cost
Twizy 45	7000 Euros
Embedded computer	700 Euros
Servo motor + Gear box	1200 Euros
Throttle device	400 Euros
RPLIDAR	600 Euros/Unit
Camera IDS 3240LE-NIR USB3	700 Euros
Barrier of US	100 Euros
RTK GPS Drotek	250 Euros/Unit
IMU xsens MTi 100-series	900 Euros
Nexus 6	500 Euros
Additional batteries	200 Euros
CAN bus	700 Euros

compared in Fig. 10. The proposed test is accomplished with a constant low speed of 5 km/h and consequently the longitudinal acceleration is not great.

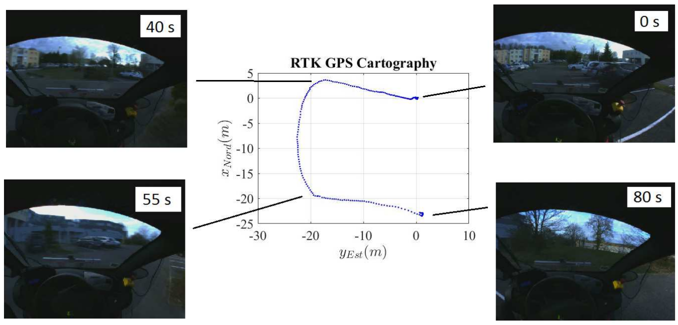

Fig. 9. Trajectory with some views

As can be seen in Fig. 10, these IMUs offer different levels of performance particularly with respect to the noise level. The measurements given by the Nexus 6 are more noise sensitive but they are quite similar to the measurements obtained by the professional IMU Xsens MTi 100-series. In fact, the correlation coefficients are $c_{long} = 0.9625$ and $c_{lat} = 0.9$ for the longitudinal and lateral acceleration respectively. The negative longitudinal acceleration obtained at 68 s is due to the breaking action to stop the vehicle. Finally, the two turns provide lateral positive and negative accelerations as shown in Fig. 10.

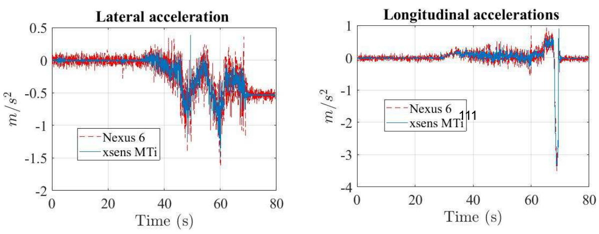

Fig. 10. IMUs measurements

4.2 Perception experimental tests

A perception experimental test is proposed here considering, for simplicity, that the vehicle is stationary. Fig. 11 shows a camera view of the considered environment with several static obstacles.

From measurements given by the front RPLIDAR, a modelling of the surrounding environment of the vehicle can be established using, for instance, the accumulation grid approach (Elfes, 1989). First, the measurements provided by the RPLIDAR are obtained for a complete 360^o rotation (see Fig. 12 *a*).

Fig. 11. Camera view

The environment is modelled as a 2D plan decomposed into several grids (the size and the number of grids can be specified) as shown in Fig. 12 *b*. At this step, the whole grids are empty. A grid is finally considered as occupied, i.e. detection of an obstacle, when the number of points given by the RPLIDAR inside a grid is upper than the desired density level. According to the desired density, the navigable zone for the autonomous vehicle can be accurately built at each sample time as illustrated in Fig. 12 *c* and *d*. Let us remark that the proposed results are obtained off-line using Matlab. A specific RTMaps block should still be developed and integrated for on-line application.

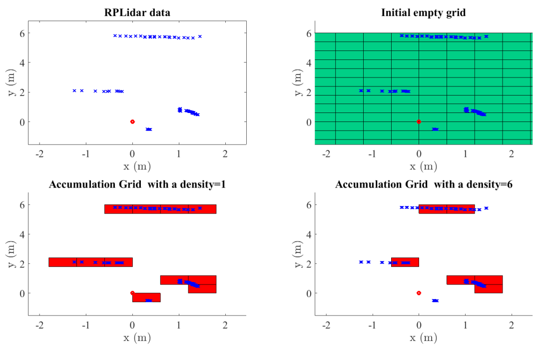

Fig. 12. Accumulation grid results. The red point is the RPLIDAR.

5. DISCUSSION AND CONCLUSION

Current research on autonomous driving requires prototypes to validate solutions for perception, planning, and control. The proposed developments show that this kind of prototype can be made from a Renault Twizy® 45. The challenge of the low cost equipment into a limited place is met through original solutions. The proposed instrumentation is still not enough for advanced autonomous developments of driving automation levels 3, 4 or 5. However, as shown through several experiments, the proposed platform can be very useful to proof driver-less concepts using an open plate-form based on a commercial car. Future research work include the automation of brake which can be accomplished using for example the integrated ABS. However, the ABS is a safety device an its modification must be carefully made to avoid undesired and conflictual behaviors. Finally, implementation of lateral control laws for driver-less tests constitutes the next step.

ACKNOWLEDGEMENTS

We thank all undergraduate students who participated at this project in particular J. Al Safadi, E. Alexandre, O. Benjeddi. F. Bourouih, A, Dartois, H-M, Filipe, K, Leininger, T. Linger, N. Merieux, S. Mrous, A, Oberlé, J-B, Regnez, T. Zussy. This work would not have been possible without their help and enthusiasm. This material is based upon work supported by the AAP-UHA 2017.

REFERENCES

Alzu'bi, H., Dwyer, B., Nagaraj, S., Pischinger, M., and Quail, A. (2018). Cost effective automotive platform for ADAS and autonomous development. In *18: SAE WCX World Congress Experience*. Detroit, USA.

Attia, R., Daniel, J., Lauffenburger, J.P., Orjuela, R., and Basset, M. (2012). Reference generation and control strategy for automated vehicle guidance. In *2012 IEEE Intelligent Vehicles Symposium*. Alcalá de Henares, Spain.

Attia, R., Orjuela, R., and Basset, M. (2014). Combined longitudinal and lateral control for automated vehicle guidance. *Vehicle System Dynamics*, 52(2), 261–279. doi:10.1016/j.conengprac.2014.02.003.

Broggi, A., Grisleri, P., and Zani, P. (2013). Sensors technologies for intelligent vehicles perception systems:a comparison between vision and 3D-LIDAR. In *16th International IEEE Annual Conference on Intelligent Transportation Systems*. The Hague, TheNetherlands.

Chan, C.Y. (2017). Advancements, prospects, and impacts of automated driving systems. *International Journal of Transportation Science and Technology*, 6(3), 208 – 216.

Elfes, A. (1989). Using occupancy grids for mobile robot perception and navigation. *Computer*, 22(6), 46–57. doi: 10.1109/2.30720.

Laghmara, H., Boudali, M., Laurain, T., Ledy, J., Orjuela, R., Lauffenburger, J.P., and Basset, M. (2019). Obstacle avoidance, path planning and control for autonomous vehicles. In *2019 IEEE Intelligent Vehicles Symposium*. Paris, France.

Lozoya Santos, J. and Tudon-Martinez, J. (2017). Towards a supermileage autonomous vehicle. In *17: SAE WCX World Congress Experience*. Detroit, USA.

Pendleton, S., Andersen, H., Du, X., Shen, X., Meghjani, M., Eng, Y., and Rus, D.and Ang, M. (2017). Perception, planning, control, and coordination for autonomous vehicles. *Machines*, 5(1).

Shimchik, I., Sagitov, A., Afanasyev, I., Matsuno, F., and Magid, E. (2016). Golf cart prototype development and navigation simulation using ROS and Gazebo. In *International Conference on Measurement Instrumentation and Electronics*. Munich, Germany.

Silva, M., Garrote, L., Moita, F., Martins, M., and Nunes, U. (2012). Autonomous electric vehicle: Steering and path-following control system. In *16th IEEE Mediterranean Electrotechnical Conference*. Yasmine Hammamet, Tunisia.