Advanced Driver Assistance Systems (ADAS)

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Introduction

A driver is one of the "best sensors in the vehicle" and is the main responsible for avoiding crashes. But still, a large proportion of crashes are attributed to the driver errors. A survey was conducted to identify the critical reason for each crash, and the national sample of US crashes from 2005 to 2007 was examined [1]. It was noted that the driver error was the critical reason contributing to 94 percentage of crashes as shown in Fig. 1. These errors included recognition errors, decision errors, performance errors, and nonperformance errors. Recognition errors are the result of inattention and inadequate surveillance of the driver; decision errors arise due to the misjudgments of the driver; performance errors arise due to overcompensation, poor directional control, etc.; and nonperformance errors arise due to sleeping and fatigue [2].

The development and deployment of the new in-vehicle technologies to counteract these driver errors and hence to support the driver to prevent crashes is ongoing. Advanced driver assistance systems (ADAS) are a group of vehicle technologies that warn the drivers timely regarding the risky or hazardous situations to avoid crashes. Some ADAS technologies actively and automatically intervene to avoid hazardous situations or when the system detects that a crash is imminent.

ADAS technologies are the precursor to autonomous vehicles and, depending on the combination of ADAS equipment installed in a vehicle, can allow level 1 to level 2 autonomous driving at the present time as represented in Fig. 2 (SAE International 2014).

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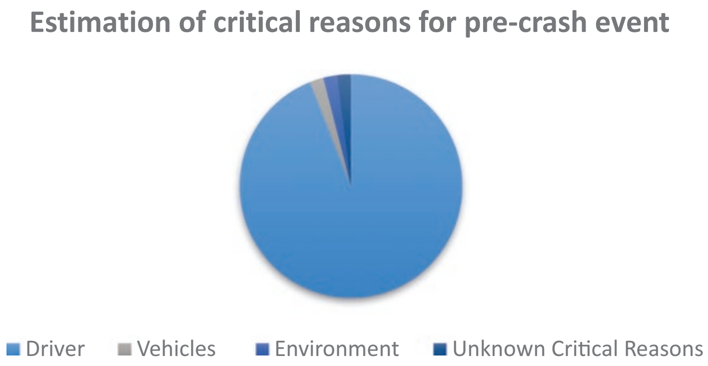

Fig. 1 Estimation of the critical reasons for pre-crash event. Data source: NMVCCS 2005–2007

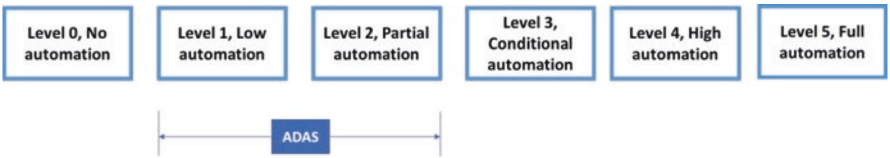

Fig. 2 Levels of autonomous driving as per the SAE classifications and ADAS role in the automation

ADAS Technologies

Driver assistance systems (DAS) were developed aiming at the development of systems that are designed to assist and improve the comfort level of the driver while driving. Initial systems developed as driver assistance systems include parking assistance system (PAS) and cruise control (CC). With the advancements in DAS technologies, the focus got shifted on to the increased level of safety of both the driver and pedestrians. Such advanced driver assistance systems (ADAS) refer to electronics, light-based, or sound-based systems that are integrated together to the development of technologies that automate, facilitate, and improve systems in the vehicles in order to assist drivers for better and safer driving. There are numerous components now developed to be known as ADAS technologies. A complete overview of the features of ADAS technology is shown in Fig. 3.

Various ADAS technologies in a vehicle are realized with the help of many types of environment sensors such as radars, lasers, ultrasonic sensors, and cameras. These systems are equipped with control algorithms that signal the drivers or directly control the brakes or throttles. The control systems of the vehicle with ADAS will behave based on the signals from the environment and according to the state of the vehicle such as steering angle, GPS data, etc. or state of the driver. The ADAS technologies used in modern cars are described in short as below:

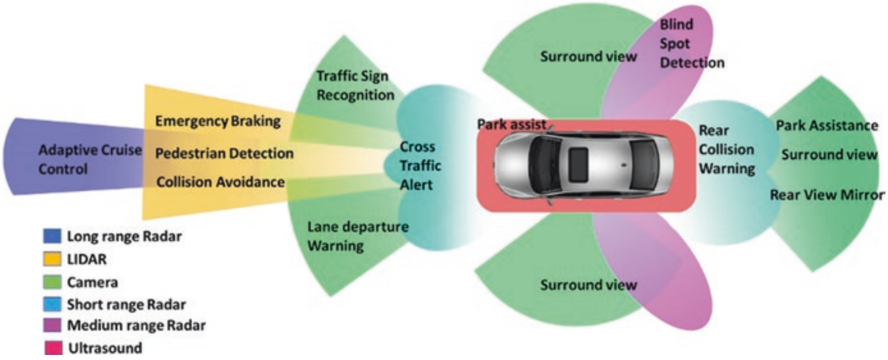

Fig. 3 Overview of ADAS technologies used in a vehicle

Adaptive cruise control (ACC) also known as radar cruise control is a system developed to control or adjust the speed of vehicle to maintain an optimum distance between the vehicles with the help of a radar or a laser system. In ACC, three radar sensors are needed, two short-range radars used to detect objects in the adjacent lane and one with a long range used to detect objects in-path.

Forward collision control with autonomous emergency braking alerts the driver when the speed of the vehicle can result in a collision with a vehicle or an object in front. Autonomous braking (AEB) will prevent collision by applying brakes when there is a high risk of collision and the response of the driver is inadequate to avoid the collision.

Lane departure warning systems give warnings to the driver while there is a risk or straying across the lane markings. The feature uses the long-range radar sensors for the sensing purpose. A Lane estimation algorithm is used to gather the information for lane departure warning (LDW) and lane keeping rely features for ADAS technologies.

Side- and rear-view assistant systems monitor surrounding areas to warn the driver for the blind zones with the help of cameras or radar sensors.

Traffic sign recognition displays are seen on the instrument panel reminding drivers of the current speed limit. The traffic signals are recognized with the help of the same camera which recognize the speed limits. Even the navigation system of the vehicle can be supported by storing the information regarding the speed limits in unsigned roads.

Blind spot detection (BSD) helps the driver to view the blind spots while overtaking. A short-range radar is used for monitoring the road area behind and warning the driver while overtaking the vehicles.

Rear cross traffic alert (RCTA) uses two radars that can monitor at 120 degrees and help in detecting accidents while reversing out in the parking space.

Pedestrian detection technology monitors and detects the pedestrians in the road and provides the driver the necessary safety guidelines with the help of normal and IR cameras.

Fig. 4 Steps taken in the ADAS technology

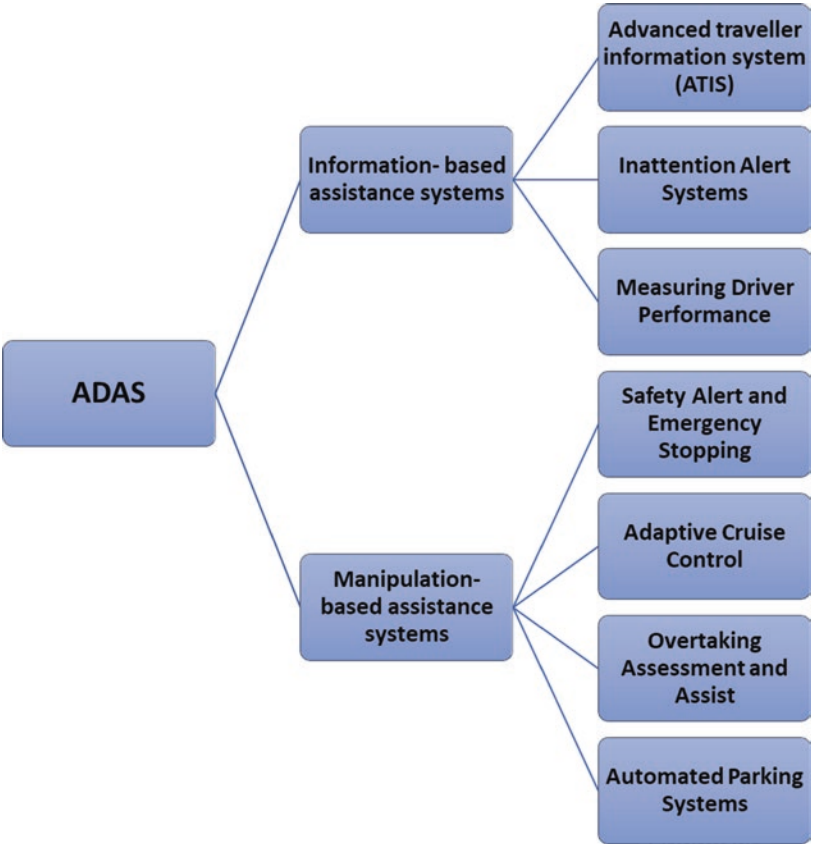

Fig. 5 Classification of ADAS technologies

In each ADAS technology, there are three steps taken as shown in Fig. 4.

1. Recognition
2. Judgment
3. Operation

The first step in the ADAS technologies is recognition with the help of sensors such as radar, LiDAR, cameras, and ultrasonic sensors. Based on the signals from the sensors, the control action is decided with the help of advanced imaging processing or machine learning algorithm.

ADAS systems are basically classified into information-based assistance systems and manipulation-based assistance systems [3]. The detailed classification is shown in Fig. 5.

Information-based assistance systems provide only necessary information and warnings to the human driver. They don't implement any driving decisions and physically operate the vehicles by small amount.

Manipulation-based assistance systems only operate on the vehicle in case of emergency or when asked by the driver.

Information-Based Assistance Systems

During driving, a lot of concerns are present in the mind of a driver regarding the correct route to be taken, the level of traffic congestion, and time delay in reaching the destination on the right time. The information-based assistance systems address all these questions, and such a system do not control the vehicle by itself. The information-based assistance systems are further classified as Advanced Traveller Information Systems (ATIS) as shown in Fig. 5.

The ATIS system performs main functions such as dynamic rerouting and anticipation of traffic congestion and provides information about the surroundings. These information helps the driver to take key decisions regarding the route to be taken. The data for dynamic and historic information about the traffic is made available with the help of the cameras at different locations at various roads. Such information is used to anticipate the congestion and reroute the traffic.

Drivers are distracted by many expected and unexpected reasons such as sleep, tiredness, fatigue, etc. These reasons can be identified by various indicators such as eye movements (blinking frequency of the eyes), head movements (yawning), biological and neurological signals (such as EEG and ECG), and facial expressions (movement of the eyes, lips, etc.)

The indicators of inattention such as distraction are measurable. The effects of distraction can be measured based on movements of the eye, head, and face and signals obtained from the driver's body such as electroencephalography (EEG) and electrocardiogram (ECG). EEG signals carry information about the brain waves and brain activities. In contrast, the ECG signals gives information on heart changes which can be used to interpret and measure the change in the thought process of the human driver.

The general procedure for detecting inattention uses the machine learning techniques. A procedure which is typically followed for the pattern recognition system is shown in Fig. 6.

As the initial step, the noise is removed from the data collected. Data is then segmented, and the feature is extracted for training and to create the machine learning model. The real-world data is then segmented, and the feature is extracted and classified based on the training data and model for the driver to take decision.

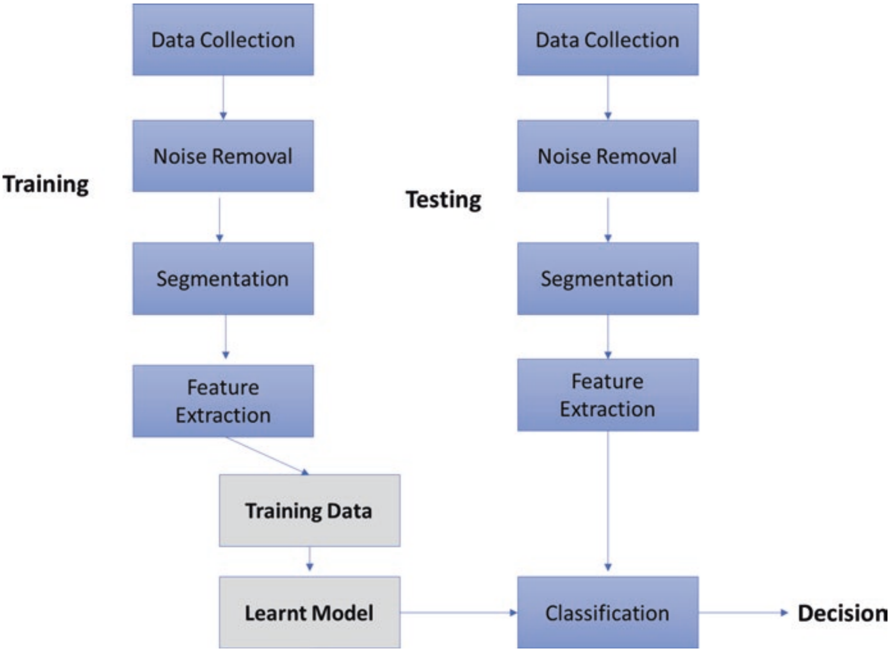

Fig. 6 Procedure used for pattern recognition problem

While detecting the images, the images are reduced in dimensionality using features like scale invariant feature transform (SIFT) and speeded up robust transform (SURF). Another possible approach is to use color filters for the detection of the face. There are numerous techniques that are used for face detection and recognition. Modelling of blinking of the eyes, gaze, and head pose was recognized in order to identify the inattention and fatigue in the drivers during driving.

The next task is to extract the features from the complete image, or signal is broken down using dimensionality reduction techniques and then can be used for classification. The techniques such as principal component analysis (PCA), independent component analysis (ICA), and linear discriminant analysis (LDA) are used for dimension reduction and extraction. Later, the classification is done with the help of popular classifiers such as neural networks, support vector machines, fuzzy inference systems, adaptive boosting algorithms, and decision trees.

Hybrid techniques are also used which include the combination of any of the above discussed techniques (Figs. 7, 8, and 9). The commonly used multiple modalities are discussed as follows:

(a) Data level fusion: Here the fusion is performed on the raw data of the different modalities. The fused data is then passed through feature extraction and classification in order to help the driver make an appropriate decision.
(b) Feature level fusion: It is fused at the feature level, and then classification is done.

(c) Score and decision level fusion: A score function is generated after classification from each data source by an integrator based on which decision is made. Here, the generated score function is fused to form the final decision.

Measurement of the driver performance is important for transportation authority to access the driver performance to extend or cancel license to drive. The systems for measuring driver performance are built inside the vehicle to continuously rate the driver's performance. The best way to indicate the driver's performance is by assessing the distances of the vehicle in front, fluctuations in speed, and the ability to make smooth lane changes and to maintain the lanes. Other parameters that can be used to measure the condition of driver are the way of handling the steering wheel, reversal speeds of steering, and pressure distribution on the seat of the driver. All these parameters are helpful in detecting fatigue and drowsiness of the driver which are continuously monitored by the ADAS technologies in the car.

Fig. 7 Data level fusion

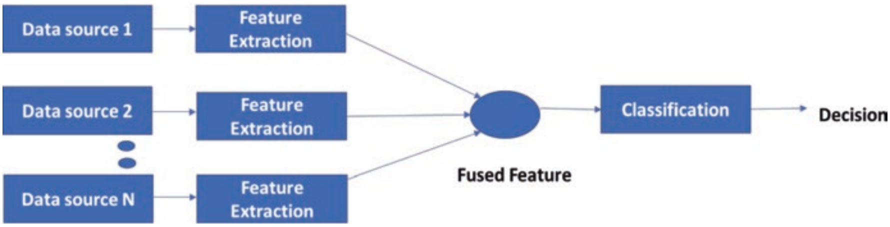

Fig. 8 Feature level fusion

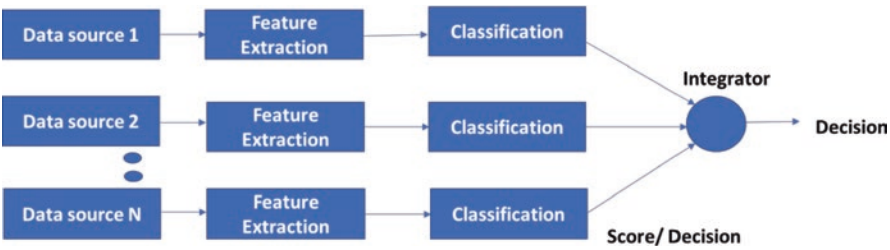

Fig. 9 Score and decision level fusion

Manipulation-Based Assistance Systems

Manipulation-based assistance systems not only detect the state or risk involved in driving but also manipulate the vehicle on behalf of the driver. These systems come into action in three situations as follows:

- When emergency actions are needed and there is no time to warn the driver
- To perform certain regular and simple tasks which do not require human wisdom
- To perform certain precise and specialized tasks that are hard for humans to perform such as overtaking and parking

There are situations where the alerting or warning of the driver is ineffective due to time constraints and there is a need of quick response in some situations to take safe action. Such situation needs to be addressed by emergency braking systems. In contrast, safety alert systems predict the risky situations and provide warnings to take necessary action. The collision avoidance system is one of the common examples to explain these systems.

Another similar problem is the collision with pedestrians, especially the old-age people and children who do not take much care while crossing the roads. There are pedestrian detection systems which detect and alert the driver to avoid collision and risks.

The adaptive cruise control (ACC) maintains the speed of the vehicle constantly by the use of brake and throttle. The driver is relieved/freed from continuously monitoring the speed by the use of ACC, and he just needs to control the steering. The sensors such as radar, LiDAR, or ultrasonic sensors will continuously monitor the distance from the vehicle and environment. While vehicle following is successful with no risk and accidents, the ACC follows an elastic band. This band is always maintained to be smooth and collision-free and tends to be the path for trajectory for the vehicle to be followed as shown in Fig. 10.

Overtaking is desirable and helps the fast-moving traffic not to be penalized by the slow-moving vehicles in the front. Overtaking assessment and assist helps in the overtaking task. It has two important tasks as follows:

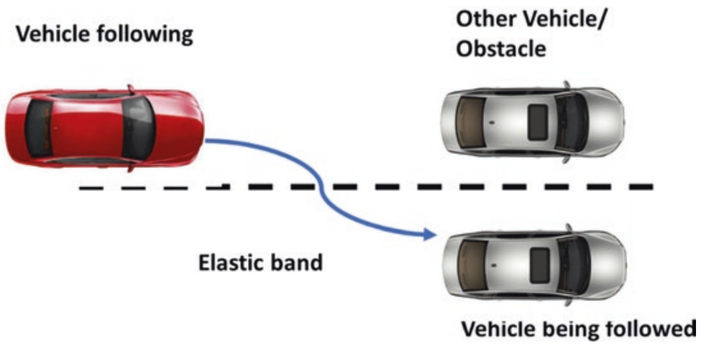

Fig. 10 Vehicle following

- Deciding the feasibility of the overtake attempt: The feasibility of the overtaking is based on the distance between the overtaking vehicles and the one being overtaken and the space in the overtaking lane
- Actual overtaking: This task requires moving the vehicle overtaking from the overtaking lane to the normal lane after overtaking as shown in Fig. 11.

One of the common problems faced by all drivers is to park the vehicle in an empty slot correctly. This problem can be solved by an automated parking system. The problem of parking resembles close to that of a robot motion planning. Some number of times, the vehicles goes back and forth before placing the vehicle perfectly in the empty slot of the parking area as shown in Fig. 12. The commonly used motion algorithms include rapidly exploring random trees, graph search, and many more [4].

Sensors Used in ADAS Technology

Various sensors are used in implementing the ADAS technology. Some of the main sensors are described in detail below:

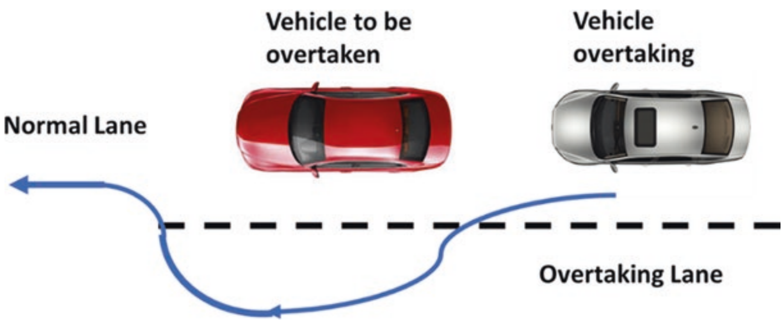

Fig. 11 Overtaking

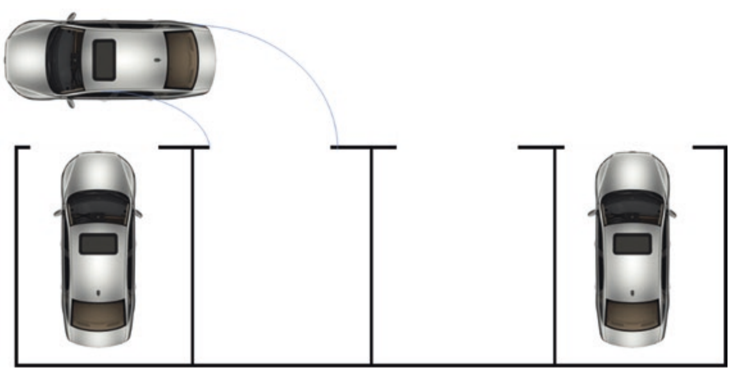

Fig. 12 Parking assistance with ADAS-based cars

Camera vision: It acts as the eyes of the ADAS technology. This vision is affected severely by weather conditions, low light, and glare. The image acquired is pre-processed using digital signal processors (DSPs). The camera sensors are typical used for applications such as traffic sign recognition, parking assistance, and lane departure warnings. Infrared cameras are used during nights which act as best night vision cameras.

Radio detection and ranging (RADAR): Compared to cameras, radars are robust in any weather and light conditions with good range. There are specific radars for long-range and short-range applications.

Light detection and ranging (LiDAR): The LiDAR measures the distances based on the light scattered w.r.t the laser irradiation that emits pulsed light. The main advantage of the LiDAR technology is that the light scattered from the object gives information distance as well as the nature of the object.

Ultrasound: These sensors work based on the principle of sound in determining the distance of the nearby objects and to warn the driver regarding the obstacles. Usually, a single car will be equipped with 12 ultrasonic sensors to completely cover the surrounding environment. The range of ultrasonic sensors are very less and is about 3 m.

The range and typical application of the sensors in the ADAS technology is tabulated in the Table 1.

Reliability Modelling

A vehicle consists of active and passive safety systems and ADAS features. The most important concept in ADAS is to maintain the safety by saving the lives. A model is demonstrated here to represent various ways on how the safety of the

Table 1 Various sensors used with typical applications

Sensors	Maximum range (m)	Typical applications
Short-range radar	20	Blind spot detection
Long-range radar	150	ACC (adaptive cruise control)
Camera vision	80	Pedestrian detection, sign recognition, parking assistance, lane departure warning
Infrared	120	Night vision
Ultrasound	3	Park assist
LiDAR (scanning)	120	Emergency braking, collision avoidance systems

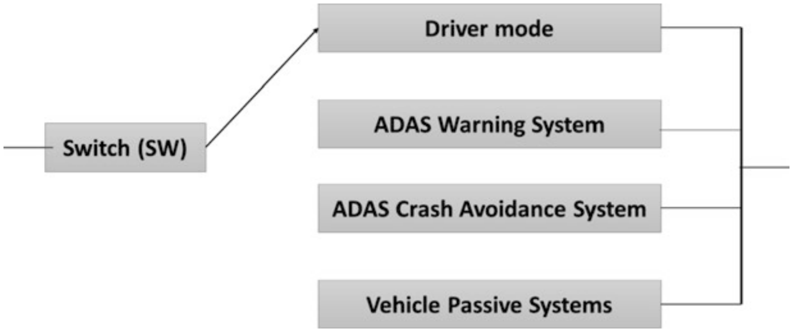

Fig. 13 RBD block diagram for a simple model

vehicle is maintained. The model represented is termed as reliability block diagram (RBD) and is shown in Fig. 13. There are four different pathways to maintain the reliability of the safety of the vehicle.

When the driver fails to operate the vehicle safely, the control systems alerts the ADAS warning system to provide the necessary warning signals. When the failure in ADAS warning systems result, it leads to the activation of ADAS crash avoidance systems. Lastly, the failure of ADAS crash avoidance systems switches on the passive safety systems in the vehicles such as airbags to active state.

Vehicular Communication in ADAS

Vehicular communication system plays a vital role in ADAS by notifying useful information through various channels like wireless communications and to implement the necessary actions especially regarding safe driving alerts. Safety is a key factor of an automotive. Every year, the increase in number of road accidents can be directly linked with increasing number of vehicles on the road. According to the WHO, globally at least 1.2 million deaths are happening every year due to road accidents. Traffic management is necessary to avoid possible accidents, to minimize carbon emissions, to improve fuel efficiency, for navigating the fastest route, to improve driver safety and comfort and to save resources. Several automobile manufacturers are doing research into the same to provide better future prospects for automobile industry. Vehicles could communicate with vehicles and other elements which substantially improvise the driving systems and safety prospects. Vehicle-2-vehicle (V2V), vehicle-2-infrastructure (V2I), vehicle-2-pedestrian (V2P), vehicle-2-cloud networks (V2N), and vehicle-2-everything (V2X) communication systems allow the vehicle to communicate to its surroundings with short-range wireless signals which is as depicted in Fig. 14.

Vehicular communication conveys to the driver about weather information, traffic and signals, road conditions, accidents, and any harmful activities around

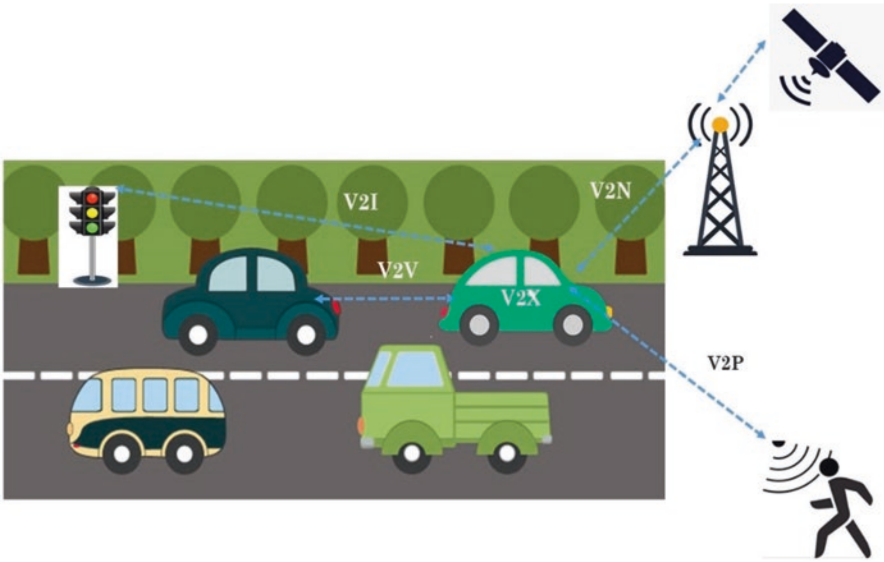

Fig. 14 Vehicular communication system in ADAS

vehicle. In autonomous vehicles, having the navigation system adds extra features when compared with traditional vehicles. One of the vehicular communication systems, V2X, has a smart working system which reports automatic payment for toll, parking slot identification, weather forecast, shortening the distance towards the destination, fuel station/restaurant notifications, etc. V2X communication has several components which integrate information that connect vehicles to everything (pedestrians, vehicles, roads, and cloud environments) aiming to reduce the number of road accidents and building an intelligent transport system (ITS) [5].

Certain features are added with ADAS by considering safety concerns like Emergency Electronic Brake Lights, Forward Collision Warning, Intersection Movement Assist, Left/ Right Turn Assist, Blind Spot/Lane Change Warning, Curve Speed Warning; by considering environment concerns like vehicle classification, traffic management, intersection analysis, destination studies, emission control, smart parking and by considering roadside mobility concerns like emergency communications and evacuation, cooperative adaptive cruise control, wireless inspection, connection protection, etc. Adding all these features with ADAS, vehicular communication will be a major advancement in the field of automotive by adopting technologies like Internet of Things (IoT), information and communication technologies (ICT), and artificial intelligence (AI), leading to safe driving environment [6].

Vehicular Communication Technologies Used in ADAS

Cellular systems, Bluetooth, microwave communication, millimeter wave communication, DSRC (dedicated short-range communications), ZigBee, WiMAX, and long-term evolution (LTE) are key wireless communication technologies used in vehicular ad hoc networks (VANETs) for effective vehicular communication. Various vehicular communication technologies used in ADAS are listed in Table 2, which could be used as wireless communication channels to connect the vehicle with everything around it depending on the applications.

Pathway Towards Nextgen: ADAS in Global Automotive OEMs

The advancements in terms of safe driving and automation carried in the form of ADAS had already arrived in OEMs globally. A leading Japanese car manufacturer introduced driving safety support system (DSSS) to its products Prius, Crown Majesta, Crown Royal, and Crown Athlete. DSSS have sensors and send messages to the driver about detected pedestrians and vehicles that were not visible to the driver's sight and alert the driver. The main benefits of DSSS are reducing the traffic accidents at intersections, increasing awareness, and reducing the driver's burden. DSSS features include pre-collision warning and braking, enhancing the road safety during night drives. DSSS uses V2V, V2I, and V2X communication systems. DSSS comes under the awareness driving phase which is the present trend in automotive sectors. Another car manufacturer hailing from Japan, Honda, thrives to demonstrate advanced V2P and V2V through DSRC communication technology. The ultimate aim of this R&D work ensures the reduction in collisions between vehicles and pedestrians. Next phase sensing and driving also make impact in the automotive sector about hazardous things on the road. In 2017 Daimler introduced autonomous driving with Mercedes E-class car using V2X communication. The sensing and driving principles had been applied to identify weather conditions and road accidents, intended to increase safety and reduce the stresses associated with driving. Few other automotive OEMs are involved in R&D of self driving cars. The third phase of advancement in ADAS comprises cooperative driving which enables V2V communications effectively. This phase operates multiple driver functions simultaneously. The German-based automotive, Volkswagen, adopted V2V communications for its vehicles from 2019, using public wireless LAN (pWLAN) with IEEE 802.11p standards. This communication enables to connect with vehicles and infrastructure which added some features like lane merger assistance, platooning, pedestrian safety, and parking reservation.

Further into the advancements in ADAS for next generation, the synchronized cooperative driving provides the features like overtaking assistance and intersection assistance. Most of the decisions would be made by the vehicle, but it requires the driver to supervise the actions. The automation is limited in this phase in terms of

Table 2 Vehicular communication technologies in ADAS

Vehicular communication technologies	Bandwidth	Purpose	Applications	Standards
DSRC (dedicated short-range communications)	5.95 GHz band	To provide high data transfers and low communication latency in a small communication area on vehicular networks	DSRC has a wide range of applications such as V2V safety messages, traffic information updates, toll fee collection, and several other applications	EN 12253 EN 12795 EN 12834 [ISO 15628] EN 13372 SAE J2735
WAVE (wireless access in vehicular environments)	5.9 GHz band	The communication between vehicles and vehicle to infrastructure with continuous and interoperable services	Avoid car accidents, parking the vehicle, identification of fuel stations and restaurants, and several other applications	IEEE 1609 2013 IEEE 1609-2010 IEEEP1609 IEEE 1609.11-2010 IEEE 1609.1 IEEE 802.1-2012
CALM (communications access for land mobiles or communications, air interface, long, and medium range)	5.9 GHz band	A set of wireless communication protocols and air interfaces for a variety of communication scenarios spanning multiple modes of communications and multiple methods of transmissions in ITS	Internet access, dynamic navigation, safety warnings, collision avoidance, and ad hoc networks linking multiple vehicles	ISO 29281 ISO 15628 ISO 24102
Infrared (IR)	Unlicensed band up to 100 Mbps and even more	Short-range communication	Vehicle information and communication system (VICS) in Japan and the truck tolling scheme in Germany	ASTM E1897 ASTM E 1933 ASTM E 1934
Bluetooth	Unlicensed band at 2.4 GHz over small distances of 10 m	Short-range communication with low power, low cost, low complexity, and robustness	Provide wireless connection between different portable or fixed electronic devices in the vehicle basically suited for communication, such as onboard communication devices	IEEE 802.15.1

ZigBee		20–250 Kbps which covers small distances of 100+ meters	Improving network services, multichannel operations, and resource management in ITS to support sensing, monitoring, and control applications with the lowest power consumption	The ZigBee sensor measures the distance between the vehicle in front of the car and will warn the vehicle in case there are any chance of collision. Emergency braking of vehicle moving in front. Supporting large number of vehicles on the road	IEEE 802.15.4 IEEE 1609
VLC (visible light communication)		Up to 500 Mbps	VLC uses lighting sources as transmitters and utilizes photodiodes as receivers for establishing communication	Environmental monitoring	IEEE 802.15.7
Cellular system	2G/3G	Up to 25 MHz	Cover an enormous geographical region which gives continuous communication to vehicles	GPS, short messages	Network standards
	WLAN/Wi-Fi (wireless fidelity)	2.4 GHz 54 Mbps covers at least 160 M	Efficient wireless access to empower intelligent transportation between vehicles and the infrastructure	Safety on the road, traffic flow, and comfort for passengers and drivers with expedited applications such as the Internet, network games, automatic electronic toll collection, drive-through payments, and digital map update	IEEE 802.11 IEEE 802.11a IEEE 802.11a
	LTE-4G	Up to 1700 MHz	Consumers would be able to access network- and cloud-based applications	Entertainment, infotainment, diagnostics, navigation, non-safety applications, such as traffic information transmission	IEEE 802.11p
	WiMAX (worldwide interoperability for microwave access)	Up to 20 MHz	To provide seamless wireless access over extensive distance	WiMAX can be effectively utilized for V2I or I2I communications, and it also provides long-range communications, which can be used for various applications	IEEE 802.16e
	5G—Millimeter WAVE	60–64 GHz	Autonomous driving, vehicle-2-vehicle (V2V), vehicle-2-infrastructure (V2I), vehicle-2-network (V2N), and vehicle-2-pedestrian (V2P) communications, enable new safety-sensitive applications V2V/V2I (V2X)	Alerts, speed recommendations, real-time updates Software updates, image sharing, automated platooning, situational awareness, and intersection management/safe intersections	IEEE 802.11ad

proper environmental conditions and complex situations which arise from the roadside. A French automotive OEM, Renault, developed communications between vehicles and roadside infrastructure such as toll booth, intersection area, school/college zones, and others. Sanef, a French motorway infrastructure, collaborated with Renault to develop features. Another example was set by the US-based General Motors division Cadillac – CTS Sedan was offered with V2V communication in 2017. They tie up with the Australian company Cohda Wireless for communication assistance and the Israeli firm, NXP Semiconductors, for developing road links for connecting with vehicles. Delphi automotive supplied antenna modules and provided data security.

The autonomous driving phase is envisioned with a fully autonomous vehicle. An autonomous vehicle would be able to make complex decisions on its own with all kinds of situations like environmental, infrastructure, and intersection conditions. The appropriate decisions are taken by the vehicle with no human intervention. The capability of reaching the destination can be fully controlled by vehicle without any concerns. One of the automotive OEMs, Land Rover, is currently working with an autonomous urban drive system under SAE level 4 standards of high automation. An autonomous car would be capable of communicating with cars and infrastructure around it (similar to V2X communication) which leads to the development of highly automated vehicles (HAVs) for long-term purpose.

Summary

This chapter discusses the ADAS technologies and its various aspects in improving the vehicle and community safety on roads. The main points discussed in this chapter on various ADAS features and the communication technologies are summarized in the following points:

- Detailed descriptions of various information-based and manipulation-based ADAS systems
- Various vehicular communication technologies used in ADAS
- Various sensors and their usage in ADAS-based systems
- Case studies and current trends in the implementation of ADAS

ADAS system have many positive impacts such as mitigation of exposure to risky conditions and improvement of driver behavior (e.g., reduced driving speed and speed variability, smaller lane deviations, faster reaction times, less harsh braking, and enhanced alertness) and eradication of driver errors. However, there are negative impacts also that are associated with the ADAS technology that include the following:

- Shifting of the driver’s attention to road environment information that results in insufficient attention to the important driving tasks

- Frustration of the driver with the warning systems due to unnecessary frequent system warnings
- Frustration of the driver when certain elements of the driving tasks are taken over by the system in contrast to the driver's desire

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