

Vehicles of the Near Future: Driverless Autonomous Cars

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Introduction

With the development of technology, many institutions and organizations from automobile manufacturers, electronics, software industry and universities are working very seriously on autonomous driving systems, which are seen as the technology of the future. These institutions and organizations continue to make highly automated vehicle prototypes and road tests, whose capacities are rapidly developing due to the development of advanced sensor processing technologies, adaptive algorithms, and high-definition mapping systems. Autonomous vehicles perform tests in the United States almost exclusively in autonomous driving mode. These vehicles make long-distance highway and arterial trips in Europe and Japan (Vanderblit, 2012). In addition, the effects caused by reasons such as safety concerns in traffic, the high number of property damage and fatal accidents, environmental effects, technological developments and the increase in comfort expectations lead to a revolutionary change in personal transportation vehicles, which have an important place in our daily lives (Tastan & Kaymaz 2017).. These reasons also play a major role in the development of autonomous vehicles. Autopilots are used today to perform very different autonomous driving operations for aircraft, since air traffic is much more convenient than ground traffic in aircraft. These systems, which make almost less errors than a pilot in terms of error rate, continue to be developed very widely. As in the weather example, the production of vehicles capable of autonomous driving is of great importance in order to prevent accidents, especially by preventing driver errors. The heavy ground traffic compared to air traffic has many problems such as physical obstacles and pedestrians. Especially as the processing capacity and speed of the controllers to be used in this regard increased, the problems that were seen as difficult before started to be solved one by one. Being able to determine the traffic signs provides a serious convenience in the decision-making mechanisms of the estimation of the object approaching the vehicle (pedestrian, animal, vehicle, etc.). Developing applications in image processing methods and developing platforms at the same time indicate that autonomous vehicles will be very common in our lives in the near future. Especially thanks to real-time image processing, it allows to make instant and fast decisions. In addition, with the developing LIDAR and RADAR technologies, approaching or moving objects can be detected. Thus, the danger is detected in advance and necessary precautions are taken. It is predicted that autonomous vehicles will have an important place in our lives in the near future due to the advancement of technology and the comfort and safety concerns of people.

History of Autonomous Vehicles

Since at least the 1920s, automatic driving systems (ADS) have been the subject of tests, with actual implementation starting in the 1950s. Japan's Tsukuba Mechanical Engineering Laboratory created the first fully automated automobile in 1977. The car used an analog computer for signal processing and two cameras to understand the white street signs. The vehicle, which was supported by an elevated track, could travel up to 30 km/h (19 mph) (McAleer, 2017). The Navlab and ALV projects at Carnegie Mellon University, funded by DARPA, began in 1984, and the EUREKA Prometheus Project at Mercedes-Benz and the Bundeswehr University Munich, funded by EUREKA, began in 1987. These projects marked the beginning of the emergence of autonomous prototype cars in the 1980s. The ALV demonstrated off-road driving in both daylight and darkness in 1987, as well as two-lane highways that were 31 kilometers (19 mph) long and obstacle avoidance in 1986. Since the 1960s and up to the second DARPA Grand Challenge in 2005, automated vehicles have been on American roads. All three of DARPA's funding partners the US Army, US Navy, and US Department of Defense have helped advance research on controls, speed-boosting sensors, and performance in increasingly demanding, quick-changing environments. Research organizations and system firms have produced prototype. In 1991, the United States allotted \$650 million for research on automating by combining embedded automation and automation, as well as research on the National Highway System, which uses automobiles on highways to show how automation technology works with highway infrastructure and highway driving. The initiative concluded in a successful demonstration in 1997, but it lacked the clear guidance and funding necessary to put the system into practice on a bigger scale. The Carnegie Mellon University Navlab traveled 4,584 km (2,848 mi), 4,501 km (2,797 mi), or 98% autonomously throughout the United States in 1995. This work was partially funded by the National Automated Highway System and DARPA. During Navlab's 2015 visit to 15 states, when Delphi drove an Audi powered by Delphi and created a 5,000 km record, its accomplishments were 99% unmatched. (Hawkins, 2017). The newest A8 will be automated utilizing "Audi AI" at speeds up to 60 kph, according to a 2017 statement from Audi (37 mph). Instead of regularly grasping the steering wheel, the driver wouldn't need to do safety checks. In addition to using cameras and ultrasonic sensors, the Audi A8 is thought to be the first production vehicle to reach level 3 automatic driving. Audi would also be the first automaker to deploy laser scanners. Waymo said in November 2017 that it has started testing a driver who was unreliable when not in the driver's seat, but there was still an employee in the car. Waymo stated in October 2018 that its test vehicles have covered 10,000,000 miles (16,000,000 km) in automated mode. (Balzer, 2002).

With the development of sensor technologies in recent years, the development and commercialization of vehicles has accelerated. Technically speaking, different

autonomous features are available in vehicles produced in the market in recent years. Vehicles with many autonomous driving features such as cruise control, lane tracking system or following the vehicle in front are frequently seen in traffic. It is clearly seen that the vehicles with only one of these features or a few different ones will be seen frequently in the traffic in the coming days.

Main Sensors Used in Autonomous Driving

The effectiveness of sensor fusion and the use of cutting-edge applications directly relates to the success of autonomous driving applications. The employment of algorithms in sensor fusion will significantly lower the error rate. Internal sensors that monitor things like location, speed, acceleration, and motor torque gather data about the actual device. Cameras, range sensors (such as infrared, laser, and ultrasonic), proximity sensors (such as photo diode detectors and touch sensors), and force sensors are examples of external sensors that gather environmental data and transfer it to the decision unit (CPUC, 2020). It is a sensor that is employed. Figure 1 depicts the general architecture for autonomous driving in autonomous vehicles.

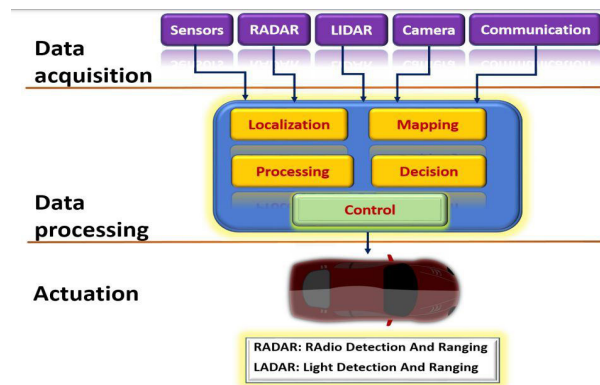


Figure 1. Basic Block Diagram for Autonomous Driving (Hussain &. Zeadally,2018)

The basic sensors required for autonomous driving, their measuring ranges and their positions on the vehicle are shown in Figure 2.

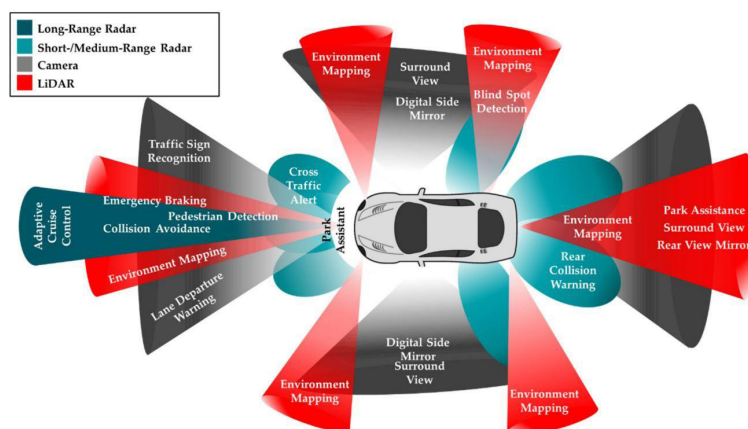


Figure 2. Basic Sensors Required for Autonomous Driving and Their Placement on the Vehicle (Hussain &. Zeadally,2018)

The following five sensors are basically used in an autonomous driving:

- Camera
- RADAR
- LIDAR
- IMU(Inertial measurement unit)
- GPS(Global Positoning System)

Camera

For manufacturers that implement many autonomous driving applications, the camera is an indispensable part. In fact, some manufacturers only use cameras in their applications. When choosing cameras, basically three important comparison features should be considered. (Trommer,2017) The first property, resolution, is the value that specifies the number of dots or pixels in an image. Resolution is the most basic way of determining the quality of the image. (Dawson,2017) The higher the resolution, the higher the image quality will be. Figure 3 shows a high resolution camera.



Figure 3. High Resolution Camera

Field of view is what the eyes see both directly in front of and around them when viewed from a fixed point. This feature can be changed with lens selection and zoom. Another important metric is dynamic range, expressed as the difference in light between the brightest and darkest areas in an image. The wide dynamic range makes it easier to perceive the image for autonomous vehicles, especially in different lighting conditions encountered during night driving. There is an important ratio between the choice of cameras and lenses between the field of view and the choice of resolution. When it is desired to increase the wide field of view, it is necessary to increase the resolution in order to perceive the same quality due to the fewer pixels that absorb light from a certain object (Grush, 2016). The above factors should be taken into account when choosing the camera, which is the most important part of autonomous driving.

RADAR (Radio Detection and Ranging)

With the development of technology, RADAR (Radio Detection And Ranging) is used in many areas besides military fields today. (Ünler & Seyfi, 2022). Radars are generally used for distance measurements for autonomous vehicles. RADAR uses radio waves to measure distance. Radio waves travel at the speed of light and have the lowest frequency of the electromagnetic spectrum. RADAR covers long distance measurements and can detect large objects in the environment well. Since it uses magnetic waves, it is not

affected much by adverse weather such as precipitation and snow. RADAR is selected based on key features such as detection range, field of view, position and velocity measurement accuracy. (Lawson,2018). Figure 4. show a 24 Ghz 100m range RADAR.



Figure 4. 24 Ghz RADAR

Unlike ultrasonic sensors, since they have the ability to measure at much longer distances, they can also ensure that the danger is detected from a distance. It has also made good use of RADAR systems and vehicle-to-vehicle communication in the autonomous vehicle industry, leading to advances such as adaptive cruise control and emergency braking.(Trommer,2017)

LIDAR, which has the same measurements as radar, can make erroneous measurements, especially in bad weather conditions. Effects such as attenuation and reflection in camera or LIDAR data need to be considered. These make detection methods erroneous in estimating object locations (Montemerlo, 2008). Considering the characteristics of RADAR and LIDAR sensors, RADARs are of great importance for autonomous vehicles in order to reduce erroneous measurements in bad weather conditions. In addition, RADARs provide great advantages when long distance measurements are needed.

LIDAR (Laser Imaging Detection and Ranging)

LIDAR (Laser Imaging Detection and Ranging) sensors are devices for measuring distance by emitting Laser light. In terms of distance measurement, they work with the same logic as RADARs that emit EM waves. Instead of the radio waves used in radar sensors, LIDAR makes distance measurements using laser pulses. Data collected from sensors is used to create highly detailed 2D and 3D maps of the environments around us. LIDAR sensors send between 50,000 and 200,000 pulses per second to cover an area and compile the returning signals into a 3D point cloud. The more points collected per second, the more detailed the 3D point cloud can be. The rapid update of 3D point clouds is directly proportional to the rotation speed of the LIDAR sensor. The power of the laser light used in the LIDAR sensor determines the measurement range (Lawso,2018). Figure 5 shows a HDL-64E model LIDAR sensor produced by google and used on autonomous vehicles.



Figure 5. HDL-64E LIDAR sensor

While the traditional mapping method is used in fields such as surveying, agriculture and mining, today, with the development of technology, LIDAR technology is preferred in many areas in order to make more detailed mapping. With the help of complex algorithms, LIDAR sensors are used to solve the Simultaneous Localization and Mapping (SLAM) problem for use in autonomous navigation in military applications, autonomous vehicles and urban search and rescue missions. Various SLAM algorithms are available for air, land and sea platforms. SLAM is preferred because it has many uses and can make much more precise measurements than GPS (Topal & Yigit,2021).

IMU ([Internal Measurement Unit](#))

The IMU consists of two types of sensors to measure the 3-axis acceleration and 3-axis rotational force on an object in motion in space. The IMU measures the acceleration, angular acceleration and rotations of the system and converts these data into instantaneous position data of the system. Figure 6 shows an IMU sensor manufactured by Bosch and used in the automotive industry.



Figure 6. AN IMU sensor produced by BOSCH

The IMU, called the inertial measurement unit, has processors that interpret the information received by the sensors from the environment like the human brain and make decisions. It is related to the inertia measurement unit INS, GPS and LIDAR, which provides safe driving by monitoring the dynamic changes in the movement of the vehicle (Gao et al., 2015)

The two-sensor models produced with previous technology basically contain two separate sensors as an accelerometer and a gyroscope placed on the x-y-z axes. With the developing technology, the magnetometer in the three-sensor model has been added to the IMUs as the third sensor. The magnetometer measures the magnetic direction of the spindle bearing, so the reading of the gyroscope is improved relative to the 2 axes. (Hazry et al. ,2013)

GPS (Global Positioning system)

They are positioning systems with the help of certain mathematical calculations using GNSS and GPS satellite systems. Position estimation is made when the receiver sees at least 4 satellites. As the number of satellites seen by the receiver increases, the position sensitivity also increases. Figure 7 shows a standard GPS receiver.



Figure 7. A GPS receiver

Satellite-based positioning and navigation systems are preferred in real-time applications. The US navy TRANSIT navigation satellite system is known as the first system that uses the Doppler Effect in positioning and navigation applications of moving objects. Today, GPS is the most widely used satellite-based positioning system. Interruption of satellite signals in urban, rural and indoor areas creates problems in GPS applications. In order to prevent such problems, within the scope of GNSS-based positioning technologies, GPS is supported with additional equipment called inertial measurement equipment (IMU). (Chiang, 2004; Ozcelik, 2009). Inertial navigation systems are systems used in addition to GPS equipment in positioning, target tracking and navigation applications of air, land, sea and space vehicles. The system's inertial sensors (gyroscope and accelerometers) measure the acceleration, angular acceleration and rotations of the system and convert these data into instantaneous position data of the system (Ozcelik, 2009; Walcho, 2002; Bayraktar, 2004).

Accumulation of errors increases with time in INS measurements. Errors in GPS measurements are independent of time. Integration of INS, which gives effective results in short time intervals, and GPS data, which gives effective results in long time intervals, is used more (Walcho, 2002; Bayraktar, 2004). Therefore, since GPS/INS integration provides reliable and more accurate location and navigation information, it is preferred in applications where small-scale precision is required (Bayraktar, 2004).

The GPS satellite orbits are about 20200 kilometers away from the planet. Two frequency values are present in GPS satellite signals: and. To mimic the delays in the atmosphere, distinct L1 and L2 wavelengths are utilized. These signals are modulated using one or both of the C/A code and P code PRN (Pseudo Random Noise) codes. L2 carrier phase is exclusively modulated with P code, whereas L1 carrier phase is modulated with C/A and P code. Every millisecond, the C/A code is broadcast at a frequency that is one-tenth that of the GPS signal (10.23MHz). Every 267 days, the P code is delivered at its original frequency. GPS receivers measure the apparent transit time of the satellite signal between the satellite and the user, called pseudorange. Pseudorange includes receiver clock deviations and signal delays (Chiang, 2004; Ozcelik, 2009).

GPS is not a self-directed or automated system. To perform position determination, the

sensors must see enough satellites. Satellite visibility may decrease due to structures such as buildings, bridges, tunnels. In kinematic applications, electronic interference or other interference may cause errors/deficiencies in the detector's detection of carrier phase waves. The data frequency of many sensors is usually 1 Hz. Most of the errors encountered in positioning with GPS are atmospheric effects that are difficult to predict (Kocaman, 2003).

Classification of Driving Automation Systems

Driving automation systems are classified in 6 different levels according to autonomous driving situations. (SAE, 2016). These levels are determined according to the rate of the driver's intervention at the time of travel. These levels are shown in Figure 8 clearly.

			Steering, acceleration / deceleration	Monitoring of driving environment	Fallback when automation fails	Automated system is in control
Human driver monitors the road	0 No Automation (1885 to 1999)	Eyes on Hands on				Never
	1 Driver Assistance (2000 to 2009)	Eyes on Hands on				Present in some driving modes
	2 Partial Automation (2000 until today)	Temporary hands off				Present in some driving modes
Automated driving monitors the road	3 Conditional Automation (current stage)	Temporary hands off				Present in some driving modes
	4 High Automation (estimate by 2025)	Eyes off Hands off				Present in some driving modes
	5 Full Automation (estimate by 2050)	Eyes off Hands off				

Figure 8. 6 Levels of Autonomous Driving (Cavazza et al.,2019)

Level 0 (No Automation)

Level zero vehicles are those without any automation and where the dynamic driving work is totally carried out by the user. These vehicles include technological equipment that can only function as a consequence of human interaction, which we refer to as manual usage at this level. In these vehicles, the human driver controls the vehicle's horizontal and vertical motion under all traffic circumstances. Any normal car without automation may be used as an example of this level, and cars at this level don't need to be taken into account for the study's problem. (SAE, 2016).

b. Level 1 (Driver's Assistant)

This level of automation requires the user to continuously watch their driving while a few controls are only partially taken over by the system. One, sometimes known as driver helper, is this level. It is the driving level where an automation system at this level cannot simultaneously take over the vehicle's vertical and horizontal controls, just the steering or simply the speed (Cavazza et al.,2019). The driver unquestionably has either horizontal or vertical supremacy, it should be stressed. This category is shown by cars with features like adaptive cruise control or parking assistance.

c. Level 2 (Partial Automation)

Contrary to the driver assistant, the level of automation in which both vertical and

horizontal control of the dynamic driving task continues is described as level two, or partial automation. The only difference between partial automation and driver assistance is that the automation system has the technology to handle both horizontal and vertical control of the dynamic driving task (Cavazza et al., 2019). For example, it is possible to consider vehicles with both adaptive cruise control system and lane alignment system in this category.

d. Level 3 (Conditional Automation)

The first and third level automation vehicles are the vehicles in which no human driver interferes with the driving activity and the driving is controlled by the system. At this level of driving automation, the entire driving task is performed by the system within a limited driving area, and under normal conditions, the user does not need to participate in the driving task. However, in case of any malfunction in the automation system, when the system calls the user to intervene, it is the driving level that the user must respond to this call (Cavazza et al., 2019). “Traffic jam assist systems”, which can perform the entire driving task in a stop-and-go traffic situation at low speed, are shown as an example of third-level driving automation.

e. Level 4 (High Automation)

Driving automation is defined as level four, which can move within a limited driving space as in level three automation systems, but unlike conditional automation, where the user does not have to respond to the intervention call sent by the system and the entire dynamic driving task can be carried out by the system without driver intervention (SAE, 2016). For this reason, it is possible to say that in a vehicle with level four automation, the operational design area can be realized by the driving automation system with the expectation that the user will take over the rest of the control, and the user is only in the vehicle as a passenger, as long as the user stays within the limits of the control task (Cavazza et al., 2019). Today, highly automated level four vehicles are still at the prototype level, but autonomous taxis and buses, which serve in a limited area and do not have human drivers, can be given as examples of these vehicles.

f. Level 5 (Full Automation)

Level five, also known as full automation, is the driving automation where it is possible to control the dynamic driving task by the system in an unlimited operational design area, in all conditions suitable for movement, without the need for any user intervention (SAE, 2016). In the event of a malfunction or unexpected road and weather conditions during the dynamic driving task in a fully automated vehicle, the system can ex officio bring the vehicle to a minimum risk condition without the need for user intervention (Cavazza et al., 2019). The biggest difference that distinguishes full automation from high automation is that the operational design space is unlimited in vehicles with this automation system, which means that there are no restrictions on weather, time or geographical conditions as to where and when the system can operate the vehicle (

Cavazza et al.,2019). Today, there is no tool that has this level of automation. In the doctrine, it is stated that the main condition for the transition to fully autonomous driving is that the vehicles are programmed completely safely, taking into account all real-life scenarios, and that there are no possible scenarios for which the system does not know the solution (SAE, 2016) . In this respect, it should be stated that it is a difficult possibility to see fully autonomous vehicles on highways in the near future and that these vehicles do not constitute a current need in terms of criminal law for now.

The Future of Autonomous Vehicles

The increase in accidents due to human errors in traffic and the situation in environmental factors is seen as a need to develop autonomous vehicles. In addition, the increase in comfort expectations increases the demand for these vehicles and the studies on these vehicles. Considering the defined levels of autonomous vehicles, it is clearly seen that they are in our lives. Especially in level 1, level 2 and level 3 traffic, it is one of the most common autonomous vehicle classes. However, although there are companies such as Tesla, which produces at level 4 and level 5, where the driver is less involved, it is not used very intensively yet. Intensive laboratory studies are continuing, especially for level 5. In the future, it is predicted that autonomous vehicles will be seen more frequently in traffic, especially with the development of sensor technology. It is thought that developments in cameras will accelerate this process even more. In order to perform real-time image processing, which is of great importance for autonomous driving, computers must have high-speed processing capability. With the developing technology, both the reduction of the size of the computers that process the image data quickly and the increase in the processing levels will accelerate this process even more. Since this situation is very necessary especially in object recognition, developments in these areas allow autonomous vehicles to develop very quickly. On the other hand, increasing the number of sensors will increase the detection accuracy of the objects around while driving. In addition, the use of sensor fusion in the interpretation of the data of the sensors used will increase the quality of autonomous driving. In addition, with the development of artificial intelligence algorithms used in these situations, the system's self-decision mechanism will improve significantly. Thus, it is thought that the obstacles in front of level 4 and level 5 will be removed.

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