

# Autonomous Vehicles



## Complex Innovations Make Driving Simple

Modern technology has come a long way in making driving safer. One way is incorporating automated driving features into vehicles. There exist **five** levels of autonomously driving vehicles, each with different sensors [1].

 **Did you know?**  
Sensor packages include systems like LIDAR, RADAR, and Cameras [2].



"Level Zero"

### No Driving Automation

- No automation; the driver performs all the dynamic driving tasks (DDT) such as steering, braking, etc.
- Driver responsible for vehicle motion control, and object event detection and response (OEDR) [1].
- Vehicles may have basic sensors, such as camera systems [2].

### Driver Assistance

- Both the driver and system responsible for vehicle motion control [1].
- Driver responsible for OEDR and DDT [1].
- Camera and RADAR sensors [2].



Level One



Level Two

### Partial Driving Automation

- Only the system responsible for vehicle motion control [1].
- Driver responsible for OEDR and DDT [1].
- Camera and RADAR sensors [2].



### Conditional Driving Automation

- System responsible for vehicle motion control + OEDR [1].
- System normally responsible for DDT, but a driver fallback system is in place [1].
- Camera, RADAR, LIDAR sensors [2].



Level Three



Level Four

### High Driving Automation

- System fully responsible for vehicle motion, control, OEDR, and DDT [1].
- No expectation that the driver will intervene [1].
- Camera, RADAR, and LIDAR sensors [2].


### Full Driving Automation

- System fully responsible for vehicle motion control, OEDR, and DDT [1].
- Only level where vehicle has unlimited operational design domain (ODD) [1].
- Camera, RADAR, and LIDAR (if not more) sensors [2].

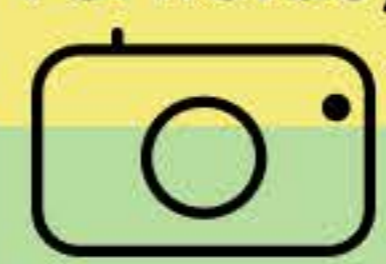


Level Five




 **More about Sensors**  
Sensors help a self driving car "see." Together, camera, RADAR, and LIDAR sensors provide a car a visual of its surroundings, and detect the speed, distance, and shape of nearby objects [2].

Cameras (found in almost all vehicles), take picture + video data [3].



RADAR transmits radio waves to locate objects [3].



 LIDAR creates 3D images via a pulsating laser [3].

SOURCES  
 1 "Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles", 2018, SAE-J  
 2 "How Does a Self Driving Car See?", 2019, NVIDIA  
 3 "Three Sensor types drive Autonomous Vehicle", 2017, Fierce Electronics

# Autonomous Vehicles

## A guide to autonomous vehicle levels and sensor packages

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Self driving vehicles, also known as autonomous vehicles, are instrumental in providing a safer, easier, and more convenient driving experience. Unlike traditional vehicles, autonomous vehicles incorporate automated features that can allow for breaking, steering, and even full control of the entire dynamic driving task (DDT). As the field of autonomous vehicles becomes more promising, technology companies, car manufacturers, and universities are investing a greater amount of resources into the development of autonomous driving. There currently exist several levels of autonomous driving, ranging from no driver automation ('level zero') to full driving automation ('level five') (2).

Each autonomous driving vehicle has different sensor packages associated with it. These sensors allow the vehicle to 'see' its environment in order to know where they can and cannot drive, detect external roadblocks, and handle unexpected circumstances. The most common primary sensors in vehicles include camera, radio detection and ranging (radar), and light detection and ranging (LiDAR) sensors (1).

The first level of driving automation is a system in which the entire task of driving falls upon the driver of the vehicle. This is commonly nicknamed "level zero," or No Driving Automation. In this level, the driver alone is responsible for lateral and longitudinal vehicle motion control, such as maintaining speed, applying brakes, and allowing for an appropriate gap between it and a preceding car. The driver is also responsible for object event detection and response (OEDR) (2). Level zero vehicles may have a few automated features, such as cruise control; however, these do not replace the need for a driver on a sustained fashion. The vast majority of cars on the market offer level zero features (3).

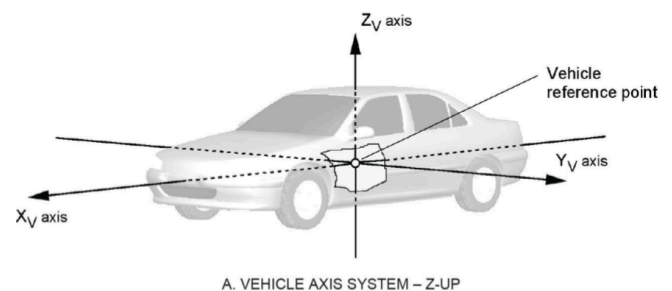
Level one vehicles, also known as Driver Assistance Vehicles, rely on both the driver and the system for vehicle motion control (2). These vehicles have features such as adaptive cruise control and lane keep assist. These features assist drivers, but still require the driver to be in control (3). The driver is solely responsible for OEDR. The operational design domain

(ODD), or the operating conditions in which the can function, is limited (2). The majority of vehicles in production today also offer level one features (3).

Level two vehicles are also known as Partial Driving Automation vehicles. These vehicles are distinctive because the system performs lateral and longitudinal vehicle motion control (2). These vehicles can assist with controlling speed, steering, and maintaining a safe distance around the vehicle (3). However, the system does incorporate a driver DDT fallback in case of emergencies or if the driver simply wants to take control. Like level one vehicles, the driver is also responsible for OEDR and the ODD is limited (2). Some examples of level two vehicles include the Tesla Autopilot and the Volvo Pilot Assist (3).

Level three vehicles are known as Conditional Driving Automation Vehicles (2). These vehicles can drive themselves, but only under certain conditions and with certain limitations (3). Drivers are still required behind the wheel and must remain alert in case they need to take over (4). The system is responsible for OEDR and vehicle motion control. The 2019 Audi A8L is an example of a level three vehicle (4).

Level four vehicles are known as High Driving Automation Vehicles (2). The main difference between level three and four vehicles is that level four vehicles can intervene if there is a system failure. Because of this, these vehicles do not require human interaction in most instances, although a 'driver' still has the ability to manually override the system (4). Therefore, vehicle



In level 2+ vehicles, longitudinal (x axis) and lateral (y axis) vehicle motion control is the primary responsibility of the system (2).

motion control, OEDR, and DDT fallback are all the responsibility of the system (2). However, level four vehicles are subjected to geofencing, meaning they can only operate within a limited geographic area in which conditions are carefully monitored and controlled (4). Therefore, as in levels 1-3, the ODD is limited (2). Most level four vehicles are aimed at ride-sharing (4). For example, in 2018, Waymo introduced a level four taxi service in Arizona (5).

The final level of autonomous vehicles is not yet available to the general public (4). These vehicles are also classified as Full Driving Automation vehicles, meaning there is no need for human attention. The automation system is fully responsible for vehicle motion control, OEDR, and DDT fallback. Unlike all previous levels, the ODD the unlimited (2), meaning this vehicle is free from geofencing and can travel anywhere an experienced driver can (4). However, while these vehicles are undergoing testing by many technological and manufacturing companies, their introduction is likely several years away (3).

Part of what makes the capabilities of autonomous vehicles possible is the sensor packages associated with them. The three primary sensor systems in autonomous vehicles include camera, radar, and LIDAR systems. The majority of vehicles use sensor fusion, or the blending of different sensor systems to create a more “aware” vehicle. Each sensor has its own strengths and weaknesses which include differences in detection capabilities, reliability, and range. High level autonomous vehicles typically have more expensive and extensive sensor packages (1).

The most common sensor in vehicles is a camera. Almost all vehicles in development, from level zero to level five vehicles, have some sort of camera to detect and recognize objects. Vehicles with lane departure warning systems (LDW) employ front facing cameras that detect painted road markings. As vehicle autonomy increases, more cameras, often with wider range lenses, are incorporated to build a more comprehensive view of the vehicle’s environment. Infrared cameras are also commonly employed in high level vehicles to allow extra sensing capabilities and visibility in darkness. However, there are some weaknesses that cameras alone entail. Multiple cameras generate high volumes of video data, which requires extensive computing software. Furthermore, basic, non-infrared cameras do not work well in low visibility conditions, such as fog, rain, or night (1). While cameras



A 360 degree panoramic camera (1)

may detect objects, they often have difficulty locating the exact distance objects are away. Because of this, many higher level vehicles employ radar technology as well (6).

Radar is a technology that traditionally has been used to detect aircrafts, ships, and weather formations, but is now a staple of autonomous vehicles (6). For example, adaptive cruise control, which is found beginning in level one vehicles, relies on radar sensors (1). Radar sensors help aid camera vision during times of low visibility, such as night, fog, and snow. Radar works by transmitting radio waves in pulses. Once these waves hit another object, they return to the original sensor. This gives information about the presence, location, and speed of surrounding objects (6). The two most common varieties of radar in vehicles include 77 GHz and 24 GHz radars, with the 77GHz used for longer-range sensing and the 24 GHz radar used for shorter range sensing (1). Overall, using a combination of different radar sensors along with cameras increases the detection capabilities of the entire vehicle (6). However, radar is not flawless. Radar works best at detecting objects made of metal so random metal objects near the road, such as dented road sign, may give inconsistent data about surroundings (1).

For full driverless capabilities (level 3 and above), LIDAR sensors are often utilized. LIDAR is a sensor that measures distances via a pulsating laser (6). The laser beams hit objects in the environment and sends the information back to a photodetector. Once the beams are analyzed, a 3D image of the environment is created (1). This is especially useful because it allows cars to visualize not only the shape, yet also the depth of nearby objects. LIDAR is also able to create 3D images almost instantly because the lasers travel at an incredibly fast speed (6). Similarly to radar, LIDAR also works well in low light conditions. However, LIDAR is often much more

expensive than both camera and radar technologies because often one singular device can allow for a complete view of surroundings (1). Furthermore, rare metals are needed to make LIDAR sensors which drives up the price (7).

While LIDAR, radar, and cameras together provide the vast majority of signal and 'sight' for a given vehicle, there do exist other sensors in vehicles. High definition maps, inertial measurement units (IMUs), global positioning system (GPS), and vehicle-to-everything (V2X) communication are some examples of these accessory sensors (1).

Overall, sensors play a critical role in autonomous vehicles, as they allow for a vehicle to monitor its surroundings. In combination with software and computers they eventually allow for the system to take full awareness. The exact sensors placed in a vehicle depend heavily on the level of the vehicle, the price put into manufacturing the car, and technology available during at the time the car was manufactured (3). For example, the cameras placed in a level one vehicle ten years ago usually offer much less visibility than cameras placed in a level one vehicle today. While the field of autonomous vehicles continues to advance, existing sensors continue to be innovated and improved upon (1).

## References

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