2014 IEEE Intelligent Vehicles Symposium (IV)
June 8-11, 2014. Dearborn, Michigan, USA

From Virtual To Reality, How To Prototype, Test And Evaluate New ADAS: Application To Automatic Car Parking

Dominique Gruyer[1], Sungwoo Choi[2], Clément Boussard[1] and Brigitte d'Andréa-Novel[3]

Abstract*— Over the past decade, a lot of researches have been done on the development of advanced driver assistance systems (ADAS). Most of these ADAS are now active and need to be tested and evaluated before large deployment. In these ADAS, the prototyping and the implementation of the control stages are risky stages and not so easy to carry out. Indeed, the prototyping and the test of such reactive algorithms need heavy hardware and software supports (dedicated vehicle, actuators, hardware architecture, software architecture, sensors). To achieve such active devices, additional developments and implementation of numerous expensive embedded devices are required. Therefore, in order to reduce both time and risk, in early design stage, it becomes necessary to have a very realistic simulation environment dedicated to the development and to the evaluation of these ADAS. For such virtual platform, it is mandatory to provide physics-driven road environments, virtual embedded sensors, and physics-based vehicle models. In this publication, we present a dedicated couple of platforms with their efficient interconnection for the prototyping of such ADAS. Initially, the SiVIC simulation platform has been developed to generate the virtual world (environments, sensors, actuators, vehicles). In order to improve the real time prototyping capabilities of SiVIC, an efficient interconnection of this first platform has been done with RTMaps platform. This second one is mainly dedicated to the multi-sensors data processing (data management, fusion, flow recording and replaying). In this paper we will show the interest of such bi-directionnal interconnected platforms to prototype complex and real time embedded ADAS. This interconnection can be done not only on one computer but also on a distributed and distant computers architecture. The relevance of this approach will be illustrated with an automatic parking application.

I. INTRODUCTION

Many laboratories work on developing and evaluating Advanced Driving Assistance Systems (ADAS) and partially autonomous driving assistance systems (PADAS) in order to improve the safety and to reduce the risk of hazardous situations. These assistance systems can be divided into several groups of applications: informative applications and active applications. For active applications, the data coming from the perception algorithm are used together with the data coming from the proprioceptive sensors or observers to compute control actions. These orders will allow to control the vehicle dynamics through the actuators. The control/command algorithms can be elaborated either for lateral maneuvers, longitudinal maneuvers or both lateral and longitudinal coupled maneuvers. From these controllers, it is possible to prototype and to develop a huge set of ADAS (lane tracking, automatic speed regulation, automatic path following, interdistance regulation, collision mitigation, Stop&Go, Adaptive Cruise Control, ...).

It is really easy to have an idea of the complexity of such an application prototyping and implementation. Several years ago, the development of a software architecture dedicated to vehicles, infrastructures, and sensors simulation (SiVIC), has been launched for supporting these research activities on ADAS. This software enables the simulation of multi-frequency sensors embedded in static or dynamic devices, equipments and vehicles commonly used in ADAS. In this context, raw data from perception systems or actuators systems are substituted by realistic synthesized data or devices. This functionality is useful in case of scenarios building with hazardous physical environment, complex situations, lack of data or failures (sensors and actuators). Moreover, the developed applications can be, at every time, tested and evaluated with an accurate and reliable ground truth. At first, the SiVIC platform was built with the objective to prototype local perception applications. Recently, extensions of this sensor simulation platform have been done in order to allow the virtual prototyping of new control/command algorithms and software in the loop applications [6], [7].

Other simulators exist but often have different perspectives and are dedicated to specific needs. For instance, a first group of simulators is dedicated to the vehicle dynamics modeling. Among these vehicle simulators, the most known, for free use, is probably Racer ([2]) which is a driving simulator with a very realistic and real time vehicle model. But Racer does not integrate the complex sensor modeling, the dynamic loading of classes, the management of script attributes during the simulation stage, or the capacities to setup reference scenarios in order to evaluate and validate embedded algorithms. Moreover, we can quote CALLAS from OKTAL, or AMESIM from LMS, or CarMaker ([9], [10]) from IPG. But these two softwares are either too complex for a real time ADAS or PADAS prototyping in a complex situation with several vehicles and traffic management (see e.g. [3]), or the scene rendering is not realistic enough ([4]). Some other solutions are in progress in order to test automotive controls such as cruise control, anti-lock braking system, traction control and stability control in hardware in the loop architecture. Among them, we can quote AutoPlug, an automotive electronic controller unit test-bed to diagnose,

[1]Dominique Gruyer and Clément Boussard are with LIVIC (dept. COSYS, IFSTTAR), 77, rue des Chantiers, 78000 Versailles, FRANCE dominique.gruyer@ifsttar.fr, clement.boussard@ifsttar.fr

[2]Sungwoo Choi is with Renault S.A., Guyancourt, FRANCE, sungwoo.choi@renault.com

[3]Brigitte d'Andréa-Novel is with Mines ParisTech, Centre de Robotique, 60 bvd Saint-Michel, 75272 Paris Cedex 06, FRANCE brigitte.dandrea-novel@mines-paristech.fr

978-1-4799-3637-3/14/$31.00 ©2014 IEEE

test, update and verify controls software ([11]). Other work are developed by Audi in order to provide an Hardware-in-the-Loop architecture for computer Vision Based ADAS ([12]). Nevertheless, this last simulator is mainly focused on optical simulation. But we can quote that this work proposed an interesting way in order to build scenarios.

Many other simulators are dedicated to the drivers' behavior modeling or to road traffic simulation. This is the case of SIM2, ARCHISIM, VISSIM, AIMSUN, SUMO and SCANeR simulators. A first comparison is made at the simulation and traffic models levels in [13], [14]. In this second type of simulators, there is no easy way for integration and evaluation of ADAS, such as emergency braking, lateral or longitudinal control systems with realistic embedded sensors.

From another point of view, a lot of simulators have been developed to model and to simulate specific types of sensors. This is the case of Winprop for the electromagnetic wave propagation channel modeling ([1]), or SE-RAY-EM for RADAR modeling, or SE-RAY-IR for Infra Red rendering ([5]). Unfortunately, these ones often simulate only one type of sensors (RADAR, GPS, Telecommunication, camera, IR camera). The only one comparative sensors simulation platform is the PreScan platform from TNO [15], [16], [17]. Nevertheless, PreScan mainly provides simple sensor models for an easy traffic management and ADAS prototyping but not enough realistic for control/command applications.

A French project (eMotive) was done in order to reach this objective of development of such a solution with an interconnection of SiVIC, SCANeR, AMESIM, RTMaps platforms in a distributed software. In this eMotive platform, a great number of vehicles and sensors models are available (see [8], [18], [19]). At this moment, the SiVIC platform interconnected with RTMaps platform offers an easy and efficient way to respond to the ADAS prototyping, tests and evaluation. Effectively, SiVIC involves good enough vehicle, sensors and reference sensors models. These models constitute a good compromise between too easy models and too complex ones.

This paper presents the way to develop a control application from this current SiVIC/RTMaps interconnected platform. The representative application is: path planning for low speed maneuvers with the example of parallel parking. Furthermore, the environmental simulation gives guidelines for the implementation of actuators and sensors embedded in a vehicle in order to transmit reliable and well-timed information to the algorithms. In the remainder of this paper, the sensor and vehicle simulation platform will be presented in section 2: successively SiVIC and RTMaps and finally the interconnection of these two platforms to obtain our desired ADAS prototyping environment. Section 3 will be devoted to the presentation of path planning applications and control algorithms. Finally, we will present some results and conclude in sections 4 and 5.

II. A VIRTUAL ALTERNATIVE FOR ADAS PROTOTYPING

A. The SiVIC platform

Many developments aim to improve the safety of road environments through driving assistance systems. These studies generally take into account an ego vehicle perception and the corresponding reaction of the vehicle (e.g. braking and accelerating). However, in many situations an ego perception is no longer sufficient. Additional information is needed to minimize risk and maximize the security of driving. This additional information requires additional resources which are both time-consuming and expensive. It therefore becomes essential to have a simulation environment allowing prototyping and evaluating of extended, enriched and cooperative driving assistance systems in the early stage of the system design. A virtual simulation platform has to integrate models of road environments, virtual embedded sensors (proprioceptive, exteroceptive), sensors on the infrastructure and communicating devices, according to the laws of physics. In the same way, a physics-based model for vehicle dynamics coupled with actuators (steering wheel angle, torques on each wheel) has been developed. SiVIC meets these requirements and is therefore a very efficient tool to develop and prototype a high level autonomous driving system with cooperative and extended environment perception (see figure 1). Actually, the SiVIC software platform represents a real benefit for fast design. Moreover, it offers a valuable support for the development of cooperative systems such as V2V and V2I applications and for the assessment of the performance and reliability of such systems.

In its current state, this platform includes several types of exteroceptive, and proprioceptive sensors, thus communication media. The exteroceptive sensors are mainly the cameras, the laser scanner, and the RADAR. The proprioceptive sensors involve odometers and Inertial Navigation systems. Then communication sources for cooperative systems include both 802.11p communication media and beacon (transponder). The camera sensor is modeling with 3 different levels. The third level (the most accurate level) takes into account realistic physical process of a real camera coupled with a set of post processing filters (optical distortion, tone mapper, auto exposure, noise, depth of field, ...) [19], [20]. The laser scanner is modeled with 2 levels: with ray tracing and with depth buffer [8]. The Radar takes into account 4 levels of modeling: A first level without propagation channel and with an extension of the depth buffer functionalities, a second level with RCS and propagation channel based on multi-reflexion raytracing mechanism [22], the third level with a realistic energy propagation and some dedicated processing in an image space (processing on GPU), the last level uses an intensive parallelism mechanism with GPU and CUDA functionalities. The communication level is modeled with 2 levels. The fist one is a statistical model obtained from real 802.11p communication experiments [21]. The second level is based on an adaptation of the RADAR propagation channel and a coupling with NS3 library. For all this sensors and media, it is possible in real time and during the simulation stage

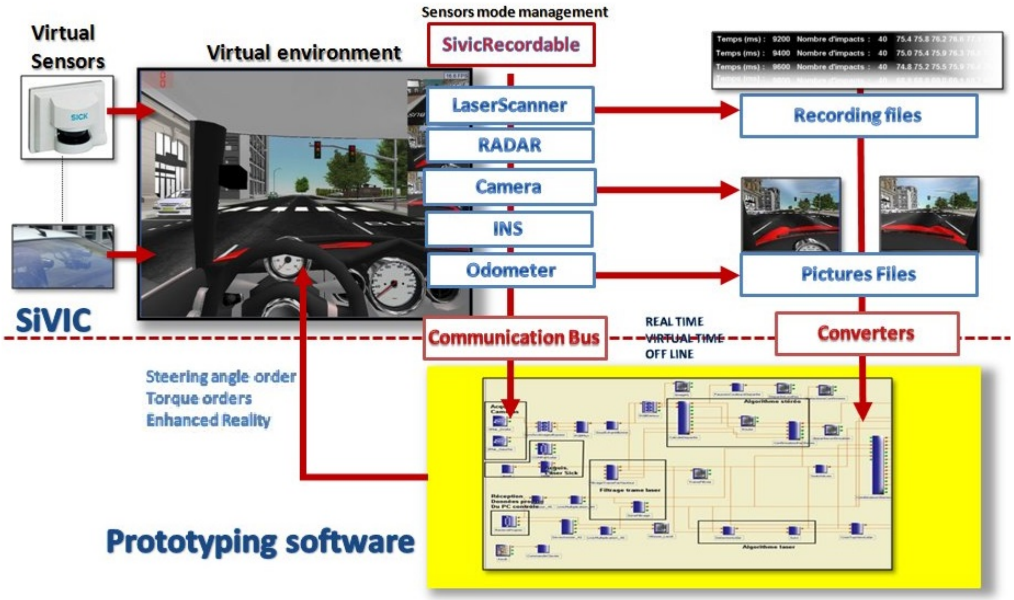

Fig. 1. General principle scheme for ADAS and PADAS prototyping with virtual environment

to tune and to fix the sampling frequency and the intrinsic and extrinsic parameters. Moreover several mode of operating are available and can be modified during the simulation: 'Off' and 'On' for to switch on or switch off a sensor. 'Record' in order to collect data in a file, 'RTMaps', 'DDS', and 'Matlab' to send sensor data in external applications. SiVIC is especially built in order to manage in same time a great set of different type of sensors for ADAS prototyping. Some example of these sensors are showed in 2

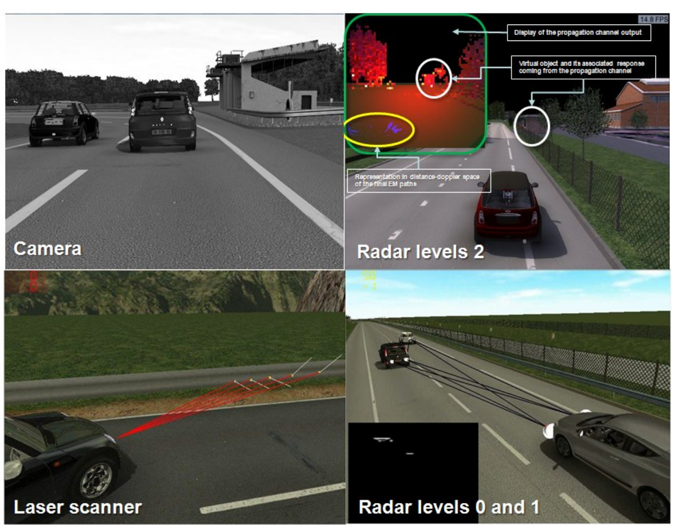

Fig. 2. Some exteroceptive type of sensors in SiVIC

B. RTMAPS platform

RTMaps is a product developed in Mines ParisTech by B. Steux ([23]) and is now sold by the Intempora company. This platform has been developed for the real time, multisensors, advanced prototyping. Its main goal is to manage and to process a great number of raw data flows like images, laser scanner, GPS, odometer, and INS raw data. The algorithms, which can be applied to the sensor data, are involved in several dedicated image processing and multisensors fusion libraries (RTMaps packages). Once these data are recorded and processed, it is very easy to replay them. This type of architecture gives a powerful tool in order to prototype embedded ADAS with either informative outputs or orders to control vehicle dynamics. At each stage, the sensors data and modules outputs are time-stamped for an accurate and a reliable time management (http://www.intempora.com).

C. SiVIC/RTMAPS: an interconnected platform for efficient ADAS prototyping

The coupling of SiVIC with RTMaps brings RTMaps the ability to replace real-life data by simulated data. Moreover, these interconnected platforms provide a solid framework for advanced prototyping and validation of the control/command and perception algorithms. Indeed, this coupling fully and very effectively allows developing SIL applications (Software In the Loop) including virtual prototypes of vehicles with their proprioceptive and exteroceptive embedded sensors. The real-time virtual data coming from vehicles and sensors modeled in SiVIC are sent to RTMaps. In RTMaps platform, these data can be used as inputs for perception algorithms and control/command modules. Similarly, orders can be sent from RTMaps to virtual vehicles used in SiVIC in order to control them (figures 1). This chain of design is very efficient because the algorithms developed in RTMaps can then be directly transferred as micro-software on real hardware devices. Therefore, the simulation model can be considered very close to reality (real vehicles, real sensors).

The different types of data handled by this interconnection library are shown in figure 3.

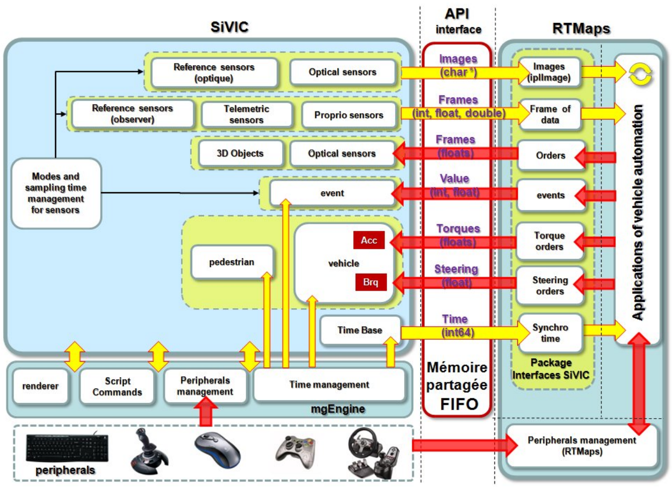

Fig. 3. SiVIC/Types of data managed between SiVIC and RTMaps

Several mechanisms have been implemented and tested. The results of the comparison of these different types of data transfer are given in figure 4. The best solution is clearly the optimized FIFO method which allows the transfer of a great number of data in a short time. It is a very critical functionality in order to guarantee a real time link between SiVIC and the perception/data processing/control algorithms.

Transfer method	5 000 000 frame of 1 data	50 000 frames of a 400x300 data (image)	
FIFO simple, 1 data	38 to 42 s	9.4 s	
FIFO simple, 10 data	12 s	5.1 s	Gain x4
FIFO optimized, 10 data	3.2 s	4.9 s	Gain x17
Pipe	Not available	13.2 s	
TCP from loopback	43 to 57 s	38 s	
ReadProcessMemory()	20.7 s	27 s	

Fig. 4. Performances of the different modes of data transfer between SiVIC/RTMaps

In order to correctly manage time, a synchronization module is available. This synchronization allows providing a time reference from SiVIC to RTMaps. Then RTMaps is fully synchronized with SiVIC components (vehicle, pedestrian and sensors). The SiVIC/RTMaps simulation platform also enables to build reference scenarios and allows evaluating and testing of control/command and perception algorithms. In fact, the SiVIC/RTMaps platform constitutes a full simulation environment because it provides the same types of interactivity found on actual vehicles: wheel angle, acceleration, braking, etc.

III. The example of the automatic car parking

In this section, we present a low speed automation example in the case of parallel parking. In general, the automation of parallel parking maneuver consists of a path planning followed by a tracking control [24] and [25]. In this study, we use the geometric approach presented in these 2 references.

The complete strategy for path planning in n trials was first simulated on our simulation environment on Matlab. Fig. 5 shows two examples of the parallel parking in multi trials showing sampled motions with traveled instantaneous circles of each step. The first one shows parking maneuver in 3 trials and the other one shows a case of 66 trials that a human driver can never do. It shows also that our method is completely independent of the initial position of the vehicle, if the vehicle is parallel to the parking space, as shown in the bottom of Fig. 5.

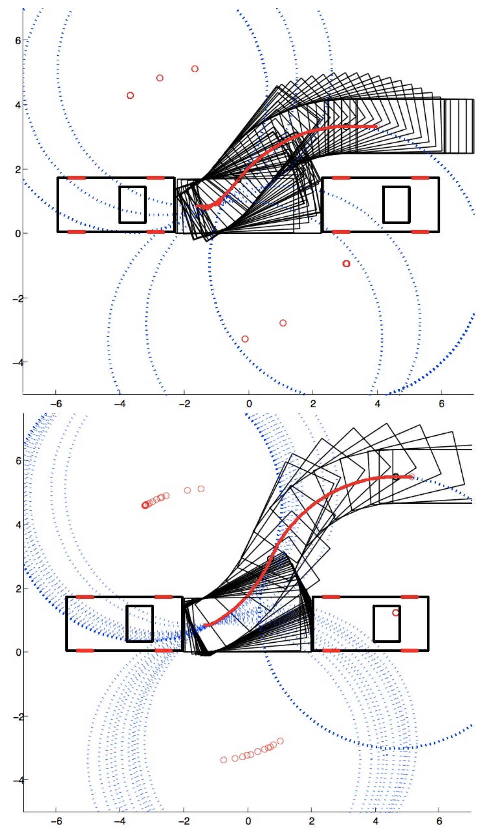

Fig. 5. Simulation on Matlab of the path planning in n trials, vehicle length = 3.62 m, space length = 4.5 m (above), 4 m (bottom).

The implementation of such an algorithm with the SiVIC platform is easy. The distances from the obstacles (front and rear vehicles already parked) are computed or measured from either car observers, or from a set of short range laser scanners (similar to ultrasonic sensors). These data are sent in RTMaps with the use of either Share Memory mechanism, or DDS bus. In SiVIC, the ego-vehicle (to be parked) is set in “RTMaps mode” in order to be controlled from RTMaps platform. Once a free place, with enough space, is detected then the controller can send orders to the ego-vehicle in order to carry out the good parking maneuvers. In this “software in the loop” architecture, it is interesting to quote that the algorithm developed in RTMaps platform will be the same used in a real embedded architecture. The figures 6 and 7 show respectively the general architecture and its application in both SiVIC and RTMaps platforms.

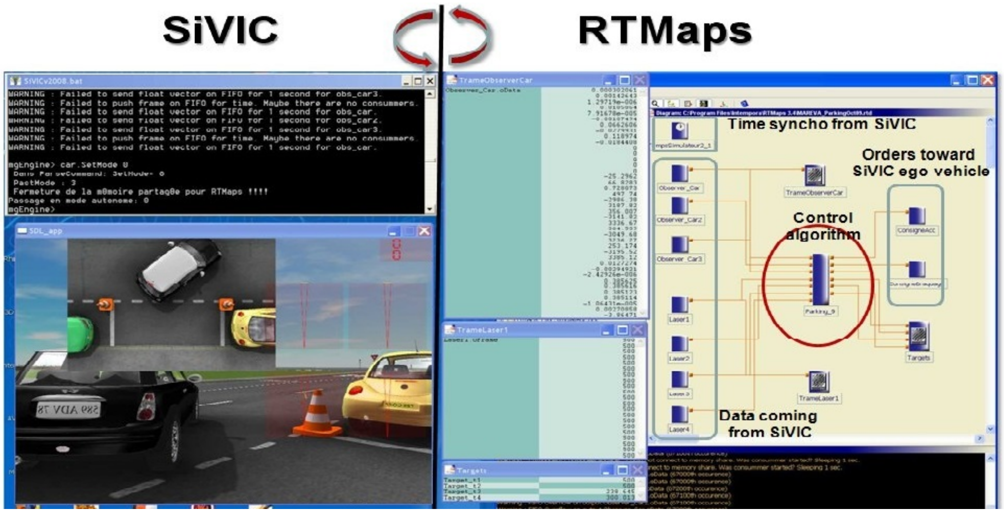

Fig. 7. Software implementation of the parking application

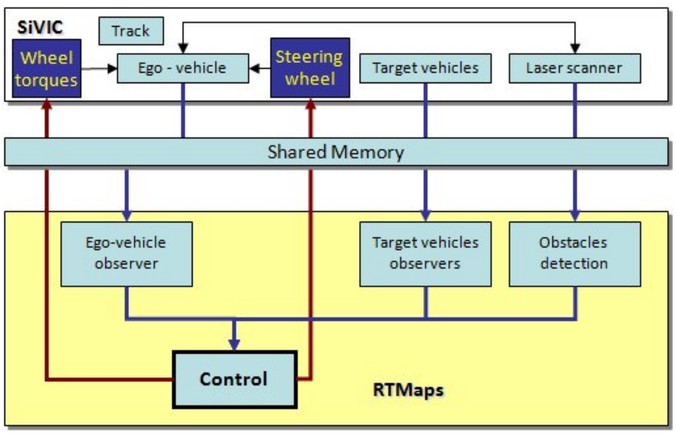

Fig. 6. Principle scheme of parking application

IV. Results

The SiVIC/RTMaps platforms were used to test our algorithm before conducting a real experiment. The location and size of the parking place and the initial position of the vehicle are already known. By using our algorithm, a path can be planned. Then, we elaborated a very simple control to make the vehicle to follow the path.

The final results of a parking maneuver obtained with the SiVIC platform and with the controller developed in RTMaps are shown in figure 8.

Then in order to validate our generic parallel parking algorithm in a real situation, we tested it on a real electric vehicle called $Cycab$ of a French laboratory IMARA (INRIA). It is a vehicle with two seats designed for experiment and small scale demonstrations. The vehicle has four motors (one per wheel) and two steering plunger (both front and back wheels can steer). The vehicle has been equipped with diverse sensors, computing and communication capabilities as shown in Fig. 9. The maximum speed of the vehicle surrounds 5 [m/s] (20 [km/h]) however in practice it is manipulated at much lower speeds 1 [m/s] (comparable to a walking pedestrian).

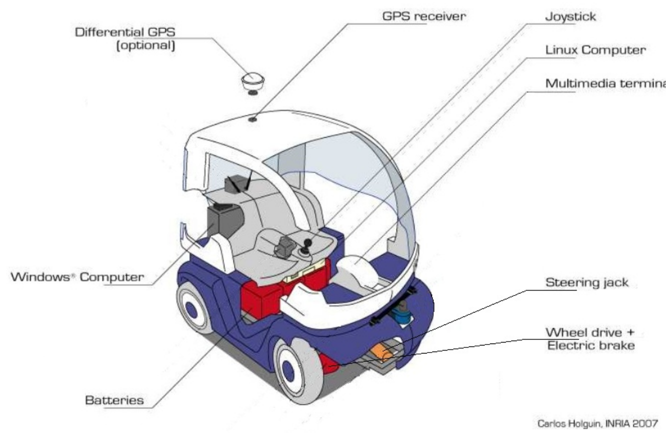

Fig. 9. Extruded view of Cycab

For this test, the same control law was applied while using a DGPS receiver to obtain precise positions of the vehicle and the parking slot. Some sampled scenes of this experiment showing that our path planning algorithm can park a real vehicle in multiple trials are given in Fig. 10[1]. The result of this experiment can be seen in Fig. 11 and Fig. 12.

remark: The control law used for this experiment was a quite simple P-controller. This controller is enough to verify the relevance of our path planning method. However, for a practical use in real conditions, a more sophisticated control like grey-box control [25] will be needed to tackle with external unknown dynamics, i.e. slope of the parking place.

V. Conclusions and Future Works

In this paper, we have presented a new general virtual platform (SiVIC) allowing to model sensors, vehicles and

[1]The complete video of this experiment can be found in http://www.youtube.com/user/laraimara.

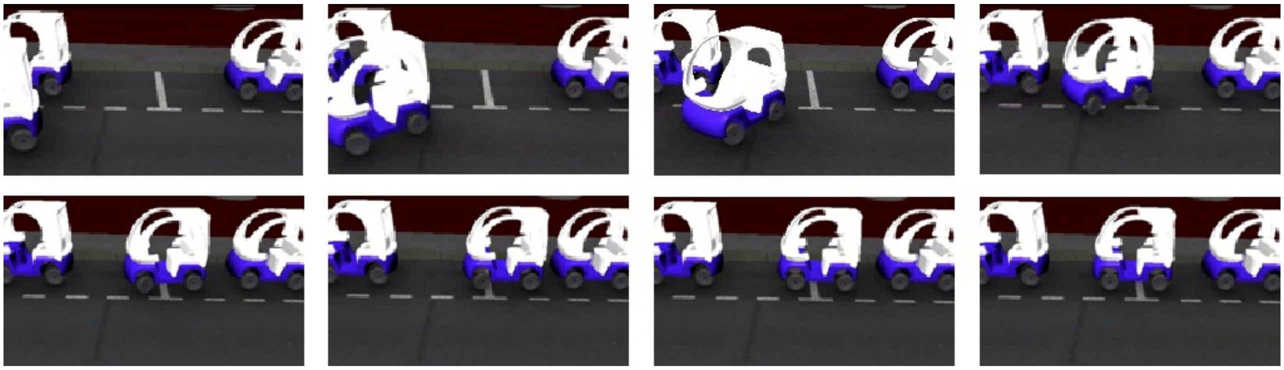

Fig. 8. Test with the platform SiVIC/RTMAPS

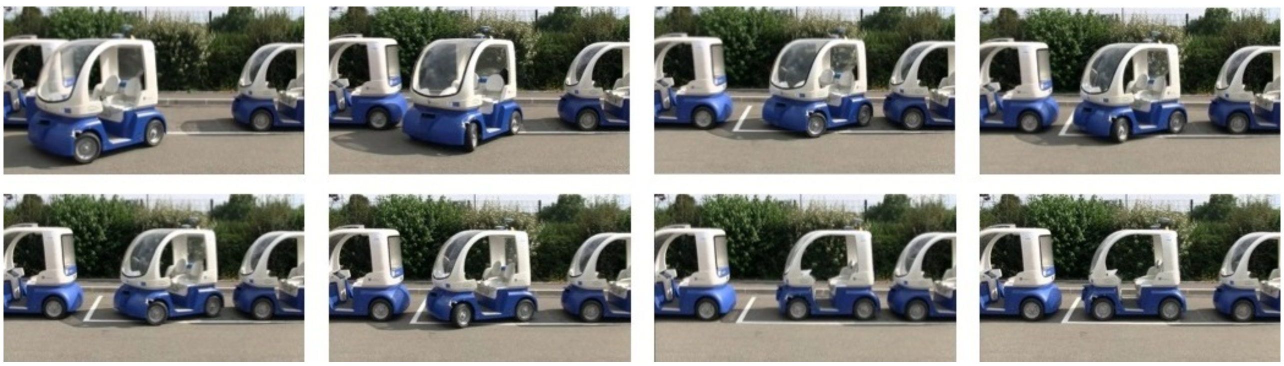

Fig. 10. Real experiment on an electric vehicle

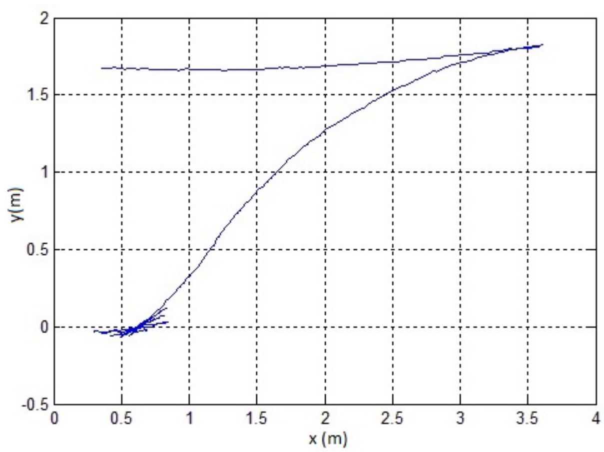

Fig. 11. Result of the real experiment

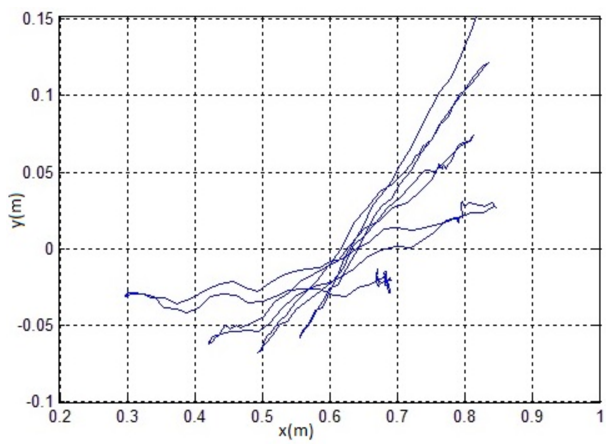

Fig. 12. Zoom of the result of the real experiment

infrastructure in order to prototype, to test and to evaluate control/command algorithms. In its current state of development, SiVIC is operational and offers a large set of functionalities making it possible to model and test various advanced sensors. It can reproduce, in the most faithful way, the reality of a situation, the behavior of a vehicle and the behavior of the sensors which can be embedded inside the vehicle. Parallel to its graphical capacities, SiVIC allows to test and to evaluate the perception and control algorithms. This functionality is one of the most important advantages of this platform. Indeed, this enables to test and to evaluate in real time and under extreme conditions the innovating approaches of environment perception and vehicle control. Comparatively to the existing simulation platforms, a lot of time dedicated to specific sensors or to specific dynamic objects modeling, the presented platform offers a great number of real time functionalities in order to prototype easily new embedded applications. The vehicle model is complex enough to be very close to the application developments in real conditions. Moreover, in order to manage and to optimize the computation resources, a Distributed Data Storage mechanism is available in order to share the computation either on several applications with one computer, or several applications on several computers. This mechanism is very useful for handling very complex vehicle model, complex virtual environment, and complex sensor modeling. Moreover, the coupling of SiVIC with the RTMaps Platform brings to RTMaps the ability to replace real-life data by simulated data. Moreover it also allows to open in RTMaps the perspective for prototyping on desktop the control/command algorithms since SiVIC takes advantage of a physical car model. The need for an equipped vehicle is no longer necessary for the first stages of the prototyping cycle. In fact, the SiVIC-RTMaps platform constitutes a full simulation environment because it provides the same types of interactivity as found on the real vehicles: wheel angle, acceleration, braking, etc.

In order to show the efficiency of such a platform, a control/command embedded application has been presented. It is important to point out that this application also has been embedded and tested on a real vehicle.

More and more applications now need to predict and anticipate a situation in order to provide a better response to a risky situation. In order to achieve this extended application, the control/command stage will be based on extended and cooperative perception. In order to model such a situation, cooperative sensors will be implemented in the SiVIC platform. Among those new devices, we can quote the communication devices (WiMax, WiFi 802.11p, ...).

ACKNOWLEDGEMENT

The Authors would like to thank the French National Agency of Research (ANR) which has partially supported this work in the frame of the CooPerCom project (French/Canadian Project)

REFERENCES

[1] web site http://www.awe-communication.com
[2] web site http://www.racer.nl
[3] web site http://www.oktal.fr
[4] web site http://www.ipg.de/
[5] web site http://www.oktal-se.fr
[6] D. Gruyer, S. Glaser, B. Monnier, ‘Simulation of vehicle automatic speed control by transponder equipped infrastructure’, *in proc. IEEE ITST2009*, Lille (France), october 2009.
[7] B. Vanholme, D. Gruyer, S. Glaser, S. Mammar, ‘Fast prototyping of highly autonomous cooperative driving system for public roads’, *in proc. IV2010*, SanDiego, June 2010.
[8] D. Gruyer, S. Glaser, B. Monnier, ’SiVIC, a virtual platform for ADAS and PADAS prototyping, test and evaluation’, *in proc. FISITA2010*, Budapest (Hungary) 30 may-4 june 2010.
[9] T. Haraguchi, ’Reducing Fuel Consumption by Improved Vehicle Efficiency’, *in ATZ Autotechnology magazine*, issue 4, volume 113, April 2011.
[10] C. Miquet, W. Schick, B. Schick, O. Blanco-Hague, B. Durand-Gasselin, E. Mallet, ’Advanced Vehicle Dynamics Simulation by Physical Modelling with Transient Tire Behavior of TameTire’, *presented at chassis.tech plus*, june 2011.
[11] U. Drolia, Z. Wang, R. Mangharam, ’AutoPlug: An Automotive Test-bed for Electronic Controller Unit Testing and Verification’, *in proc. ITSC 2011*, Washington (USA), October 2011.
[12] M. Nentwig, M. Stamminger, ’Hardware-in-the-Loop Testing of Computer Vision Based Driver Assistance Systems’, *in proc. IV 2011*, Baden Baden (Germany), June 2011.
[13] Z. Kokkinogenis, L. Sanchez Passos, R. Rossetti, J. Gabriel, ’Towards the next-generation traffic simulation tools: a first evaluation’, *in proc. of DSIE’2011, 6th Doctoral Symposium in Informatics Engineering*, Porto (Portugal), 27-28 January 2011.
[14] S. Panwai and H. Dia, ’Comparative Evaluation of Microscopic Car-Following Behavior’, *IEEE Trans. on Intelligent Transportation Systems*, Vol. 6, No. 3, September 2005.
[15] ‘preScan, a simulation and verification environment for intelligent vehicle systems"’, *in preScan R4.5 Help manual*, TNO, 2010.
[16] F. M. Hendriks, R. Pelders, M. Tideman, ‘Future Testing of Active Systems’, *in Automotive Engineering International magazine*, vol. 119, no 2, march 2011.
[17] M. Tideman,‘Scenario-based Simulation Environment for Assistance Systems’, *in ATZ Autotechnology magazine*, january 2010.
[18] F. Gallee, C. Appere, D. Leroux, A. Peden, M. Ney, D. Gruyer, ’Development of a simulation platform for ACC radar application’, *in IEEE International Conference on ITS Telecommunications (ITST 2011)*, Saint-Petersburg (Russia), August 23-25, 2011.
[19] D. Gruyer, N. Hiblot, P. Desouza, H. Sauer, B. Monnier, ’A new generic virtual platform for cameras modeling’, *in proc. of International Conference VISION 2010*, Montigny le Bretonneux (France), 6-7 october 2010.
[20] D. Gruyer, M. Grapinet, P. Desouza, ’Modeling and validation of a new generic virtual optical sensor for ADAS prototyping’, *in proc. of IEEE IV 2012 Conference* , Alcalá de Henares (Spain), 3-7 june 2012.
[21] S. Demmel, A. Lambert, D. Gruyer, A. Rakotonirainy, E. Monacelli, ’Empirical IEEE 802.11p Performances Evaluation on Test Tracks’, *in proc. of IEEE IV 2012 Conference* , Alcalá de Henares (Spain), 3-7 june 2012.
[22] S. Pechberti, D. Gruyer, V. Vigneron, ’Optimized simulation architecture for multimodal radar modeling: Application to automotive driving assistance system.’, *in proc. of 16th International IEEE conference on Intelligent Transport Systems ITSC 2013* , Den Hague (Netherlands), 6-9 october 2013.
[23] B. Steux, ’RTMaps, un environnement logiciel dédié à la conception d’applications embarquées temps-réel. Utilisation pour la détection automatique de véhicules par fusion radar/vision’, *PhD. thesis from Ecole des Mines de Paris*, december 2001.
[24] S. Choi, ‘Estimation et contrôle pour le pilotage automatique de véhicule : stop&go et parking automatique’, *Ph.D. thesis*, Mines ParisTech, September 2010.
[25] S. Choi, C. Boussard, B. d’Andréa-Novel, ‘Easy Path Planning and Robust Control for Automatic Parallel Parking’, *in proceedings of IFAC2011*, Milan, august 2011.