A new approach on the technologies used to develop, test and validate CAVs (Connected and Automated Vehicles) systems

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ABSTRACT

Connected and automated vehicles (CAVs) is a disruptive technology that has great potential to change the way we live, work and drive. Among so many benefits this technology supports dynamic route guidance, better management of traffic flow and intervenes in potential life-threatening situations from the driver which has been demonstrated to prevent accidents through auto-collision avoidance features. With the benefits also comes the challenges, and this technology require significant infrastructure. In this context, this research aims to approach the technologies used to develop and validate CAVs features, the tests that are being done and the controlled environments used to perform these tests. To perform this study, Applus IDIADA's capabilities and CAV domain knowledge was utilized. It is presented a vehicle on-board unit (OBU), that encompasses several individual CAV components into on single unit. It makes possible to retrofit connectivity features into non-connected vehicles for research and development purposes, such as vehicle-to-everything (V2X), 5G cellular and global positioning system (GPS) technologies. Finally, this study contributes to the automotive industry exposing the current status of CAVs technology and the challenges to integrate this technology in Smart Cities.

Index Terms - CAVs, Connected and autonomous vehicles, Automated and connected mobility

I. INTRODUCTION

In the last decade, the landscape of private and public transport has been revolutionized with the adoption of connectivity and high-powered computing capabilities into vehicles. Such revolutions improve traffic flow, the delivery of immersive in-vehicle entertainment and contribute towards the safety of those in and outside of the vehicle.

The incorporation and amalgamation of connectivity and autonomy into vehicles offers innovative new capabilities compared to those found in vehicles marketed until some years ago. Such capabilities support vehicles to interact with nearby vehicles (Vehicle-to-Vehicle / V2V), smart infrastructure such as traffic lights (Vehicle-to-Infrastructure / V2I) and in some instances with vulnerable road users (Vehicle-to-Person / V2P). This collective information, along with the smart city paradigm helps to improve the driver experience, car-sharing leading to fewer parking lots and contribute towards improved road-safety.

In fact, it's been estimated [1] that by 2030, almost a quarter of "all the miles traveled" in the United States could be shared autonomous cars. [2] estimates that by 2030, there will be more than 11 million driver-less vehicles shared on the roads worldwide - or about 5% of the world's traffic population.

However, for these estimates to be fulfilled, continuous innovations in R&D (research and development), PoC (proof-of-concept) activities and real-world testing are needed. The R&D project [3] developed an advanced vehicle control system, designed to allow the vehicle to imitate a "natural" human driving style, using machine learning and developing artificial intelligence (AI) to improve comfort, safety and the user experience. [4] is a R&D project called "CAVRide", designed as a prototype of an SAE Level 4 automated taxi service, in which the taxi is able to autonomously navigate around a geofenced area, where users can travel to the location chosen without any intervention on the steering wheel or pedals, since the vehicle was designed to accurately detect the road environment without human input.

It's clear that bringing these ideas to real-world PoCs require a selection of flexible components and technologies. It's also important to be vehicle agnostic, and (where possible) technology-agnostic due to the automotive industries complex supply chain. In addition to components and new technologies, controlled testing facilities are an essential first step in validating these technologies in the real-world prior to public road testing. This way, this paper presents a vehicle OBU (on-board unit) that is capable of turning a non-connected vehicle into a connected vehicle optimally, with less space and less time spent on the project and integration, in addition to showing what infrastructure is needed to correctly validate connected and automated vehicles.

The structure of the paper is as follows. In Section II is presented the OBU and its capabilities. The controlled environments and infrastructure used to develop CAVs systems are presented in Section III. In Section IV some case studies developed recently are shown. The future challenges on integration in Smart Cities are given in Section V. Finally, Section VI concludes this work.

II. CONNECTED AND AUTOMATED VEHICLES

There has been a seismic shift in technology deployed in modern vehicles compared to those 20-30 years ago. There's been a wider adoption of Unix-like operating systems into infotainment units and companies who have pioneered graphic processing units (GPUs) in the early 1990s are now instrumental in vision sensor processing and AI for the automotive industry.

The importance of connectivity and intelligent capabilities in vehicles is a growing area for industry. These capabilities are driven by R&D activities and requires flexible tools adaptable to many different architectures and application as possible. The suitable technologies typically have individual units, components, cables, power supplies, software applications and licenses of different manufactures.

Integrating all these components may not be an easy task. In this scope that a multi-purpose OBU is useful and necessary. The case studies approached on Section IV were developed using an industrial and market ready OBU hardware platform called IDAPT, which can be used to support development, prototyping and research activities. Its first visible advantage is the quite compact and small size, such that it could be developed on a bench and then just as easily install into a vehicle, as can be seen in Figure 1.

Figure 1. Prototyping with OBU

The OBU was designed to provide connectivity technologies that are independent to the vehicle, such as a GNSS receiver, a 4G cellular modem and a V2X module, thereby turning a non-connected car into a connected car. In addition, several CAN (Control Area Network) interfaces were added as well as automotive grade analogue and digital I/O to interface with the vehicle's electronic architecture.

A Linux based environment and modified kernel enables the R&D application developers to integrate with the independent connectivity technologies and the vehicle's system. Quite often in CAV R&D, many of these technologies are single individual units and the aim of the OBU was to bring them into one single environment to expedite development.

III. ENVIRONMENTS AND INFRASTRUCTURE

In order to validate connected and automated vehicles it is paramount to have an appropriate test infrastructure. It is very important that test tracks have an integrated approach to CAV technologies and not just a sum of its parts: the CAV ecosystem is complex and interleaved and consequently every asset must be interconnected. Among the features of a complete test track for CAV testing the following must be considered:

PHYSICAL INFRASTRUCTURE – Those hardware elements in the infrastructure that enable the tests. The traditional building blocks of classic proving grounds:

Test track geometry – The shape of each of the test track itself, with different purposes (high speed tracks, dynamic platforms, handling, urban) and options (intersections, access roads, bridges, tunnels, etc.).

Vertical and horizontal signage – Lane markings, traffic signals, traffic lights, etc. Normally not fixed or changeable but especially relevant to test automated driving sensors.

DIGITAL INFRASTRUCTURE – Those elements or systems, normally related to the information and communications technology (ICT) domain, that provide additional information to the vehicles under test or the test equipment itself:

Communications – Connectivity is the basis for infotainment systems, new mobility services and act as an additional sensor for automated vehicles. It also enables the dialogue between vehicles and thus potential complex interactions (e.g. platooning, smart intersections, etc.). There are two main access technologies, among others, that may provide connectivity at short, medium and long range to connected vehicles, consequently, proving grounds should have an appropriate infrastructure for testing purposes.

DSRC (Digital Short-Range Communications): Provide low latency (below 10ms), short distance (up to 1 km) communications between vehicles (V2V) and between

Vehicle and Infrastructure (V2I) which makes them very appropriate for safety critical applications. Two technologies are currently competing worldwide: WiFi based systems (WAVE in US, ETSI-G5 in Europe) and cellular technology based (C-V2X).

Cellular: Same technology as in mobile phones, it allows high coverage and reasonable bandwidth. Traditionally, its relatively high latency (more than 30ms) make them the preferred choice for infotainment but not safety applications. The evolution of 4G/LTE and the introduction of 5G blurs the lines with DSRC technologies.

High Definition Digital Maps – Highly accurate maps that include semantic information of the roads used for open road or test track testing in a digital format. Very useful for positioning and navigation of CAV systems that may use it as ground truth reference.

GNSS Coverage and Augmentation – All additional information that can be sent to the GNSS receiver of the vehicle to improve its positioning accuracy beyond what satellite only positioning may provide. It can be purely satellite based augmentation and/or hybrid augmentation (making use of other sensors and digital maps).

COMPLEMENTARY FACILITIES AND EQUIPMENT – To provide full validation capabilities for CAV systems it is necessary to provide additional equipment (e.g. SotA mesh connected targets and dummies) and a full integration of all the above described. This enables additional services as Virtual Validation testing (e.g. MIL/SIL/HIL and VIL) and HMI validation (e.g. integration with advanced driver simulators).

Figure 2. Private Cellular Network example configuration - IDIADA's Proving Ground in Spain

In this context, the capability to create specific network scenarios, control the network parameters, perform tests using the networks of the future as 5G and retain sensitive data in safety requires new facilities. In Figure 2 can be seen a proving ground that encompasses all these required capabilities that are being used in several R&D, PoC and real-world testing. It's equipped with real radio, not simulated, availability of twenty-four hours a day, since the network is private and dedicated.

IV. CASE STUDIES

In this section is presented some recent projects that are significantly contributing to the advancement on CAV solutions.

MUCCA – The MuCCA project [5] [6] led by IDIADA set out to create a next-generation driver assistance aid to avoid or reduce the incidence and severity of multi-car collisions, not achievable from human drivers. The objective was to combine connectivity (V2V) with autonomy to enable real-time collaboration between vehicles to achieve cooperative-based autonomous maneuvers.

Each “MuCCA” vehicle was equipped with the OBU, which was responsible for controlling the lateral and longitudinal movement of the vehicle, localize the respective vehicle’s position, and interact with other nearby “MuCCA” vehicles using V2V technology.

Achieving real-time cooperation required significant flexibility, as it required tailored V2X communications which was not achievable with official messaging standards available at the time. Having such flexibility in the OBU allowed the team to experiment with communication parameters and messaging protocols [5] to achieve demonstrable cooperative behavior [7]. An example of the cooperation can be seen in Figure 3, the obstacle (red) is a car that has broken down and both cars (right in image) cooperatively plan and agree a course of action using direct V2V technology, and both vehicles autonomously execute the action without driver intervention.

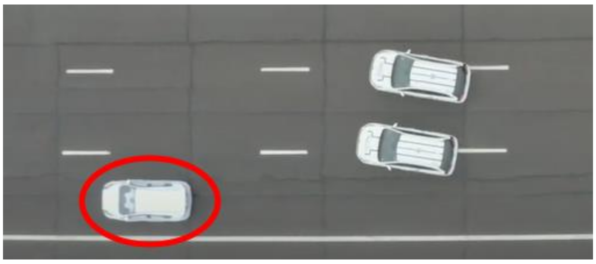

Figure 3. MuCCA V2V Cooperation

Another example of real-time cooperation can be seen in Figure 4, a simulation of “MuCCA” vehicles working together. Each vehicle in the simulation is connected with an OBU that is communicating its trajectory plans with all the others OBUs. In this way the “MuCCA” algorithm, which is not specific to only two vehicles, is able to draw a scenario in real time to avoid collisions.

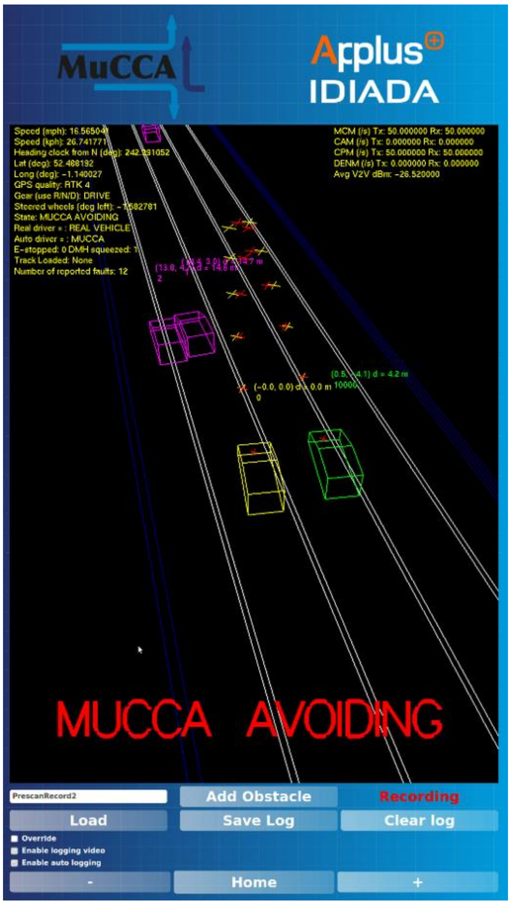

Figure 4. MuCCA V2V Cooperation

SECUREIOT – The SecureIoT project [8] (funded by the European Union under the Horizon 2020 framework program) aimed to offer a cross-industry Security as a Service (SECaaS) offering to sectors within IoT market. IDIADA led the automotive element of this project which used the OBU as a device embedded in the vehicle with the capability of interacting with cloud-based services. The role of the OBU was to collect data from a variety of vehicle sensors, process the data locally and upload data to an IoT cloud service. In addition to vehicle specific data (such as performance information, vehicle speed, braking conditions, etc.) low level metrics such as CPU / RAM metrics, vehicle CAN bus metrics, network performance metrics were also collected on the OBU and uploaded to the project's Security as a Service (SECaaS) deployment for analysis. To test the security detection mechanisms from the project, malicious and erroneous data was injected at the vehicle network level, OBU application level and Edge level. Performing this type of research with commercial vehicle systems is not safe as demonstrated by Miller and Valasek [9], however the OBU allowed the freedom to manipulate the vehicle data and make introduce complex attacks without compromising the safety of the vehicle system. Such attacks included V2X messaging manipulation and the Figure 5 shows the vehicle's GPS position (orange) on the road, while the vehicle's V2X message containing information about the vehicle's position (shared with other nearby vehicles) can be seen (blue). This compliments the MuCCA project presented earlier, as MuCCA relies on accurate information received from other nearby vehicles to coordinate manoeuvres, when in fact the vehicle is really in one position (orange) but informing nearby vehicles it's in another (blue) position around 20 meters to the left.

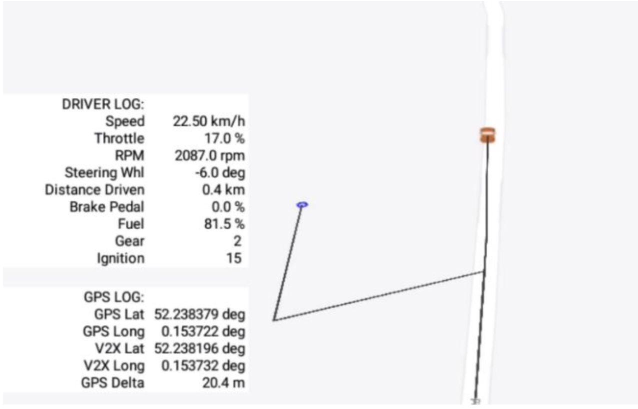

Figure 5. V2X / GPS Position Manipulation

ENSEMBLE – The ENSEMBLE project [10] (funded by the European Union under the Horizon 2020 framework program) is developing multi-brand truck platooning. Platooning of vehicles refer to road trains that due to the use of connectivity can establish fixed, safe but short distances between vehicles with the potential to reduce fuel consumption thanks to the aerodynamic benefits (see Figure 6).

Figure 6. Truck platooning – "Source [10], 2020"

ENSEMBLE tackles the traditional fragmentation and non-interoperability between brands which stalls large scale deployment of this very promising technology.

These multi-brand test will take place in IDIADA (the leader of the validation activities within this project in which will have to test the platooning performance at functional but also communication level) test tracks in Spain and will make use of the deployed communications infrastructure to interact with the platoon as well as monitor its performance.

An additional public road test campaign will take place in Spanish roads. The OBU will be used in this context as an advance data-logger, not just of the V2X communications but also of other external sensors.

VRAIN (Vehicular Road Awareness Intelligent Network) – The VRAIN system [11] was developed as a vehicle agnostic V2X warning system. The OBU provided independent GNSS and V2X communications to the vehicle and implemented a longitudinal and lateral collision warning application to communicate with nearby vehicles and infrastructure. An HMI (Human Machine Interface) was installed in the vehicle which informed the driver of any hazards, such as a lane change warning if a nearby vehicle was approaching too fast in an adjacent lane. This system was designed to utilize emerging connectivity technology to improve test track safety. In Figure 7, the HMI can be seen alerting with a red indication a vehicle that is approaching at high speed.

Figure 7. Project VRAIN

C-MOBILE – The C-MobiLE [12] [13] project (Accelerating C-ITS Mobility Innovation and depLoyment in Europe), funded by the European Union under the Horizon 2020 framework program, is the leading initiative in Europe for the deployment of Cooperative Intelligent Transport Systems (C-ITS) services in urban environments. C-ITS, using connectivity and IT infrastructure, enables new mobility concepts and a safer driving experience through the sharing of trustful, in-time information to the drivers (the vehicle in CAV), road traffic authorities and mobility service providers. IDIADA is the coordinator of this EU funded project and leads the implementation, deployment and evaluation of the piloting results of 7 C-ITS applications in the city of Barcelona, which is one of the 8 European cities (see Figure 8) working together in this project.

Figure 8. C-MobILE deployment sites

These C-ITS applications and services can run in a mobile phone but the greatest achievement is the back office where all the information coming from the municipality, as well as third parties (taxis, firefighters, ambulances, tunnel control systems, traffic control centers) is aggregated and served, where appropriate and when relevant, to the end users.

V. CHALLENGES

There are many challenges foreseen for the integration of connected and automated mobility in our roads. Some of them have a technical nature while others are more related to legal, economic and user acceptance. As a non-exhaustive list, we have considered the following ones:

INTEGRATION IN SMART CITIES – Seamless integration of CAV technologies in the public and private transportation system is paramount. A lot of efforts and synergies must be appropriately coordinated to give a legal, trustworthy framework for the deployment of automation. Data management and delivery is critical for its success. The C-MobILE project is demonstrating the feasibility and benefits of C-ITS application in a urban environment as a milestone for fully automated vehicles.

STANDARDISATION AND INTEROPERABILITY – Two technologies can provide the necessary bandwidth, latency and scale required by the automotive and mobility sectors: 802.11p protocol stacks (WAVE in US / ETSI-G5 in Europe) and C-V2X protocols (based in cellular technology). Although both technologies can coexist for long range communications, it is when we are considering short range ones that incompatibilities appear. Currently some world regions are already making some decisions (e.g. China has chosen a C-V2X approach), while others still are deciding which one should be chosen (e.g. EU and US).

FUNCTIONAL VALIDATION AND PERFORMANCE ASSESSMENT – How do we know when a connected and automated vehicle is safe enough? This is one of the key challenges for automation. European projects like the EU funded HEADSTART (Harmonized European Solutions for Testing Automated Road Transport) project is developing a harmonized methodology to make this validation and performance assessment [14]. The MUCCA, VRAIN and ENSEMBLE project are examples about how connectivity should be addressed in the context of vehicle automation.

BUSINESS MODELS AND USER ACCEPTANCE – We still need to fully build a business model for connected vehicles beyond safety features. Several initiatives (e.g. C-MobILE and ENSEMBLE) are working in this direction. However, it is important to build a market that is self-sustainable while providing the very promising benefits of its deployment. How to monetize data while maximizing user acceptance of these technologies are the key parameters to be considered.

SEAMLESS INTEGRATION WITH VEHICLE AUTOMATION – Connectivity has its own market, however its merging with automation would bring both technologies to its optimal path. However, this integration must reconcile safety and effectiveness of the solutions, going beyond a simple addition of features. The MuCCA and the VRAIN project make use of a same development unit (the OBU) but followed different integration objectives.

VI. CONCLUSION

CAV R&D is an ever-expanding landscape of complexity as development progresses further towards SAE level 5 autonomy. The level of robustness in these systems and technologies are key in bringing these features into the public domain. As the computing power increases and size of chips decreases in size and cost over time, the need for CAV R&D is instrumental in pushing boundaries and enabling innovative solutions that work towards robustness and safety.

The OBU IDAPT provides a platform of which will enable these ideas and solutions. The MuCCA project was the first time V2X and autonomy was combined to achieve multi-vehicle synchronous movement to avoid a collision, not achievable with human drivers. The ENSEMBLE project is closing the gap between different implementations of the communication protocols in order to maximize platooning technology deployment in open roads. The VRAIN is an example of how connectivity can improve road safety in a straightforward, non-intrusive way. The C-MobILE project is a leading project in Europe for the deployment of connected vehicle services in urban environments and researching the best approaches to massively deploy these services in cities worldwide.

Finally, some challenges for Connected and Automated Vehicles were presented. Some of the previous initiative are already working to answer them and provide exploitable results to the industry, the academia and the policy makers to support their development and deployment efforts. Global partners to the automotive industry are committed to these objectives and we strongly believe this is the future of the automotive and mobility sectors.

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