Autonomous Driving and Its Sensor Technology

Autonomous driving has the potential to improve the safety and efficiency of the transportation system. Sensors are the key components of autonomous vehicles.

The Levels of Autonomous Driving

Human monitors the environment

L0 — No Automation. Human driver completes all driving tasks.

L1 — Hands **or** feet off. | The System controls **either** the vehicle's speed or steering. *cameras and RADARs*

Ex: any car with auto braking or lane assist

L2 — Hands **and** feet off. | The system controls **both** the vehicle's speed and steering. *cameras and RADARs*

Ex: TESLA, MOBILEYE

The system monitors the environment

L3 — Human driver will be needed at times. Eyes off. | The system handles "dynamic driving tasks" under limited driving condition. *Cameras, RADARs, and LIDARs* [2]

Ex: (Audi), NVIDIA, WAYMO

L4 — Human driver can be needed to intervene. Brain off. | The system handles "dynamic driving tasks" under certain driving condition. [1]

Ex: none

L5 — The system has a full control of all driving tasks under all driving conditions.

Ex: none

The Sensor Packages

Autonomous Vehicles (AV)

Exteroceptive Sensors

Camera
allows the vehicle to identify road signs, traffic lights, lane markings and determine the distance to an object

LIDAR
- used for measuring distances
- sends out a pulsed laser of light and measures the time it takes for the pulse to be reflected back

RADAR
uses radio waves to measure the distance, angle and velocity of objects

Ultrasonic
uses sound waves to measure the distance to an object

Proprioceptive Sensors

GPS
provides geolocation and time information

IMU
Inertial Measurement Unit
- used for control and guidance of autonomous vehicles
- measures a body's force, angular rate and magnetic field

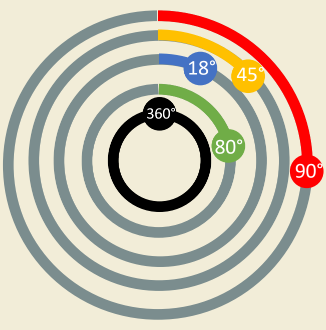
Encoders
- used to provide odometer data on the vehicle
- provides information on position, direction and velocity within a control system [3]

Connected Vehicles (CV)

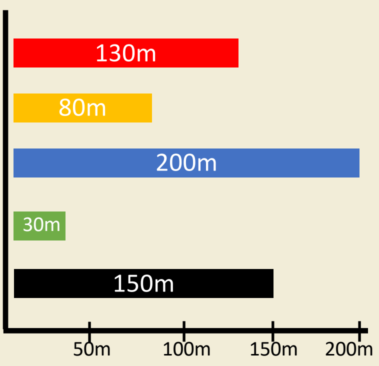
Dedicated short-range communications (DSRC)

vehicle-to-vehicle and vehicle-to-infrastructure wireless communications used for connected vehicles. CVs can communicate recent and future actions with each other. [4]

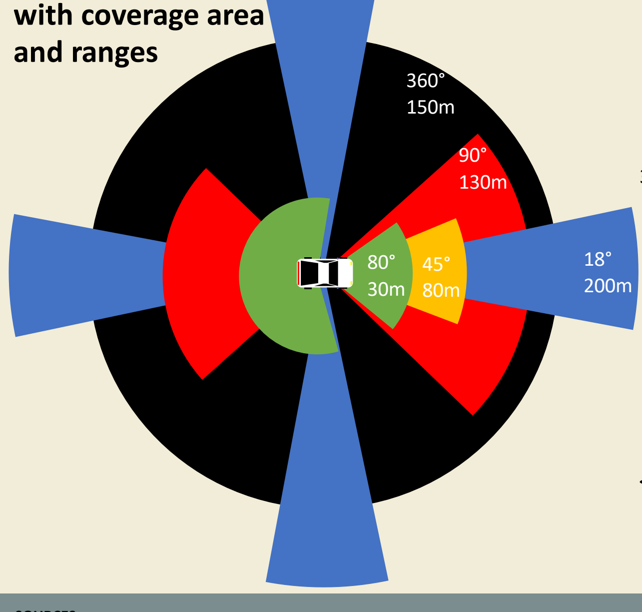
Field of View(Horizontal) in degrees



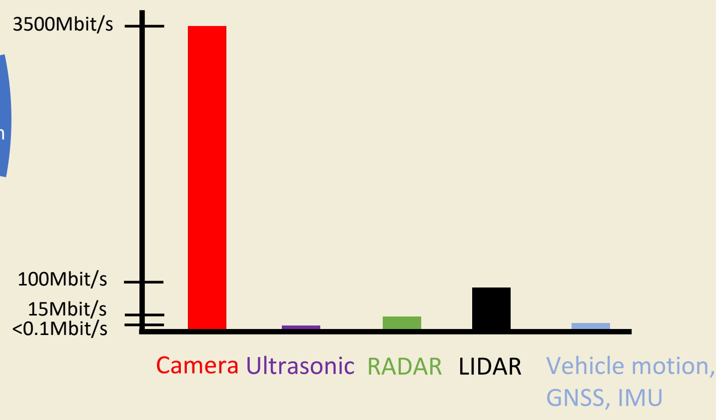
Range in meters



Various sensors, with coverage area and ranges



Data generated per sensor [5]



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CREATED BY
Tergel Molom-Ochir
UMass Amherst
Dec, 2019

Autonomous Driving and Its Sensor Technology(Supporting Document)

Tergel Molom-Ochir
University of Massachusetts Amherst
Amherst, Massachusetts

***Abstract*— This supporting document will address and clarify topics from the infographic "Autonomous Driving and Its Sensor Technology" by reviewing the levels of autonomous driving and the sensor packages used to create autonomous vehicles. For any type of autonomous vehicle, sensors are crucial to sense the environment to make calculated decisions. This supporting document elaborates on the level of autonomous driving, sensors, their advantages and disadvantages, and a comparison between the sensors.**

Keywords: levels, sensors, autonomous driving.

I. INTRODUCTION

Driving is a necessity for today's life. In recent years, research in the field of autonomous vehicles has advanced remarkably due to the research and development in the field of sensors [3]. As a consequence, the levels of autonomous driving have been defined and the advantages and disadvantages of each sensor have been evaluated [3]. In this supporting document, we review the levels of autonomous driving (Section 2) and the sensors that are frequently used in modern autonomous vehicles, their advantages and disadvantages, and a comparison between the sensors (Section 3) expand upon and clarify topics from the infographic "Autonomous Driving and Its Sensor Technology."

II. LEVELS

To better inform the public, the National Highway Traffic Safety Administration of the United States Department of Transportation published "Automated Vehicles Safety" in which they discussed timeline, levels of autonomous driving and benefits of automation [6]. The following are the levels of autonomous driving.

- Level 0 – No automation

This level has no automation. The human driver completes all driving tasks under any driving conditions.

- Level 1 – Driver Assistance

The system can control either the vehicle's speed or steering. The driver can be hands or feet off. At this level, the human driver monitors the environment and driving. Cameras and RADARs are widely used at this level. Any car with auto-braking or lane assist feature is level 1 [1][4].

- Level 2 – Partial Automation

The system can control both the vehicle's speed and steering. Level two autonomous vehicles have Automatic Emergency Braking (AEB) plus Lane Keeping Assist (LKA) features. The human driver can be hands and feet off. At this level, the human driver still monitors the environment and driving. Cameras and RADARs are widely used at this level. Vehicle control is shared between the human driver and the system. Companies such as Tesla and Mobileye are known for producing Level two autonomous vehicles [1][4].

- Level 3 – Conditional Automation

The system can perform driving tasks under limited driving conditions, but the human driver will be needed to intervene and resume driving at times. The human driver engagement can be considered to be "Eyes-Off engagement." Starting from this level, the system monitors the environment and driving. Cameras, RADARs, and LIDARs are commonly used at this level. Vehicle control is shared between the human driver and the system. Companies such as Nvidia/Audi and Waymo are known for building experimental level three autonomous vehicles [1][4].

- Level 4 – high automation

The system will perform all driving tasks even if the human driver does not respond. Driver engagement can be considered to be "Brain-off engagement". The system monitors the environment and driving. The automated system has full control over the vehicle. There are no examples because level four automation has not been developed yet [1][4].

- Level 5 – Full Automation

The system will perform all driving tasks without any help from the human driver. The human driver does not need to be present. Driver engagement can be considered to be "Brain-off engagement". The automated system has full control over the vehicle and monitors the environment and driving. Level five has not been developed yet; therefore, there are no examples [1][4].

III. SENSORS

Figure 1 presents two main types of sensors: exteroceptive sensors and proprioceptive sensors. Exteroceptive sensors are used to get information about the surrounding environment while proprioceptive sensors are used for measuring values within the system [3]. As shown in Figure 1, camera, LIDAR, RADAR and ultrasonic sensors are exteroceptive sensors, used to perceive the environment while GPS, IMU, and encoders are proprioceptive sensors, used to provide motor speed, wheel position, latitude and longitude, etc.

A. Exteroceptive sensors – Autonomous Vehicles

1) Camera

Because with cameras, color vision is possible, autonomous vehicles will be able to identify road signs, traffic lights, lane markings, which is crucial for dealing with traffic. A real-time video object detection is used for autonomous vehicles. The field of view is ~ 45° to ~ 90° for cameras. Furthermore, the range varies for different types of cameras with different focal lengths but generally, the range is ~150 meters for monocular systems and ~100 meters for stereo systems. Resolutions vary by a large margin [3]. The main advantage cameras have over other sensors is that they can see colors and textures. In contrast, the main disadvantage of cameras is that they can be affected by weather conditions and they are sensitive to low-intensity lights [4].

2) LIDAR

LIDAR, which stands for Light Detection and Ranging, is a remote sensing technology that is used for determining accurate distance and size information of objects in the surrounding environment. LIDAR operates by sending out a pulsed laser of light and measuring the time it takes for it to be reflected. This principle is known as the time of flight (TOF). Measurements are gathered and are used to generate a 3D map of the surrounding environment. The field of view for a LIDAR sensor is 360°. The range is about 200m on average. It can be over 250m for long-range sensors [3]. The main advantage of LIDAR sensors is their high precision and accuracy. However, the main disadvantage is their high cost and low availability [4].

3) RADAR

Radar is a system that sends out pulses of electromagnetic waves to determine the presence, direction, distance, angle, and velocity of objects. The field of view of a radar sensor is ~ 15° for long-range radar sensors and ~ 90° short-range radar sensors. The range can be around 250 meters [3]. Radar sensors offer many benefits for autonomous vehicles, two of which are low cost and high availability. Due to their high availability, ADAS systems (advanced driver-assistance systems) are common in modern vehicles [4]

4) Ultrasonic

An ultrasonic sensor uses sound waves to measure the distance to an object by emitting it towards the object and measuring the time it takes for the waves to return. The main advantage is that they are the cheapest exteroceptive sensor that can be found for autonomous vehicles. Ultrasonic sensors are good at short range measurements; they are the most accurate sensor for close proximity applications. However, the main disadvantages of these sensors come from disturbances in the sound waves. The sound waves can be disturbed by temperature and humidity as sound travels in a medium [3].

B. Proprioceptive sensors – Autonomous Vehicles

1) GPS

GPS is a system that provides geolocation and time information by connecting the GPS receiver to GPS satellites. For autonomous vehicles and driving, GPS sensors are crucial for navigation and localization. The main advantage is that they are accurate; their accuracies can range from a few centimeters to 3 meters. The main disadvantage, however, is that because GPS sensors need a direct line of sight with the satellites, navigation indoor or underground cannot be calculated [3].

2) IMU

IMU, an Inertial Measurement Unit, is a device that measures force, angular rate, and magnetic field of a body using three accelerometers, gyroscopes, and magnetometers. From the raw IMU data, linear velocity, altitude, and angular positions (relative to a global reference frame) of autonomous vehicles can be calculated. There are a few disadvantages of IMU due to how they work. The main disadvantage is that they only provide motion information and not location information. Another disadvantage is that the data can be affected by drift errors. These problems can be solved by implementing GPS devices [3].

3) Encoders

Encoders are electro-mechanical devices that provide information on position, direction, and velocity within a control system. They are commonly used to provide odometer data. The main advantage is that they are cost-efficient and easy to install. However, the disadvantage is that slippage between the wheels and the ground can affect the data, providing wrong localization and velocity information [3].

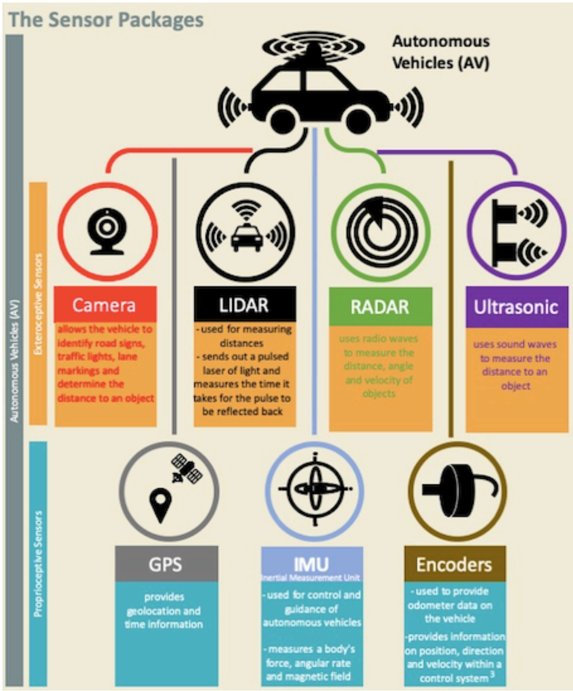

Figure 1. Exteroceptive Sensors and Proprioceptive Sensors

C. Dedicated short-range communication (DSRC) – Connected Vehicles

DSRC is a wireless communication method for connected vehicles. Connected vehicles will be able to communicate recent and future actions with each other. Each connected vehicle will be able to wirelessly send and receive information [3].

IV. COMPARISON

On the infographic "Autonomous Driving and Its Sensor Technology," comparisons between sensors were made as shown in Figure 2. First, when the horizontal field of view was compared, LIDAR had the most field of view of 360° and long and mid-range radars had the least field of view of 18°. Second, when comparing the ranges, long and mid-range radars had the longest range and short-range radars had the shortest range of all the sensors. Lastly, how much data each sensor generates was displayed as a column chart. Cameras generate the most data and ultrasonic sensors generate the least amount of data among all the other sensors [4].

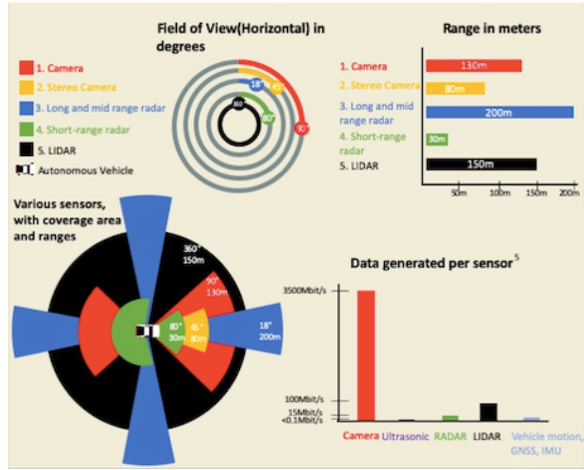

Figure 2. Comparison between exteroceptive sensors

V. CONCLUSION

This supporting document expands upon and clarifies topics from the infographic "Autonomous Driving and Its Sensor Technology" by elaborating on the level of autonomous driving, sensors, their advantages and disadvantages, and a comparison between the sensors. In recent years, with the improve in the field of sensors, the field of autonomous vehicles has improved drastically. Autonomous driving has the potential to improve safety and transportation on roads.

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