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Review article

Perception, information processing and modeling: Critical stages for autonomous driving applications

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A B S T R A C T

Over the last decades, the development of Advanced Driver Assistance Systems (ADAS) has become a critical endeavor to attain different objectives: safety enhancement, mobility improvement, energy optimization and comfort. In order to tackle the first three objectives, a considerable amount of research focusing on autonomous driving have been carried out. Most of these works have been conducted within collaborative research programs involving car manufacturers, OEM and research laboratories around the world. Recent research and development on highly autonomous driving aim to ultimately replace the driver's actions with robotic functions. The first successful steps were dedicated to embedded assistance systems such as speed regulation (ACC), obstacle collision avoidance or mitigation (Automatic Emergency Braking), vehicle stability control (ESC), lane keeping or lane departure avoidance. Partially automated driving will require co-pilot applications (which replace the driver on his all driving tasks) involving a combination of the above methods, algorithms and architectures. Such a system is built with complex, distributed and cooperative architectures requiring strong properties such as reliability and robustness. Such properties must be maintained despite complex and degraded working conditions including adverse weather conditions, fog or dust as perceived by sensors. This paper is an overview on reliability and robustness issues related to sensors processing and perception. Indeed, prior to ensuring a high level of safety in the deployment of autonomous driving applications, it is necessary to guarantee a very high level of quality for the perception mechanisms. Therefore, we will detail these critical perception stages and provide a presentation of usable embedded sensors. Furthermore, in this study of state of the art of recent highly automated systems, some remarks and comments about limits of these systems and potential future research ways will be provided. Moreover, we will also give some advice on how to design a co-pilot application with driver modeling. Finally, we discuss a global architecture for the next generation of co-pilot applications. This architecture is based on the use of recent methods and technologies (AI, Quantify self, IoT ...) and takes into account the human factors and driver modeling.

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1. Introduction: contextual elements on autonomous driving

We have witnessed, in the last four decades, the development of Advanced Driver Assistance Systems (ADAS), automated driving systems and Intelligent Transport Systems (ITS). Most of these systems have been developed within the framework of numerous research projects and programs that bring together car manufacturers and research laboratories around the world.

Until very recently, these systems could be seen either as informative or as active short term assistance with short range information. Now, with the challenge of highly autonomous driving, research and recent developments attempt to answer to the highest autonomy level in order to completely remove the driver's driving task.

ADAS are designed to improve safety by avoiding collision and minimizing energy consumption followed by providing comfort to the vehicle's occupants.

More recently, ADAS have clearly appeared as the most important and critical step to converge towards either semi-automated or fully automated vehicles.

In order to undertake the challenges of driving automation and to provide an intelligence level in order to autonomously perform a range of driving tasks, it is mandatory to use a set of processing functions, algorithms, and applications as shown in Fig. 1. These functionalities allow perceiving, predicting and estimating the state of the road scene. These key components can be classified into 5 main categories: obstacles (dynamic, static, vulnerable, non-vulnerable), road attributes and free driving zone (road marking, number of lanes, intersection …), ego vehicle (positioning and dynamic state), environmental conditions (weather conditions, vertical road sign …), and the driver (biological and psychological state, current actions …).

The estimation of the current or predicted state as well as their interactions creates the potential to build local or extended dynamic perception maps (see Fig. 2). Automated driving requires accurate, reliable, and robust information about the first four key components.

Table 1 provides an overview of a part of the data extracted from the sensors data processing for these main key components.

These partial or fully automated systems can be classified along three types of purposes: (i) mobility functions, (ii) safety functions, and (iii) energy management functions.

A mobility function (i) is intended to make the navigation or the driving tasks easier and more comfortable for the driver while minimizing "travel time", "distance", or "a geographical goal" for example. The technologies required in this category of applications include Adaptive Cruise Control, Parking Assist and Lane Keeping Assist.

On the other hand, many driving assistance systems have been developed more specifically to improve the user safety aspect (ii). This began with the anti-lock braking system (ABS) in the 1960/1970s, then the electronic stability control (ESC) in 1995. Finally, in the last decade, many other more complex emerging embedded systems have been sold on the mass market. We can cite, for example, a lane departure alert in 2001, and emergency brake automation (AEB) for collision impact mitigation in 2003.

Regarding the consumption aspect (iii) the main issue is to identify and implement the most relevant strategies to minimize the consumption of energy (gasoline or electricity).

In all cases, these three issues are interdependent. In order to optimize the consumption aspect (iii) one has to act on the mobility and comfort strategies (i), and by acting on the mobility strategies we will have an impact on the level of security (ii). In addition, to ensure a higher level of autonomy, it is important to manage the energy available in the vehicle. So, multi-criteria optimization approaches and adaptive strategies have to be implemented in order to find the best balance between the three issues.

Most of the systems mentioned above are now available on mainstream vehicles and not just on luxury vehicles. In 2015, the main ADAS included in consumer vehicles were parking assistance with ultra-sonic sensors, driver's view enhancement around the vehicle during parking due to multiple cameras, and adaptive cruise control (ACC). The state of current research clearly shows that we are very close to embedded systems enabling partial automation during low-speed driving in heavy traffic situations.

The ADAS market of the current decade is mainly composed of the functionalities explained in Table 2.

Most of the applications listed in Table 2 are commercialized by OEM suppliers such as Valeo, Continental, ZF, TRW, Delphi, etc.

Many suppliers propose systems to support lane keeping applications and active lane departure avoidance.

It is the same for the Park Assist service from Daimler which proposes using RADARs to detect vehicles parked on the roadside and identify potentially free parking zones. For the same application, Valeo is working on a full autonomous parking valet (Park4U) allowing the car to park by itself and have a call mechanism so that it returns to the driver autonomously.

With the increasing number of these embedded systems and the improvement of their capacities, reliability and robustness, the situation is progressing rapidly towards automated driving with the main objective to replace the driver in the driving task.

This can be problematic, in case of unmanageable situations or failure of the automated control system due to sensors, actuators, electronic equipment, software error or breakdown, because the system should be able to quickly warn the driver. To limit the risk level in this machine/human transition situation, it is necessary to predict and anticipate these situations in order to alert the driver sufficiently ahead of time to allow him to take over the control of the car. Currently, the management of this machine/human

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