## 1 Driver Assistance

The driver controls the vehicle while the driving automation system ensures safety and comfort. The system includes either the longitudinal **or** the lateral vehicle motion such as an active cruise control or automatic braking. (3)

## 2 Partial Driving Automation

The driver controls the vehicle and also has the capability to switch to the semi-autonomous driving system controls. The systems include the longitudinal **and** the lateral vehicle motion such as steering and lane control as well as automatic accelerating and braking. (3)

## 3 Conditional Driving Automation

Under certain circumstances, the driver can switch to full autonomous mode. The vehicle can operate autonomously over long distances in specific situations, however the driver must act as a fallback-ready user and must be ready to take over in a timely manner.

## 4 High Driving Automation

The driver becomes a passenger in a fully autonomous driving vehicle, however the driver can still request manual control. (1) If there is a minimal risk condition, then the driver must be capable of manually operating the vehicle.

## 5 Full Driving Automation

The driver does not need to be capable of driving in order to operate the fully autonomous vehicle. The vehicle is able to operate on manageable road conditions and the driver has the option of switching to manually operating the vehicle when safety conditions arise.
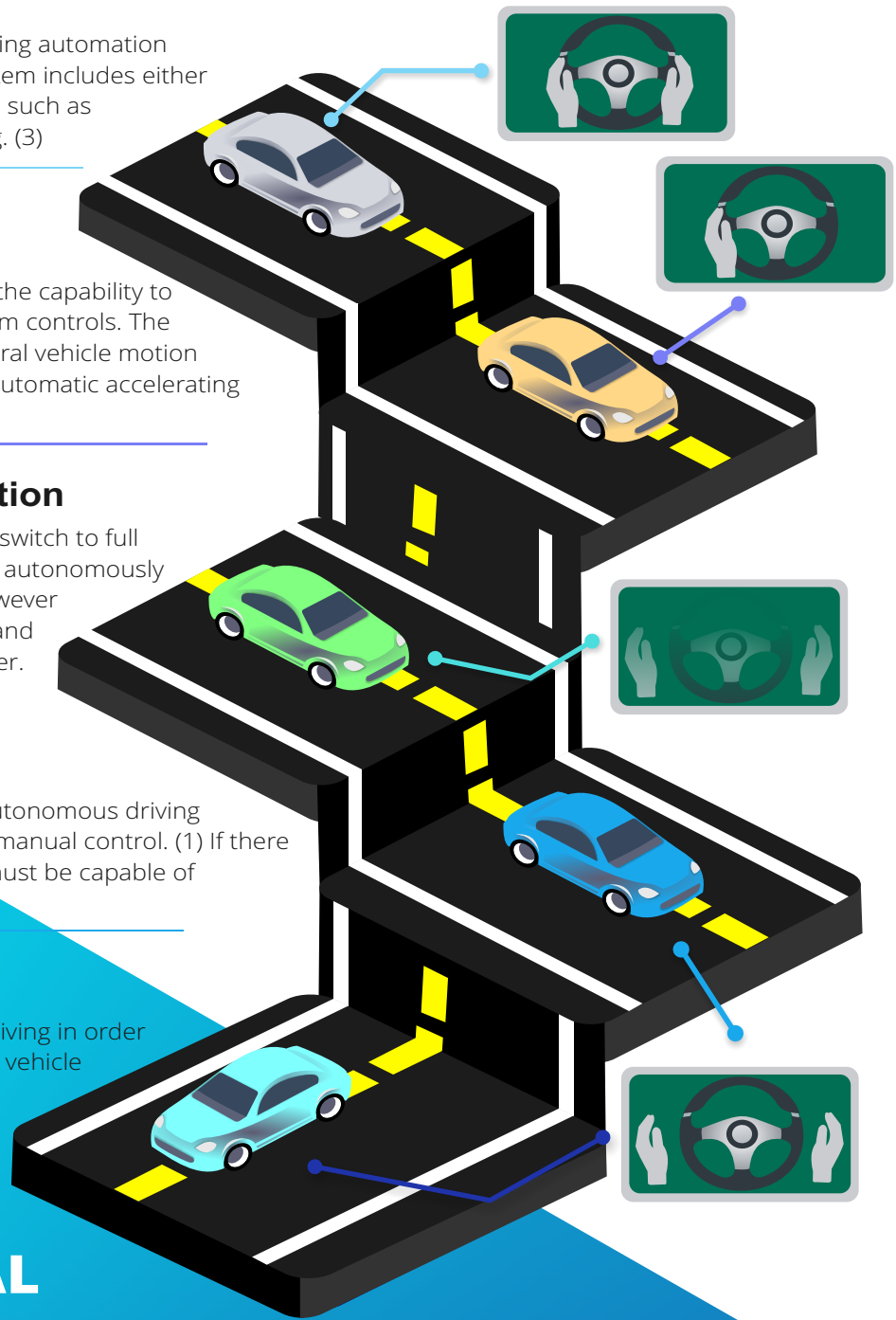
# SAE INTERNATIONAL
# LEVELS OF AUTONOMOUS DRIVING/ SENSOR PACKAGES

## Cameras

Visible light cameras are used for dectecting markings and objects on the road. AI-based algorithms are used to utilize the image data for object classification. Cameras have low capabilites in conditions with low visibility. (2)

## Radar

Radar is best used for detecting objects made of metal. (2) It is able to calculate the distance of a detected object, but it has limited capabilites to classify objects.Radar sensors are used in assistance systems for driving such as adaptive cruise control.

## LiDAR

LiDAR stands for light detection and ranging. (2) The system emits laser beams that hit objects and bounce back to the photodector. The beams formulate a point creating a three-dimensional image of the enviroment enabling the detection of everything within the surrounding area.

## Ultrasonic Sensors

Ultrasonic sensors are inexpensive sensors generally used as parking sensors. They have a short-range capability, but they provide additional sensing assistance used in low speed situations.

## Extra Sensors Localization

Other source inputs for autonomous driving are used to assist in sensing and localization such as inertial measurement units (IMUs), GPS, vehicle-to-everything communication, and high definition maps. (2)

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# OAK RIDGE INSTITUTE
## FOR SCIENCE AND EDUCATION

# SAE INTERNATIONAL:
## LEVELS OF AUTONOMOUS DRIVING
## &
## SENSOR PACKAGES

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**ABSTRACT**

The progression of autonomous and connected vehicles has developed opportunities to enhance safety in vehicles, provide drivers with an easier user experience, and improve various aspects of the transportation system with the use of driver-assistance systems. These driver-assistance systems include a range of sensors with an advanced communication network integrated into automated vehicles. According to SAE International, there are five levels of automation for vehicles ranging from no driving automation to full driving automation. This document aims to inform the public about the five levels of autonomous driving and the sensors needed for each level.

**BACKGROUND**

Automated driving systems or ADS refers to the hardware and software technology applied to  autonomous vehicles (SAE J3016 Standard, 2016). The fabrication and integration of such systems can be traced back to the early 20th century (Chan, 2017). In the early stages of development, the technology focused on autonomous speed, break, lane control, and other basic cruise control features (Faisal et al., 2019). Over the past decade autonomous vehicle  prototypes have been able to pave their way to the roads given the rapid advancements of such technologies (Faisal et al., 2019).

A few notable mentions include the first concept of automated vehicles by General Motors in 1939, later accompanied by Radio Corporation of America Sarnoff Laboratory during the 1950s (Faisal et al., 2019). Various government institutes and academia in places such as the US, Europe, and Japan worked to further research and development in the sector of automation involving automated transit, hyperintellegent vehicle systems, as well as image processing technology (Faisal et al., 2019). In 2004, the Defense Advanced Research Projects Agency's (DARPA) made major breakthroughs in AV research that made it possible for automated vehicles to travel across the desert terrain and urban roads (Faisal et al., 2019).

Proceeding the accomplishments of DARPA in addition to the efforts of Google's self driving vehicle fleet, there was a surge of industrial players furthering their research and development on automated vehicles (Chan, 2017). Currently, all of the models produced by TESLA are equipped with hardware platforms that have self-driving capabilities (Korosec, 2019). By 2020, Audi, BMW, Mercedes-Benz and Nissian are planning to introduce their line of Automated vehicles in the market (Chan, 2017).

**THE FIVE LEVELS OF AUTONOMOUS DRIVING**

The five levels of automation; has become an industry standard set by the Society of Automotive Engineers International (SAE) since 2014 (SAE J3016 Standard, 2016). The table below describes the capabilities and functions incorporated in the automated driving system as well as the responsibility of the driver for each level.

**Table 1.** Taxonomy of road vehicle automation derived from SAE (2016a)

| Level of Driving Automation | Capability | Role of Driver | Role of Driving Automation System | Automated Assistance Systems |
|---|---|---|---|---|
| Level 0: No Driving Automation | Zero autonomy present | The driver performs all of the vehicle operating functions | There is no automation system present | None |
| Level 1: Driver Assistance | Autonomous driving systems only provide assistance to the | The driver performs all of the vehicle operating | There is automation system assistance of | Active Cruise control, Adaptive cruise control (ACC), |

| | driver | functions | either steering or acceleration/dec eleration | automatic braking, distance control |
|---|---|---|---|---|
| Level 2: Partial Automation | Autonomous driving systems provide assistance to the driver that will allow the driver to disengage from some of their tasks | The driver performs all operating functions and can engage part-time driving assistance systems. The driver must monitor the vehicle at all times | There is at least one automation system assistance of either steering or acceleration/dec eleration that is fully automated | Steering and lane control assistant, traffic jam assistant, automatic braking, autonomous steering (BMW, 2019) |
| Level 3: Conditional Driving Automation | Autonomous driving systems control all monitoring of the environment | The driver can engage conditional autonomous driving but must be prepared to | There is automation system assistance of steering, acceleration/dec | CoPilot system that allows conditional autonomous driving (BWM, 2019) |

|  |  | intervene if an unexpected condition arises | elerations, and braking but only under certain conditions |  |
| --- | --- | --- | --- | --- |
| Level 4: High Driving Automation | Can switch to full automation but only when conditions are safe | The driver can engage full-time autonomous driving but must be prepared to intervene if an unexpected condition arises | There is automation system assistance of steering, acceleration/dec elerations, and braking but only under certain conditions | Full automation capabilities |
| Level 5: Full Driving Automation | Full automation under all conditions | The driver does not need to intervene or be present for operation | There is automation system assistance of all autonomous vehicle system controls | Full automation capabilities |

**SENSOR PACKAGES**

Autonomous vehicles rely on the capabilities of sensors in order to be able to sense the environment around them, detect other vehicles and objects, and react or drive accordingly (Dawkins, 2019). Driving automation systems are presently manufactured with the following three main sensors: camera, radar, and lidar (Rudolph & Voelke, 2017). The use of other sensors such as ultrasonic and extra localization are used as well, however they play a minor role in autonomous driving.

**CAMERAS**

Cameras are present in all five levels of autonomous driving. They are able to interpret objects on the road and gather image data from all angles (Khvoynitskaya, 2018). As of today, camera systems use CMOS image sensors which provide HD image data with 1 to 2 megapixels (Rudolph & Voelke, 2017). Rear and 360° cameras assist the driver with a better view of the external environment.The use of 2-D cameras provide image display in addition to information such as the angle of the steering wheel. 3D cameras can display realistic images with the input from an estimate of four to six cameras. In order to deliver a clear image, image sensors with a very high dynamic range of 130dB or more is necessary for 2-D and 3-D camera len systems (Rudolph & Voelke, 2017). The use of image sensors can automatically sense objects within range, detect the type of object, and calculate the distance between the vehicle (Khvoynitskaya, 2018). Light intensity on the image sensor also plays a key role in the quality of the camera. Forward- facing camera systems can detect objects from medium to high ranges, in areas between 100 and 275 yards (Rudolph & Voelke, 2017). The major drawbacks of camera systems

include low visibility in certain weather conditions like snow, rain, or fog,  and occasional object detection errors.

**RADAR**

In addition to cameras, radar sensors are included in all five levels of autonomous driving. Radar stands for radio detection and ranging which emits radio waves in order to detect objects and calculate the distance of them in real-time (Khvoynitskaya, 2018) . Radar sensors are commonly used for driver assistance systems such as adaptive cruise control.  Short-range [24 GHz] radar sensors are used for blind spot monitoring, lane and parking assistance. Long-range [77GHz] radar sensors are used for distance control and brake assistance. Radar sensors are able to classify objects in certain weather conditions unlike cameras, and they are efficient in detecting metal objects (Dawkins, 2019). The drawbacks of radar includes only 95% of pedestrians are able to be correctly identified and the use of 2-D radars are not able to detect objects when driving under a bridge, however the use of 3-D radars are being used to resolve this issue (Rudolph & Voelke, 2017).

**LIDAR**

Lidar sensors are included in levels three through five of autonomous driving. Lidar stands for light detection and ranging sensors which operates similarly to radar but emits lasers in order to detect objects and calculate the distance in real-time (Dawkins, 2019). The beams from the lasers hit objects in the area and then transmit back to a photodetector. This calculates 3D images of the surrounding environment that creates a 360-degree map around the

autonomous vehicle (Rudolph & Voelke, 2017). The drawbacks of lidar sensors include certain

weather conditions blocking the sensor and that lidar sensors are very expensive to incorporate.

**ULTRASONIC**

Ultrasonic sensors rely on sonar or sound navigation and ranging in order to assist drivers

with parking and short range obstacle detection. The sensors emit short ultrasonic impulses that

bounce off of objects within the area. The signals are then processed and calculated to classify

the object and detect the distance. The ultrasonic transducer within the sensor receives a digital

transmit signal from the engine control unit (ECU) which causes the ultrasonic pulse to be

emitted (Jahromi, 2019). The sensor then received the sound vibrations from the object. The

vibrations are outputted as analog signals and is then converted to digital signal. Ultrasonic

sensors have the capability to see through objects as opposed to lidar, they operate well in bad

weather conditions, they are inexpensive, and they operate well in low light and fog conditions

unlike cameras. The major drawbacks of ultrasonic sensors include inaccurate detection of fast

moving objects, short range detection only, and they are unable to sense color.

**EXTRA LOCALIZATION**

The use of other localization sensors are used to assist the direction of the vehicle.

Inertial measurement unit (IMU) is a sensor that is used to determine the movement of the

vehicle and calculate the acceleration along the x,y, and z axes (Cohen, 2018). The global

positioning system (GPS) is a system used for vehicle position (Dawkins, 2019). The global

navigation satellite system (GNSS) is used for satellite position which is used to increase

accuracy (Cohen, 2018). Simultaneous localization and mapping (SLAM) is a technique that makes it possible to estimate the coordinates of the vehicle and landmarks (Cohen, 2018). With the intensive research on deep learning algorithms and cameras, localization in autonomous vehicles are becoming more effective.

**CONCLUSION**

As autonomous systems progress, the car manufacturing industry intends to incorporate an increasing level of automation into future vehicles. The integration of sensors are used to allow the autonomous vehicle to map their environment and respond accordingly. Each type of senor has its own advantages and disadvantages regarding range, detection, and reliability (Dawkins, 2019). A sensor fusion, or a combination of various sensors, will allow driving automation systems to be more efficient and propel the advancement of autonomous vehicles.

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