Toward Intelligent Driver-Assist Technologies and Piloted Driving: Overview, Motivation and Challenges

Plenary paper

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Abstract— **In this paper we present an extensive literature review on the research progresses in Intelligent Driver-Assistance Systems (IDAS). IDAS monitor the car's environment and driving behaviour to identify and avoid a potentially dangerous situations at an early stage without human input. Based on intelligent sensor fusion technology with full or partial context-aware autonomy in decision-making IDAS aim to combat obstacles in a traffic scene using various advanced control systems such as Adaptive Cruise Control, Collision Avoidance System, Driver Drowsiness Detection System, Parking Assistance System, Lane Departure Warning System. Several adaptive safety control systems have been proposed and discussed as well as their interoperability issues to address different aspects in road situation analysis. Any autonomous advanced control system manufacturers launches should be selectable by the driver. In addition, the implementation complexity is analyzed. At the end of the paper we envision some research directions. To the best of our knowledge series-built vehicles with a piloted driving function will be technically feasible this decade over the next two to three years period.**

Keywords-autonomous; driver-assist; piloted driving

I. INTRODUCTION

The automotive industry has been moving toward more autonomous vehicles (AVs) over the past few years. Autonomous technology is a technology which is installed on a motor vehicle and which has the capability to drive the motor vehicle without the active intervention or monitoring of a human operator. The term does not include an active safety system or a system for driver assistance IDAS, including, without limitation, a system to provide Adaptive Cruise Control (ACC), Collision Avoidance (CA), Electronic Blind Spot Detection (EBSD), Emergency Braking (EB), Lane Keeping Assistance (LKA), Lane Departure Warning (LDW), Parking Assistance (PA), Traffic Jam Assistance (TJA), or other similar systems that enhance safety or provide driver assistance, unless any such system, alone or in combination with any other system, enables the vehicle on which the system is installed (also called autonomous, self-driving, driverless or robotic) to be driven without the active control or monitoring of a human operator over roads that have not been adapted for its use [1][2]. Many different competing teams by major commercial manufacturers or universities are engaged in research in this area, serving as a backbone for improving the AV technology further. With each subsequent year, the winner of the race raises the bar toward truly AVs one step higher. Companies that currently developing self-driving cars include Audi, BMW, Ford, Google, General Motors, Volkswagen and Volvo. Those AVs are still in development stage but the technology is starting to show up in consumer market as well as receiving widespread media attention. As of beginning of 2013, we have AVs that have driven autonomously for hundreds of thousands of miles. By April 2014, Google's AVs collectively have logged over 700.000 miles on city's streets and highways without a single accident attributable to the automation [3].

A. *Safety*

There are numerous reasons for bringing AV technology into people's everyday-life. The first and most important reason is safety. Proponents of electronic driving aids in AVs claim they would eliminate accidents caused by driver error, which is the primary cause of almost all traffic accidents. According to the World Health Organization (WHO), worldwide there are 1.3 million road traffic fatalities and over 20 million serious injuries per year [4]. Based on a literature survey, Smiley and Brookhuis (1987) concluded that more than 90 percent of all traffic accidents are caused by driver failure via inattention, fatigue or drowsiness. As an example, a retrospective research recently showed that applying brakes half a second earlier in a car traveling at 50 km/h can reduce the crash energy by 50 percent, but also showed that 40 percent of drivers didn't activate or apply effectively brakes before the collision. Research clearly shows that conventional fully human-driven vehicles pose a considerable safety risk. According to researchers, with use of IDAS, 50 percent of serious road traffic accidents could be avoided [5].

B. *Economic and Social Impacts*

The introduction of AVs could significantly ameliorate economic losses and negative social consequences from traffic accidents, as well as economic losses and environmental damage from traffic congestion. AVs certainly hold the potential to disrupt a number of Industries with high stakes in this rapidly evolving market: Automotive, Insurance, and Healthcare to name a few. Simultaneously, an opportunity arises for innovative firms to introduce a scale of creative new business models. Companies engaged in automotive software development for in-car applications will boom. The semiconductor market for IDAS will grow significantly in the foreseeable future, according to IMS Research's automotive semiconductor study. For instance, the microcontroller (MCU)/DSP market in IDAS applications was $70 million in 2011 and is estimated to rise to $150 million by 2018. To achieve economies of scale, IDAS must be targeted also at mid and low-end vehicles segments. IDAS would allow drivers and passengers now with new time on their hands to do other things while traveling such as working, relaxing or sleeping. Speed limits are likely to be raised significantly. Furthermore, use of IDAS could dramatically improve traffic flow, eliminate or reduce traffic collisions, cut insurance costs, while fuel economy from congestion avoidance and more efficient long-distance cruising are big potential bonuses. According to a report from investment bank Morgan Stanley, AVs can contribute $1.3 trillion in annual savings to the U.S. economy alone, with global savings estimated at over $5.6 trillion.

From a marketing point of view, driver comfort also poses a strong impetus for the development of IDAS. Commercial car manufacturers invest substantial effort in the development and improvement of comfort enhancing electronic features such as navigation, ACC and PA systems. Studies show that drivers identify with the contributions of immersive experience and enjoyment from increasing interaction while using these new technologies.

This paper is organized as follows. Below, in section II, we will give a description of the IDAS and the functional blocks that comprise it. Section III concludes the paper and presents future development directions.

II. Intelligent Driver-Assistance Systems (IDAS)

IDAS are considered a key technology when it comes to moving toward accident-free driving. IDAS monitor the car's environment and driving behaviour to identify and avoid a potentially dangerous situations at an early stage without human input. Based on intelligent sensor fusion technology with full or partial context-aware autonomy in decision-making IDAS aim to combat obstacles in a traffic scene in a non-intrusive and naturalistic manner using various advanced control systems. IDAS features are either built into cars or available as add-on packages. Bolstered by increasingly powerful and affordable sensors, vision/camera systems, car data networks, sophisticated algorithms, these invisible multi-tasking co-pilots will redefine the nature of driving. Next-generation IDAS will increasingly utilize wireless network connectivity improving Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication. Before introducing any IDAS feature, every component of the same must be certified and the consequences of such system use should be identified.

A. *Current Trends in IDAS Design*

In order to process multiple algorithms in parallel and develop a scalable architectures, IDAS designers are increasingly turning to FPGAs and PSoCs (Programmable SoC) [6]. FPGAs present a compelling viable alternative to IDAS design compared to fixed-function devices. FPGAs provide IDAS designers capability to quickly customize the I/O structures, hardware and data pipeline to be optimized for a specific algorithm as well as faster time to market, lower risk and cost of ownership than standard ASIC (Application-Specific Integrated Circuit) and ASSP (Application Specific Standard Product) approaches. The industry lacks interoperability specifications for laser, radar and video data in the car network. Also lacks standards for embedded vision-processing algorithms. For instance, commercial manufacturers use multiple data communication standards for audio-video data, such as MOST (Media Oriented System Transport), Ethernet AVB, and LVDS. IDAS must support a mass of interfaces to ensure adoption across a spectrum of possible interfaces. Most important requirements of IDAS includes:

- Higher levels bandwidth and performance for processing video streams from multiple cameras.
- Real-time processing due to multitude of sensor inputs.
- Transmit, receive, and translate between multiple communication standards.

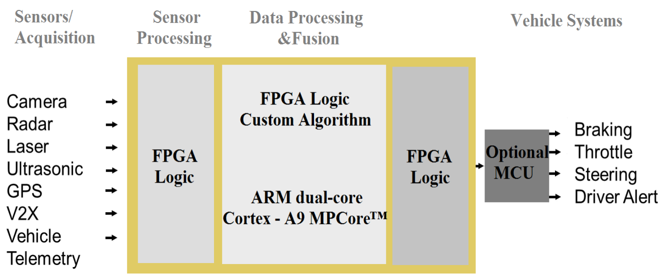

Figure 1. An example of PSoCs based IDAS architecture

B. *Digital Sensors*

Intelligent data fusion technology also known as the car's Artificial Intelligence (AI) use a probabilistic approach aggregating and analyzing many sensor readouts into a combined assumption. IDAS can respond to dangerous situations using actuators roughly 1000 times faster than humans on average, and with potentially far greater precision. By comparison, even the professional drivers can only react within about ½ second to new stimuli, while average human reaction time is over second under most driving circumstances [7]. State-of-the-art AVs use a variety of sensors such as:

1. Multi Purpose Camera – Offering megapixels resolution, monitor driver eye/face inside of car,

lane markings by spotting the contrast between the road surface and the boundary lines.

2. Stereo Vision Camera – Offer three dimensional (3D) environment detection, spotting potential hazards like pedestrians and predicting where they are headed.

3. Infrared Camera – For instance, Mercedes' Night View Assist system uses two headlamps to beam invisible, infrared light onto the road ahead. A computer converts the detected IR signature information from the windshield-mounted camera and shows the illuminated image on the driver's display.

4. Radar - High-end cars are already equipped with radars, which can detect and track nearby objects. For instance, Audi's ACC with stop & go function, uses radar system which monitors the area in front of the car in a 35-degree field of view and at a distance of up to 250 meters. Two radar sensors in the rear monitor events behind the car at a distance of up to 70 meters.

5. LIDAR – Google's AVs uses rooftop mounted Light Detection and Ranging system, which uses 64 lasers, spinning at upwards of 900 rpm, to generate 360° real-time map of the vehicle's surroundings.

6. GPS - Provide vehicle's geo-location information and navigation capabilities.

7. Wheel Encoder – Google's AVs uses wheel-mounted sensors which can measure the velocity of the car as it maneuvers through traffic.

Below is an example of how Google's cars work fusing multiple sensor inputs [8]**:**

- The driver sets a destination. The car's software calculates a route and starts the car on its way.
- A rotating LIDAR sensor monitors a 60-meter range around the car and creates a dynamic 3D map of the car's surroundings.
- A sensor on the left rear wheel monitors sideways movement to detect the car's position relative to the 3D map.
- Radar systems in the front and rear bumpers calculate distances to obstacles.
- Artificial Intelligence (AI) software in the car is connected to all the sensors and has input from Google Street View and video cameras inside the car.
- The AI simulates human perceptual and decision-making processes and controls actions in driver-control systems such as steering and brakes.
- The car's software consults Google Maps for advance notice of things like landmarks and traffic signs and lights.
- An override function is available to allow a human to take control of the vehicle.

Due to the diverse characteristics of driving sensors may fail. IDAS must function under a variety of weather and lighting conditions. For instance, if the vision based system detects that the camera lens is occluded it can warn the driver that it is currently in non-operational mode. Fusing multiple sensor inputs can often provide a more effective solution than using a single in isolation. It will be critical for IDAS to have reliable and cost-effective internal feedback algorithms that can detect electrical or physical damages of these sensing components. A sensor that fails to provide new updates is easily detected, but a sensor that occasionally sends bogus data may be more difficult to detect.

C. IDAS Technologies – Several Examples

1) Adaptive Cruise Control (ACC)

Today's ACC relies on radar or laser technology. The system regulates the vehicle's speed and distance to the vehicle ahead [9][10]. ACC enables car's speed synchronization, adjust smooth lane change, reduces the number of sudden accelerations and decelerations and reduce accident possibility [11]. For instance, Audi's ACC with stop & go function uses one or two radar sensors at the front of the vehicle to detect the reflections of objects as far as 250 meters away from the car. The driver can adjust the distance to the car ahead and the control dynamics in multiple levels. After stopping at a traffic light, it automatically drives off and follows the vehicle ahead and conversely after a longer stop, the driver must tap the accelerator pedal or activate the control stalk to resume driving. ACC with stop & go function interacts with other IDAS to continuously analyze all of the car's surroundings. The system uses knowledge base to recognize complex scenarios and offer early stage support to the driver. Because it also works together with the optional Multi Media Interface (MMI) navigation plus, it knows the course of the selected route and can use this information to regulate the car's speed. Car manufacturers typically offer a number of versions of ACC for different model series.

2) Lane Departure Warning (LDW)

LDW alerts the driver when the car begins to unintentionally stray from its lane without obvious input from the driver (for instance, due to driver's distraction or momentary lapse in concentration) [12]. Lane Keeping Support (LKS) help to counteract unintentional drift out of the marked lane by the driver, typically via audio alert or haptic warning. Both systems make use of a video camera to detect lane markings ahead of the vehicle by analyzing differences in contrast between the road surface and the lane markings. The car's position in the lane is then compared with additional information taken from the steering angle, brake and accelerator position sensors and whether or not the indicators are in use [12][13]. LDW and LKS rely on visible lane markings, hence faded, missing, incorrect, markings covered in snow or ice can hinder the ability of those systems.

3) Parking Assistance (PA)

The system finds parking spaces using ultrasound sensors and/or video cameras that scan the side of the road in two dimensions while driving at moderate speed. When system detects a space of sufficient size, it executes a near-perfect reversing maneuver while the driver operates the accelerator or brake pedal. The PA will maneuver forward and back multiple times and also help driver when leaving parallel parking spots. Visual (via the central display) and acoustic signals that feature in the PA warn the driver of any obstacles.

4) Collision Avoidance (CA)

The system typically uses radar, laser and/or video sensors to detect an imminent crash. CA allows the driver to take appropriate corrective actions in order to mitigate, or completely avoid the collision event, or furthermore, takes action autonomously without any driver input by braking, steering or both [14]. CA detects proximity of other vehicles or pedestrians in surroundings, how much vehicle's speed needs to be reduced and how close the vehicle is going off the road. Some of the precaution measures include: tension of the seat belts, moving optional memory seats forward to protect the car's occupants, closing of the car's sunroof, closing of any open windows, partial or full braking, pedestrian detection, warning occupants through a buzzer.

5) Driver Drowsiness Detection

The system prevents accidents when the driver is getting drowsy. Driver fatigue ("falling asleep at the wheel") is a major cause of road accidents, accounting for up to 50% of serious accidents on motorways and monotonous roads. The Driver Warning System (DWS) uses different acoustic, visual and haptic signals to alert the driver against his drowsiness which prevents from accidents [15].

6) Night Vision Asisstant (NVA)

NVA increases a driver's visual perception in darkness or poor weather conditions beyond the reach of the vehicle's headlights. For example, Audi's NVA uses thermal imaging camera with a 24-degree angle of aperture at the front of the automobile. It works in the Far Infrared Range (FIR) which can look up to 300 meters ahead, and reacts to the objects radiated heat. A computer converts the information from the camera into black and white images and shows them on the driver information system's central display, if desired. If the system predicts a potentially dangerous situation because a person or animal is crossing the road in front of the car, for example, the person is marked in red and a warning tone sounds. The brake system is conditioned at the same time [16].

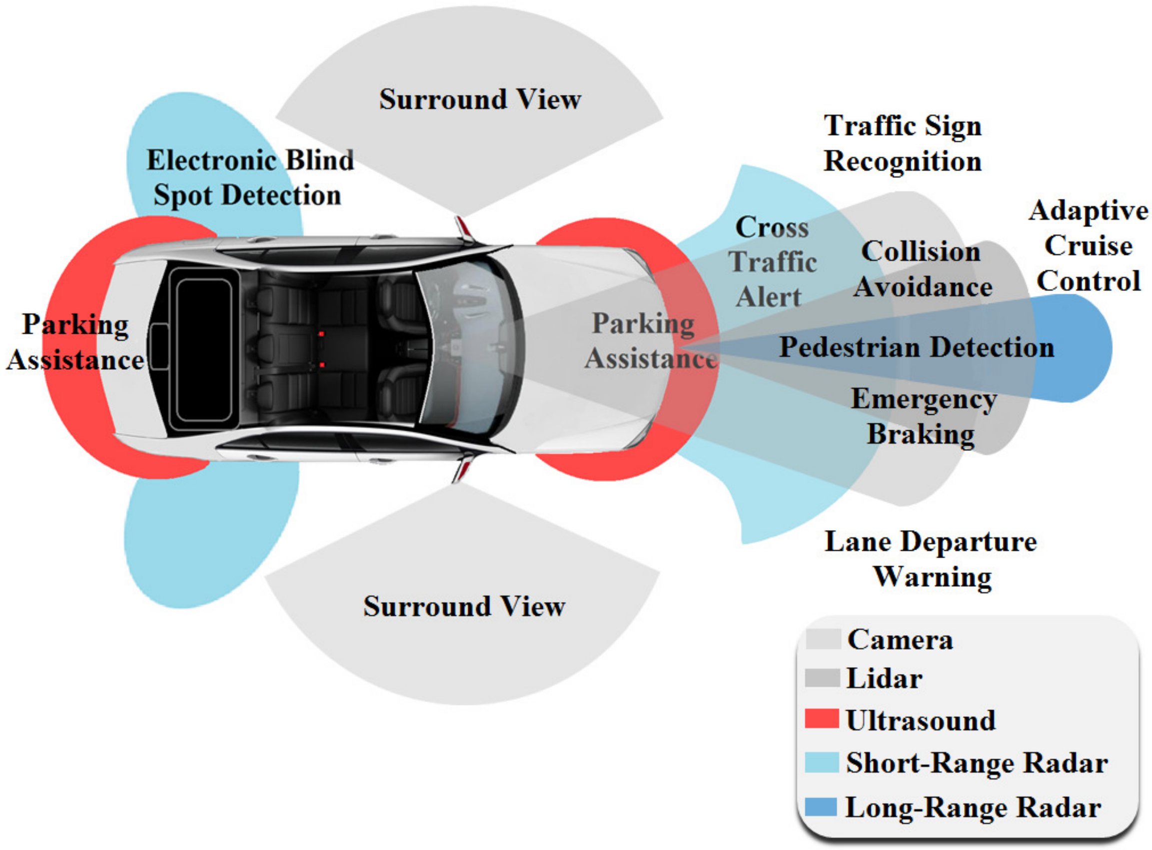

Figure 2. IDAS & sensors

III. CONCLUSION

IDAS is one of the fastest growing segments in automotive industry. In IDAS, sensors and sophisticated algorithms are combined to identify the vehicle environment so that the driver can receive assistance or be warned of potentially dangerous situations at an early stage. The research is based on numerous interviews with commercial manufacturers and a through literature review. After conducting a survey we determined that the benefits of the technology outweigh the disadvantages so IDAS should be encouraged when it is superior to an average human driver.

The social and economic implications of the IDAS are enormous. Increased safety awareness as well as government's legislation presents a driving force contributing to the IDAS market growth. IDAS features have already become established in luxury, mid-range and compact cars. Automotive OEMs need to deploy advanced IDAS technologies in their next-generation models in order to achieve five-star safety ratings as mandated by car's safety organizations such as New Car Assessment Program (NCAP). Since these systems are very similar with the systems that are used in AVs prototypes, they are regarded as the transition elements on the way to the implementation of fully AVs.

IDAS are currently used to increase safety in speed zones where driver error is most common: at lower speeds, traffic congestion, and at higher speeds as cruising on a highway for instance. There are some improvements required to be done in the future. It is expected that next-generation IDAS will likely offer greater vehicle autonomy at lower speeds and may reduce the incidence of low-impact crashes. Recent reports show that Audi's new autonomous driving system, dubbed "Piloted Driving", will debut on its luxury A8 sedan around the year 2016. The Mercedes system, dubbed "Steer Assist," is able to autonomously drive in traffic and on highways at speeds of up to 124 mph. Automotive supplier Bosch has also announced that at least one of its customers will be using its autonomous driving technology in 2014. Bosch's system is designed for heavy traffic and works at speeds of up to 30 mph.

"AVs are inevitable. It's only a matter of time," says Andrew Chatham, senior staff engineer and off-board software lead of Google's self-driving car program.

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