Autonomous Car Sensors summary

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Artificial Intelligence & Information Analysis Lab

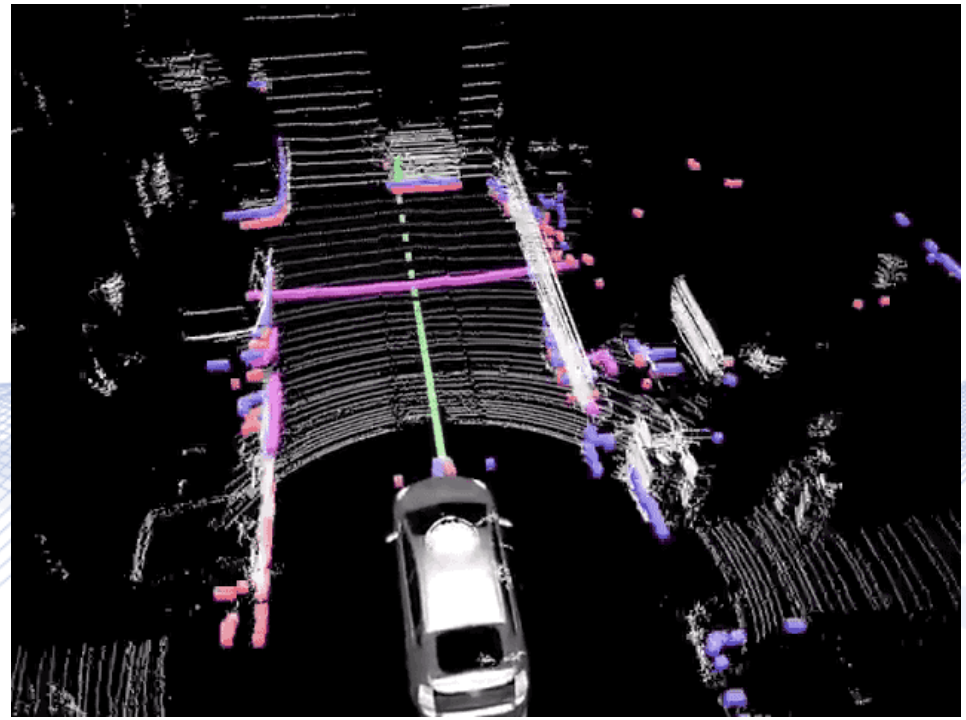
Autonomous Car Sensors

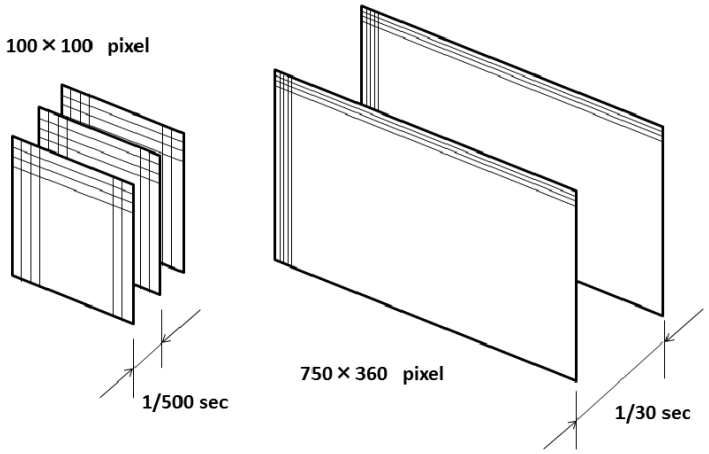
- **Introduction**
- Automation Levels
- Car Environment sensors
- 1D Signal Car Sensors
- Traffic sensors
- Present Autonomous Car Companies
- Conclusion

Introduction

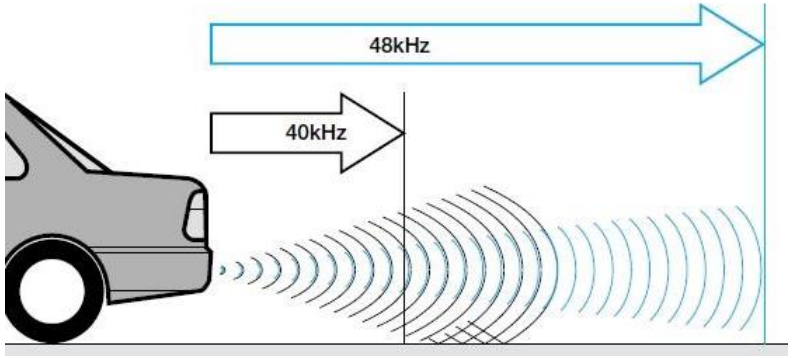
Autonomous (auto) **car sensors** are generally used to acquire data from the environment for the car to process. Each sensor is chosen as a trade-off between:

- Sampling rate
- Field of view
- Accuracy
- Range
- Overall system complexity



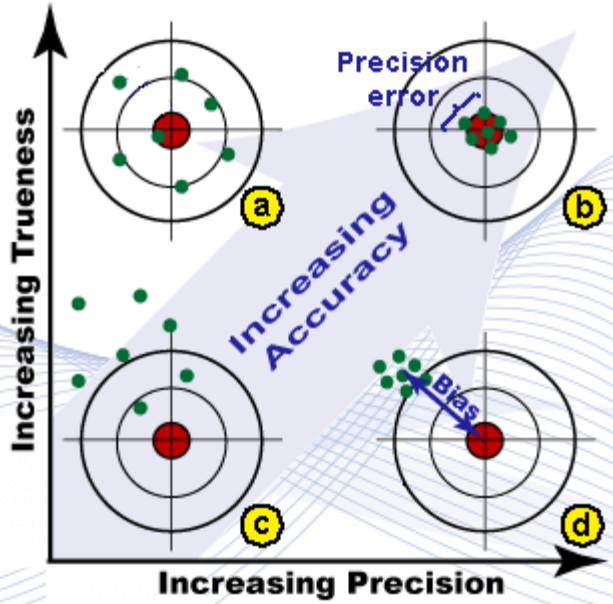


Sampling rate

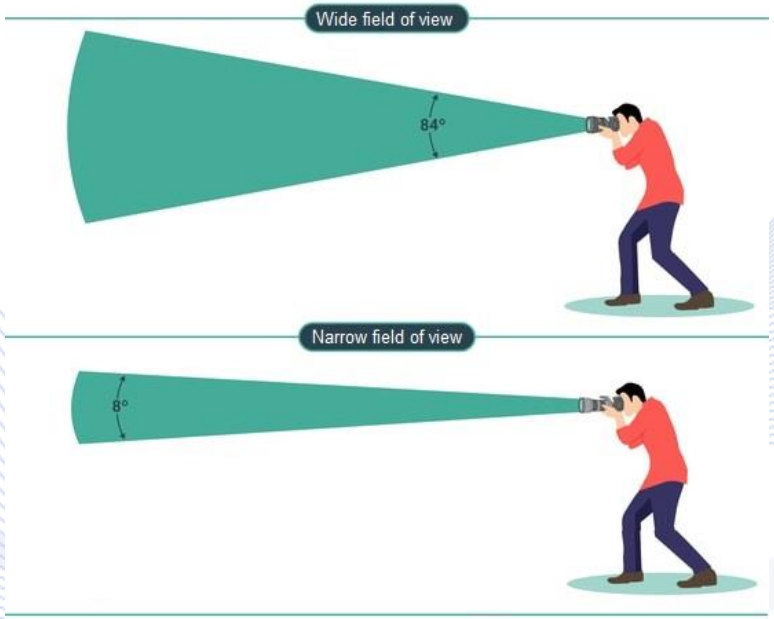


Range

Overall system complexity



Accuracy

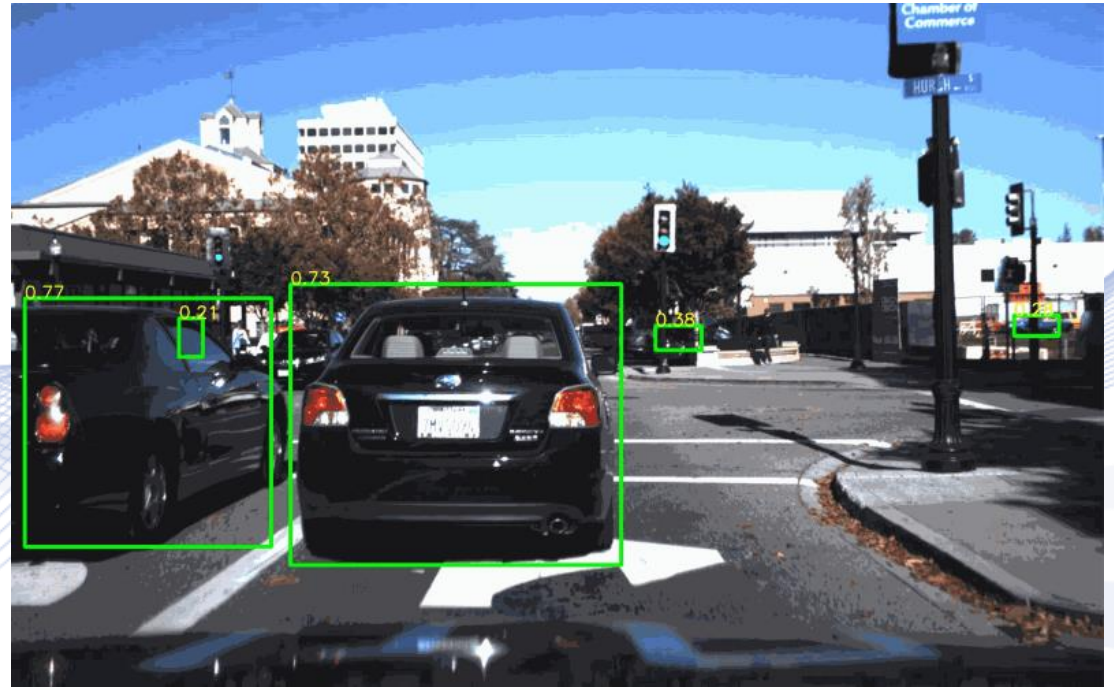


Field of view

Introduction

All that data from the sensors are processed by software to turn the car into an **intelligent machine**. Some advantages of autonomous cars are:

- Reduce pollution, emissions
- Improved safety
- Reduce congestion
- Greater efficiency, reliability, convenience
- Reduce costs, maintenance requirements



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Automation Levels

0	1	2	3	4	5
No Automation	**Driver Assistance**	**Partial Automation**	**Conditional Automation**	**High Automation**	**Full Automation**
Zero autonomy; the driver performs all driving tasks.	Vehicle is controlled by the driver, but some driving assist features may be included in the vehicle design.	Vehicle has combined automated functions, like acceleration and steering, but the driver must remain engaged with the driving task and monitor the environment at all times.	Driver is a necessity, but is not required to monitor the environment. The driver must be ready to take control of the vehicle at all times with notice.	The vehicle is capable of performing all driving functions under certain conditions. The driver may have the option to control the vehicle.	The vehicle is capable of performing all driving functions under all conditions. The driver may have the option to control the vehicle.

Automation Levels

	LEVEL 0	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
Monitoring the road						
Steering, Acceleration, Deceleration						
Monitoring surroundings						
Fallback for self-driving failures						
Automation takes full control						

 = Human  = Automation  = Some Control

Ford Model T (Level 0)

Ford Focus ST-line (Level 1)

Tesla Model S (Level 2)

Uber Self-Driving car (Level 3)

Waymo Self-Driving car (Level 4)

Audi Aicon Concept car (Level 5)

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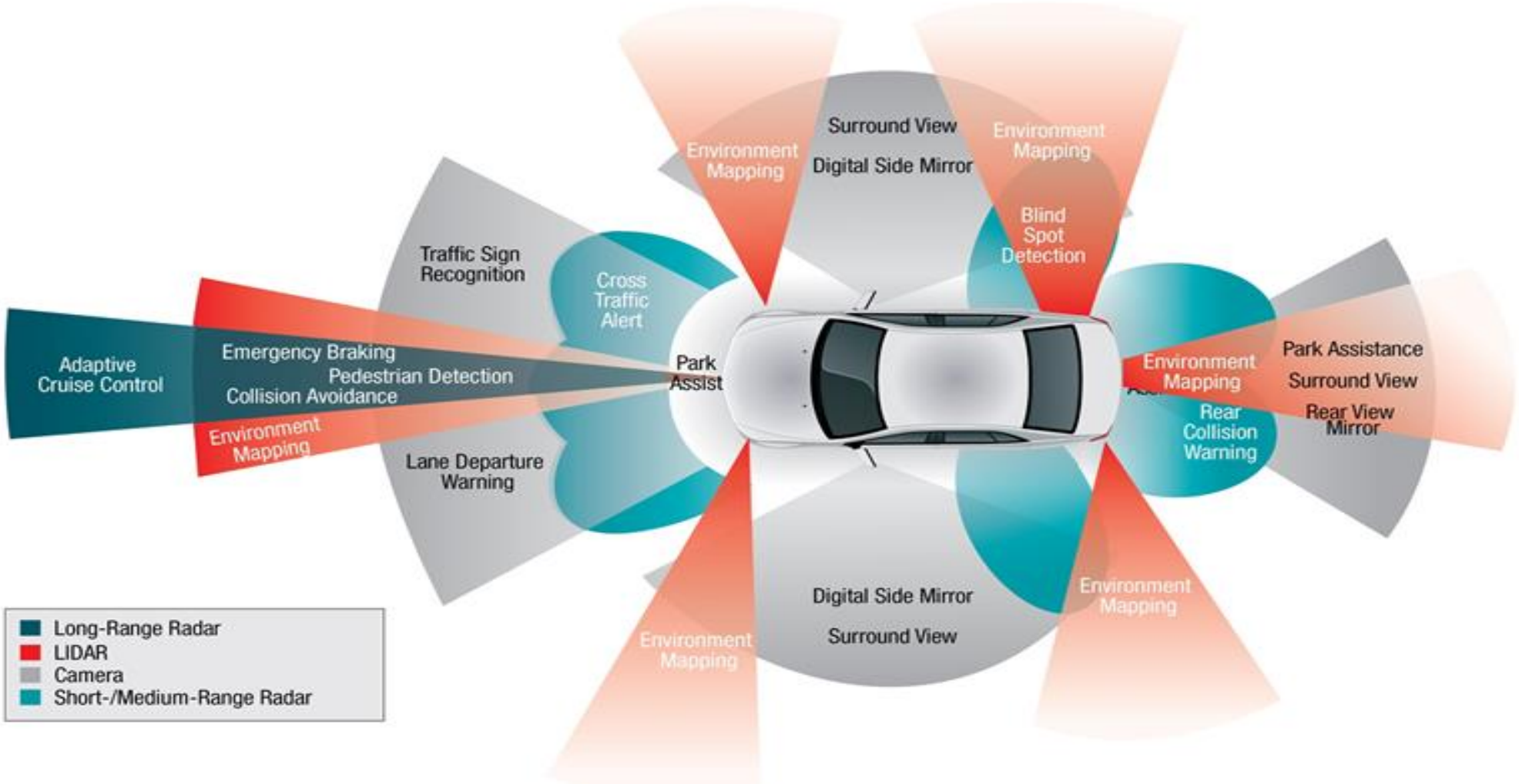
Autonomous car sensors

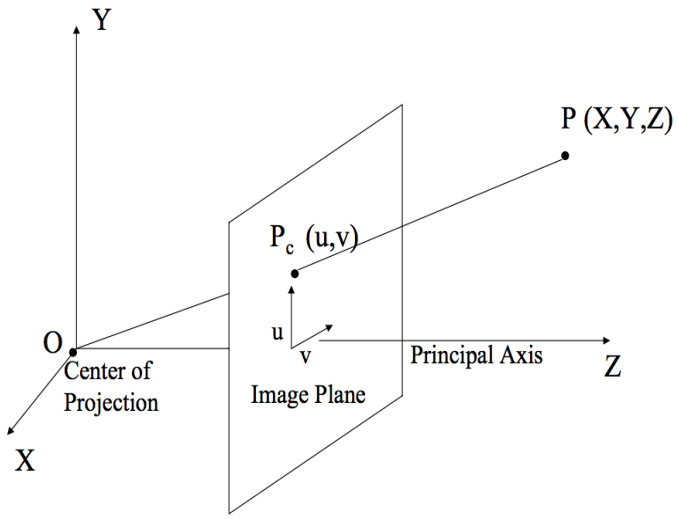


Cameras

- ***Monocular camera*** senses light passing light through a series of lenses and hits a photosensive device, e.g., a CCD.
- It is cheaper a stereo camera, but does not provide depth information.

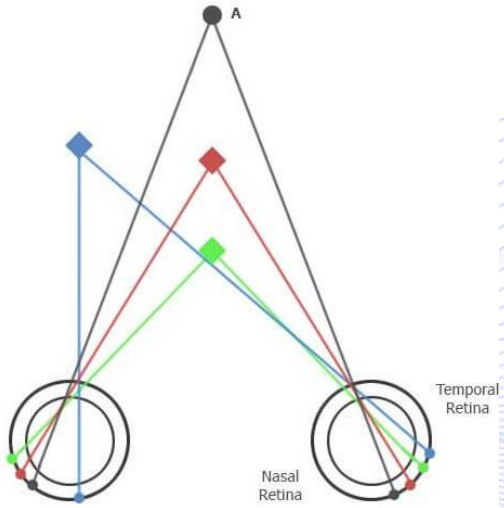
Cameras

- **Camera calibration** estimates the intrinsic and extrinsic canera parameters.
- They can be used to determine object position and size.



Cameras

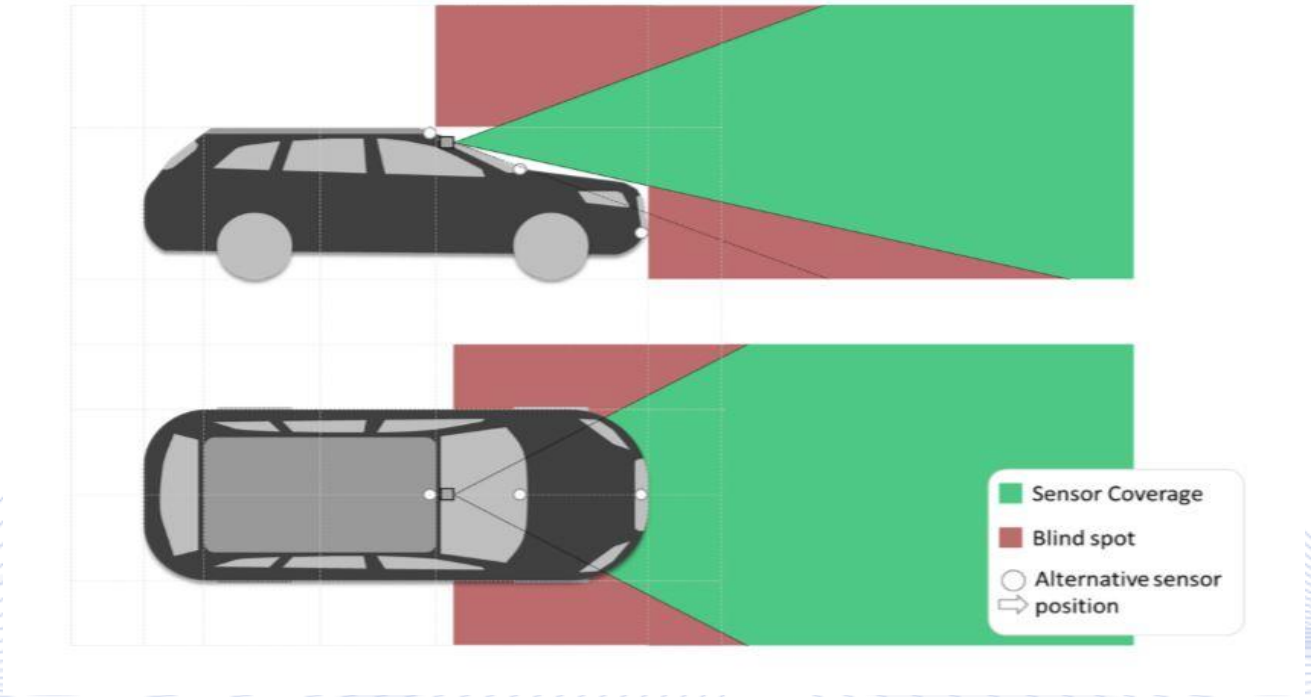
- ***Stereo camera* has** two lenses and image sensors.
- It simulate the human binocular vision and allows depth estimation.



Right Camera

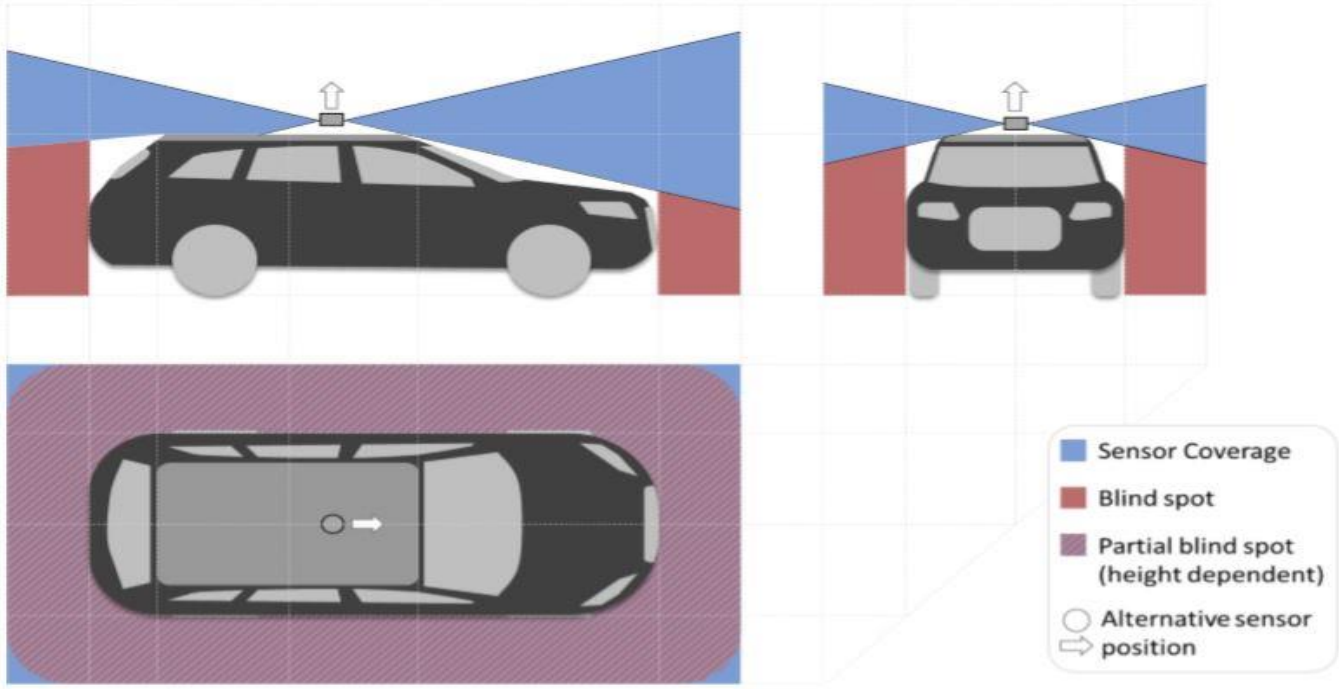
Left Camera

Cameras



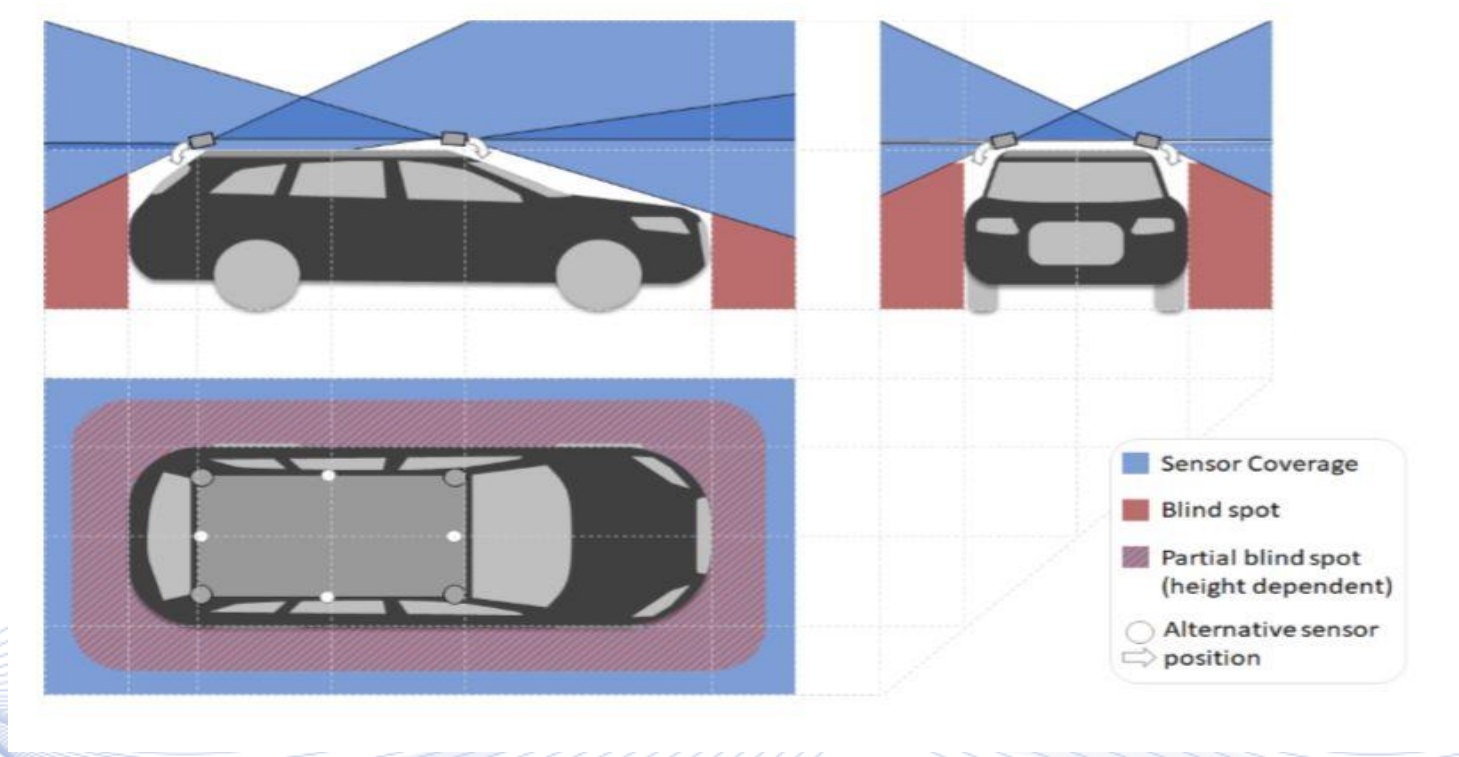
Front camera is usually located centrally on the top of the windscreen.

Lidars



Single Lidar on roof center. Blind spots exist at the bottom of the car.

Lidars



Multiple Lidars on car roof.

Other Car Sensors

- Microsoft Kinect can perform cheap 3D road geometry reconstruction.
- It is equipped with an RGB camera, an IR sensor or camera, microphones, accelerometer and a tilt motor for motion tracking facility.
- The IR camera provides depth images having resolution:
  - 640×480 pixel at 30 Hz.
  - 1280×1024 pixel at 10 Hz.
- Its working range is between 0,8 m and 4 m, making it suitable for road imaging when mounted on a vehicle.

Other Car Sensors

- ***Radars*** use radio waves to determine the range, angle, or velocity of objects.
- ***Ultrasonic transducers*** calculate the distance to an object by measuring the ultrasonic Time-of-Flight.
- ***Global positioning system*** (GPS) provides time and geolocation information for autonomous cars.
- ***Inertial measurement unit*** (IMU) measures an autonomous car accelaration, angular orientation/velocity, using a combination of accelerometers, gyroscopes and magnetometers.

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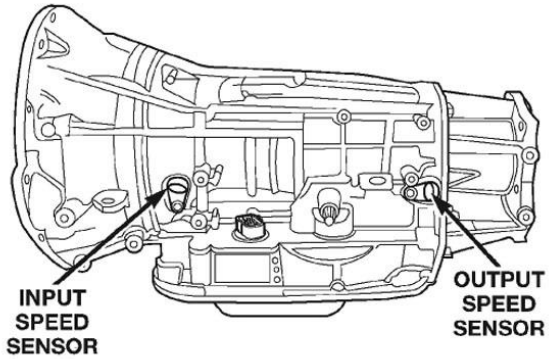
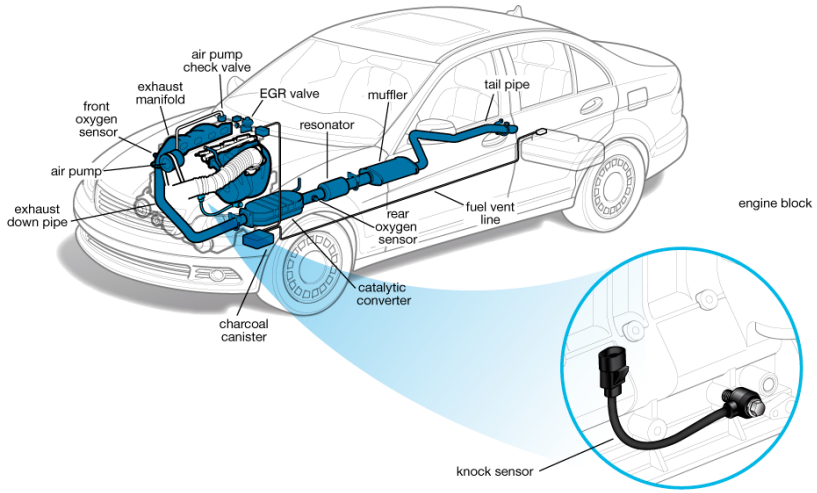
1D Signal Car Sensors

Autonomous cars need to monitor not only the outside for navigating, but also the inside functions to properly run. These sensors that regulate the later functions mainly send a one-dimensional (1D) signal. A signal which is a function of a single independent variable is called 1D signal. Some sensors that collect this kind of signal are:

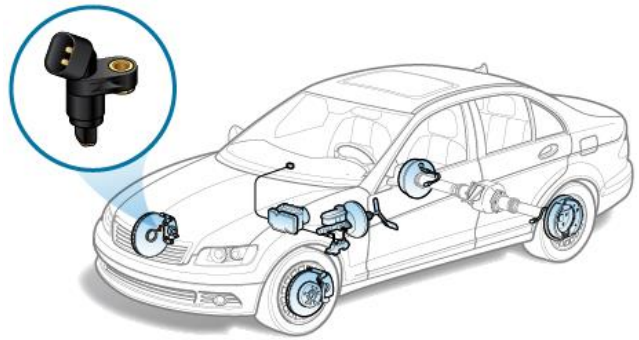
- Engine speed sensor
- Vehicle speed sensor
- Odometry sensor
- Mass air flow sensor
- Spark knock sensor
- Coolant temperature sensor
- Fuel temperature sensor
- Inertial measurement unit
- Throttle position sensor
- Steering angle sensor

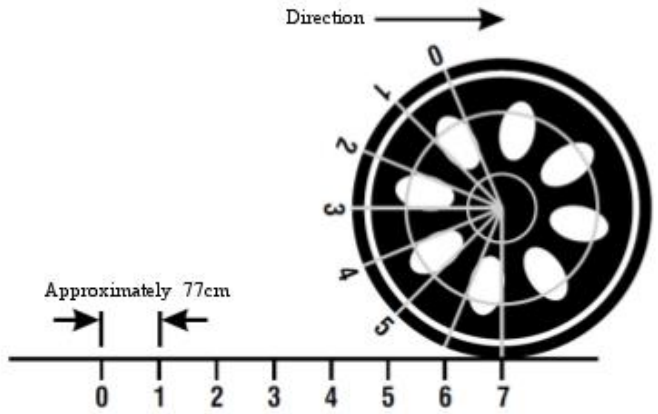


Engine speed sensor

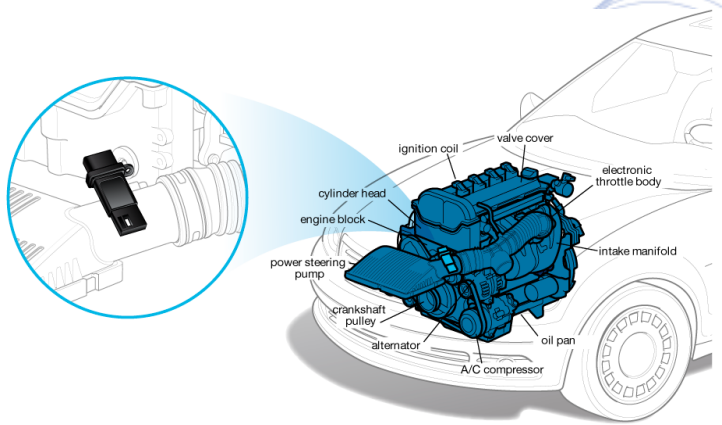


Spark knock sensor



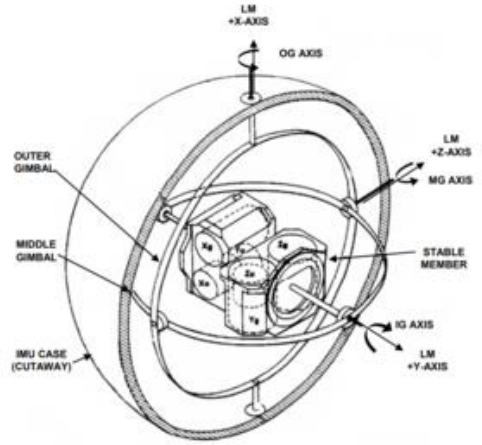


Odometry sensor

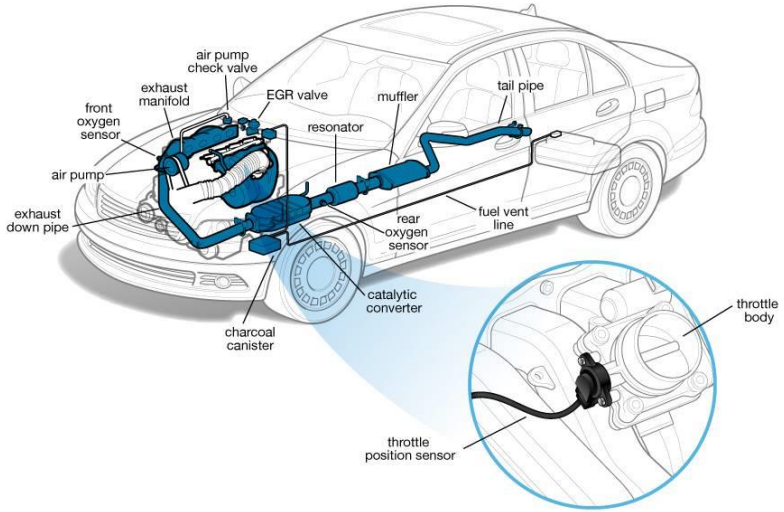


Mass airflow sensor

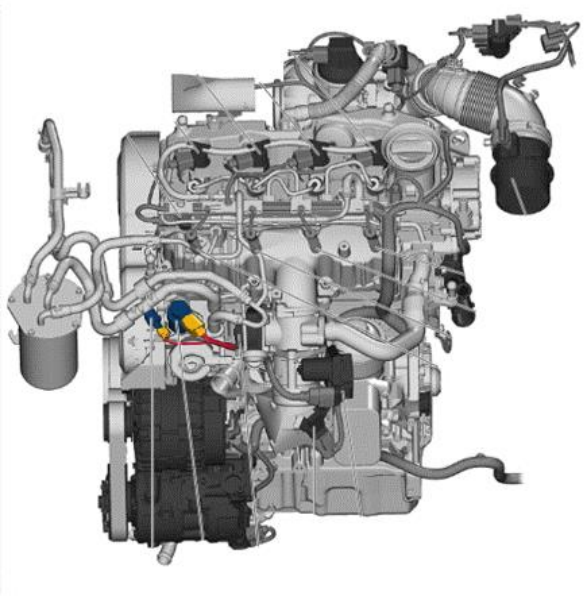
Vehicle speed sensor



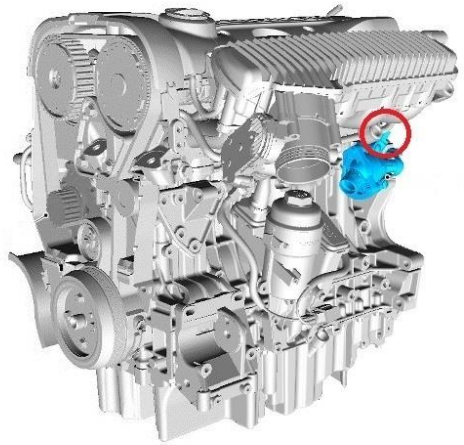
Inertial measurement unit



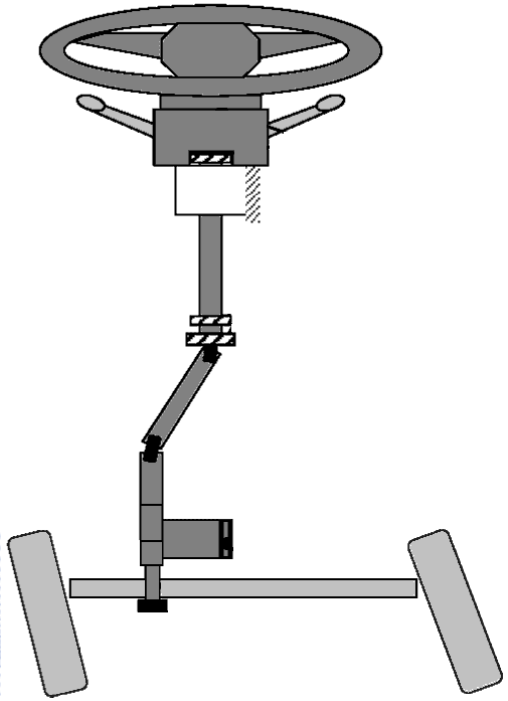
Throttle position sensor



Fuel temperature sensor



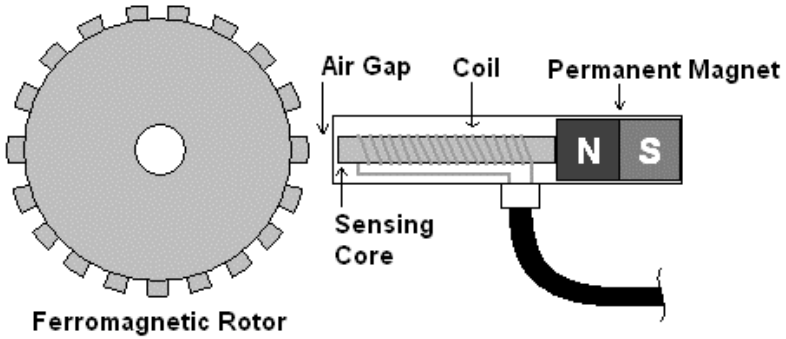
Coolant temperature sensor



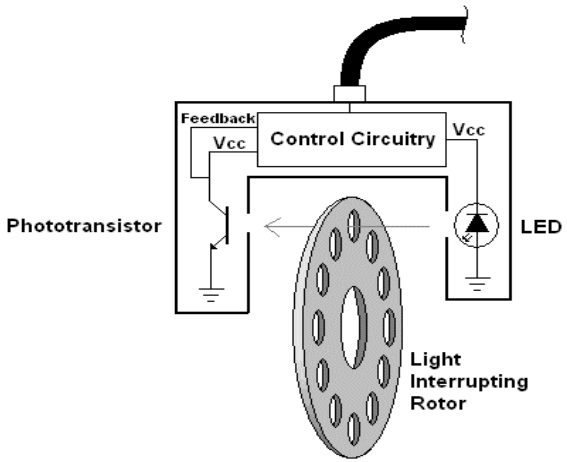
Steering angle sensor

Engine Speed Sensor

The **engine speed sensor** is the most important sensor of the engine management system. In addition to the speed, this sensor, together with the trigger wheel determines the crankshaft position. There are two types, the induction and the optical ones.



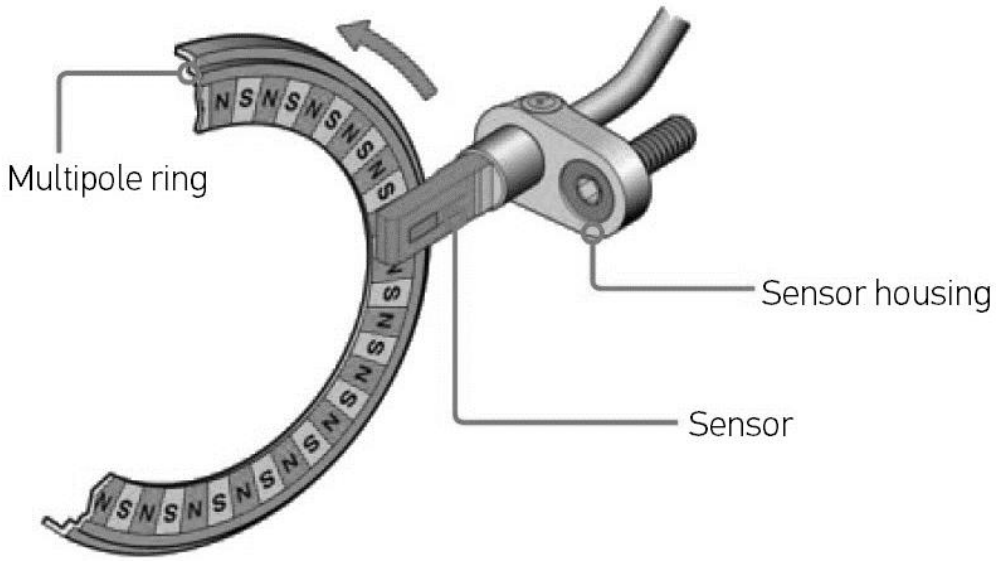
Induction



Optical

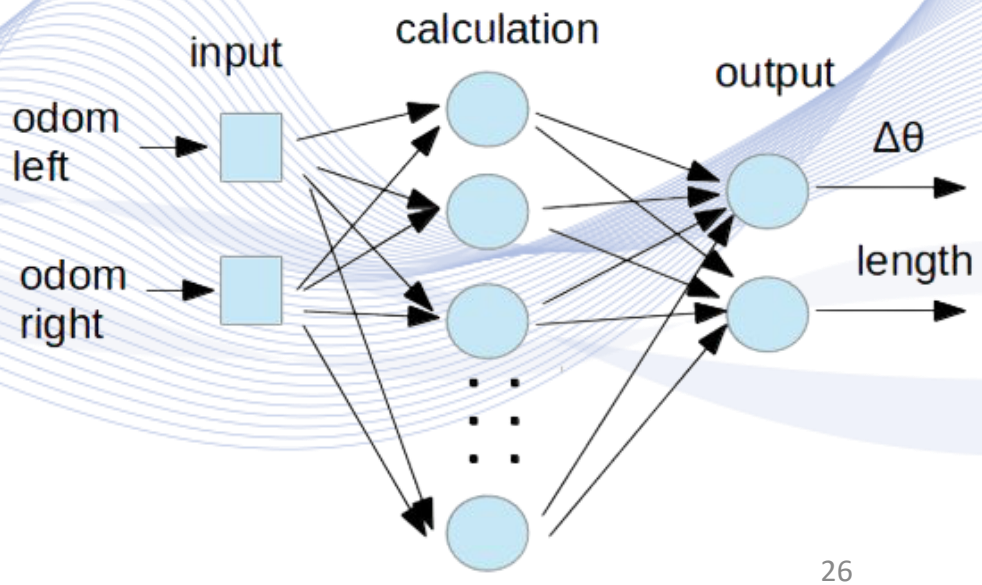
Vehicle Speed Sensor

As the name suggests, the **vehicle speed sensor** has the capability to verify the speed of the car wheels. It is a type of tachometer. This sensor is arranged within the anti-braking system (ABS). Additionally, the output of this sensor is also utilized for the odometer to read the speed of the vehicle to control gears depending on the vehicle speed.



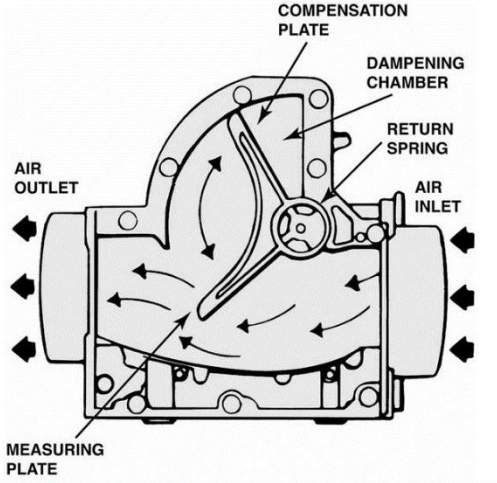
Odometry Sensor

Odometry sensors are a kind of motion sensors and are used to estimate changes in the car's position over time. They know the size of the tires and so they can determine the distance the car has traveled as well as the angle based on the difference between the left and right sensor. They help sensing the surrounding environment, but they do not offer great accuracy. That changes with the fusion of their signals with the GPS ones and in that case the car has a better knowledge of its position.

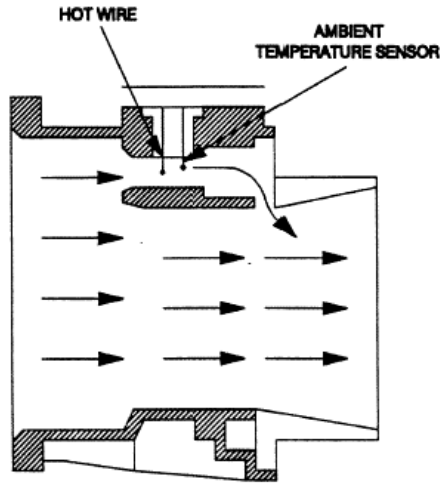


Mass Air Flow Sensor

A **mass air flow sensor** is used to determine the mass flow rate of air entering a fuel-injected internal combustion engine. The air mass information is necessary for the ECU to balance and deliver the correct fuel mass to the engine. Air changes its density with temperature and pressure. There are two types, the vane meter and the hot wire.



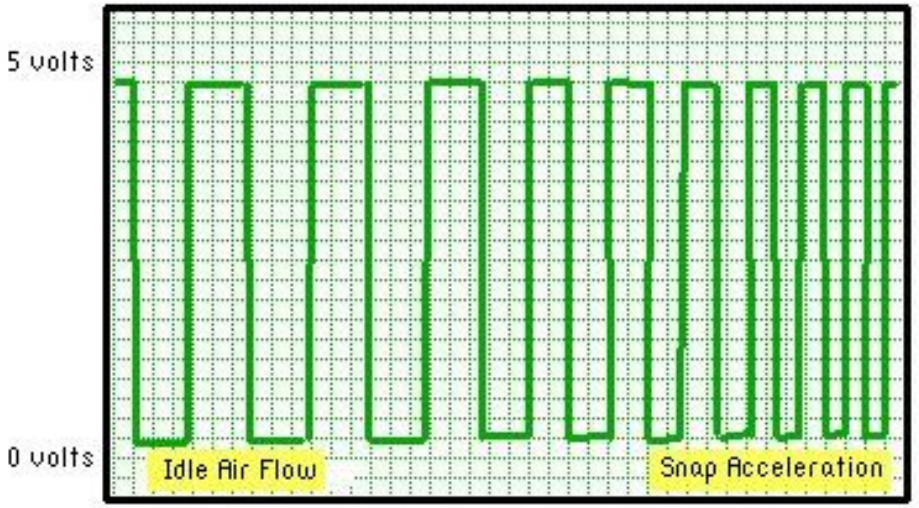
Vane meter



Hot wire

Mass Air Flow Sensor

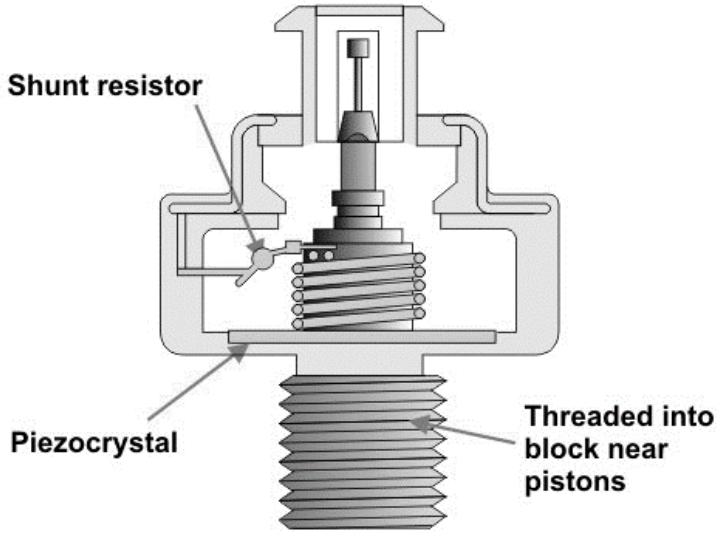
The output signal of this sensor is a variable voltage in the range 0V (no air flow – engine stopped) to 5V, whose value depends on the mass of air flow through the sensor. One side encounter cooling airflow, while the shielded backside maintains a consistent temperature, and the current differential between the two sides is measured and relayed as a square-wave digital frequency output, between around 30Hz at idle and 150Hz at wide-open throttle.



Frequency increases with the rate of air flow
Amplitude remains constant

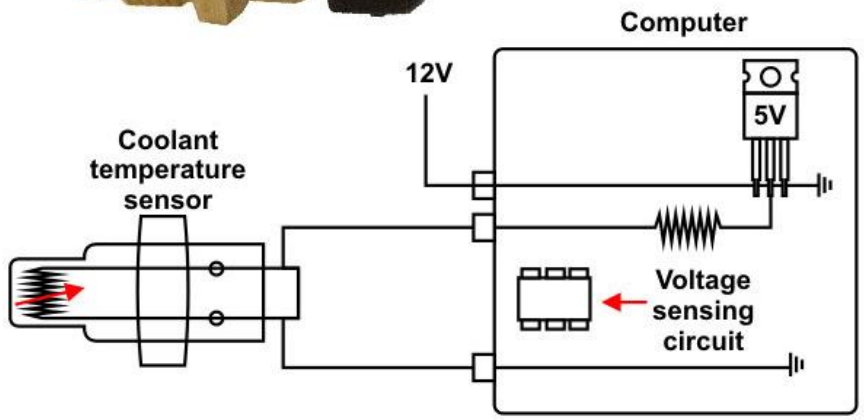
Spark Knock Sensor

A **spark knock sensor** is basically a microphone that listens for any unusual pulsations that may cause harm to the engine and check if it is working properly. This sensor recognizes the “spark knock”, which is the condition inside the engine where the fuel begins to burn before it’s supposed to.



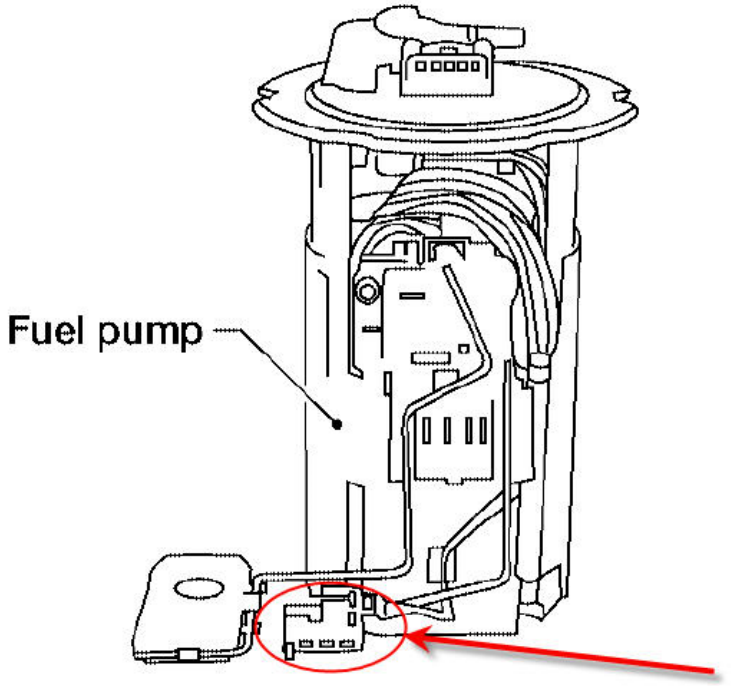
Coolant Temperature Sensor

A **coolant temperature sensor** is used to measure the temperature of the coolant/antifreeze mix in the cooling system, giving an indication of how much heat the engine is giving off. The sensor works with the car's ECU, continually monitoring the coolant temperature to make sure the engine is running at the optimum temperature.



Fuel Temperature Sensor

The **fuel temperature sensor** is used to check the temperature of the fuel continually, whether its utilization is optimum or not. If the fuel of the engine is cold, then it will take more time to burn due to its high density. Similarly, if the fuel is warm then it will take less time to burn. Here the main problem is the inflow varying levels and this can injure other parts of the car. This sensor will monitor the fuel to be injected at the right speed and temperature so that the engine works properly.

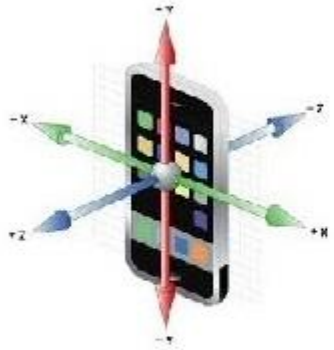


Inertial Measurement Unit

The **inertial measurement unit** (IMU) is an electronic device used to calculate and reports an exact force of body, angular rate as well as the direction of the body, which can be achieved by using a blend of three sensors:

- Accelerometer
- Gyroscope
- Magnetometer

Accelerometer

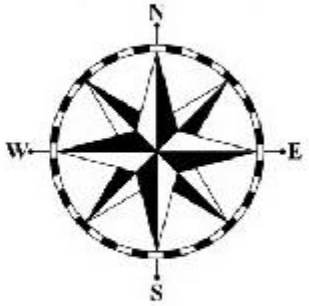


Acceleration along 3 axes

Gyroscope

Rotation speed around 3 axes

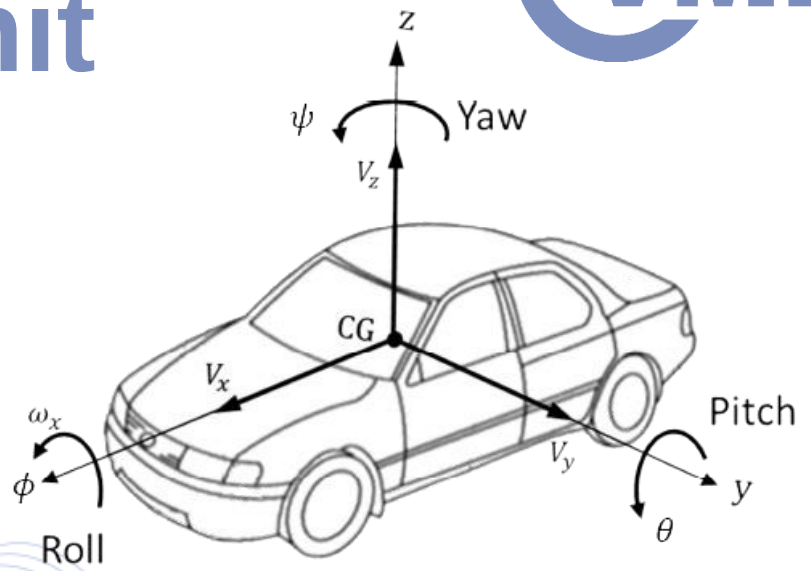
Magnetometer (Compass)

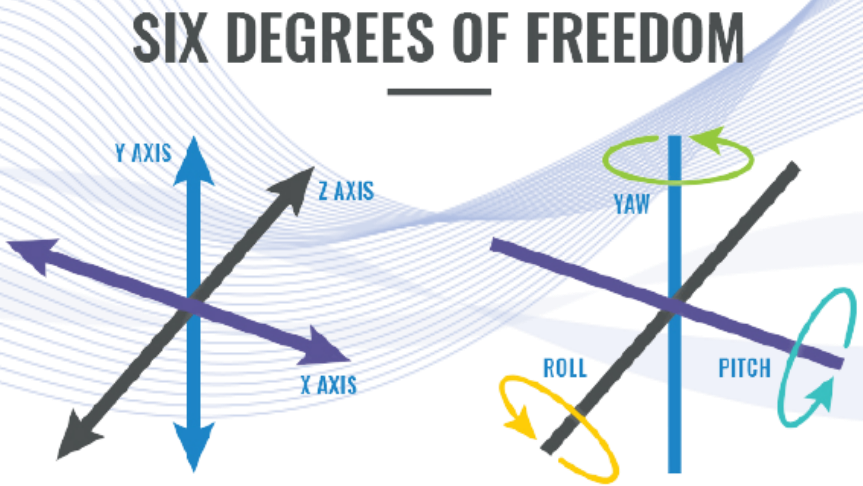


Direction of magnetic north

Inertial Measurement Unit

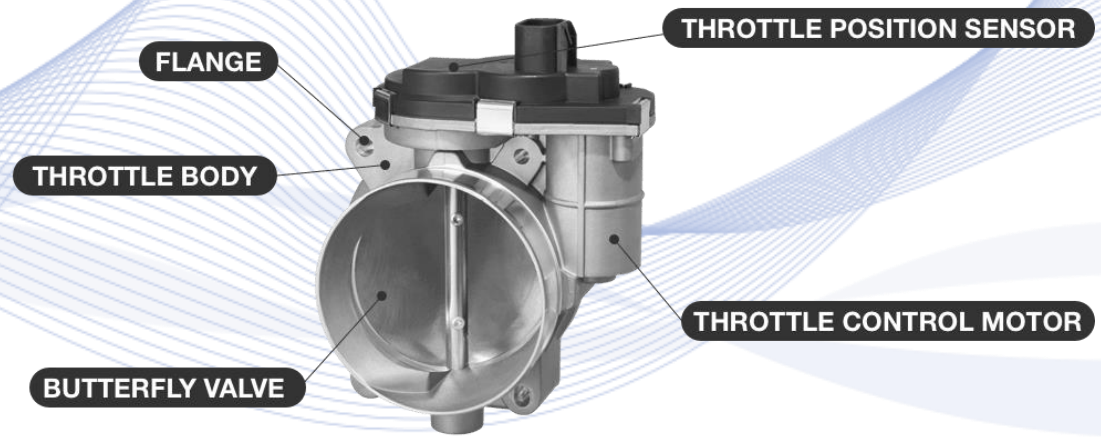
An IMU provides six degrees of freedom, which refers to the number of different ways that an object can move throughout 3D space and would include three degrees of translation movement across a straight plane/along each axis and three degrees of rotational movement across the x, y and z axes/about each axis. The raw data collected from an IMU gives some idea of the world around it, but that information can also be processed for additional insight.





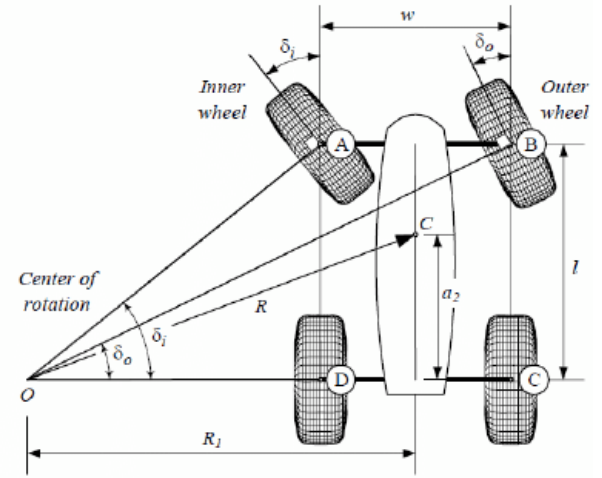
Throttle Position Sensor

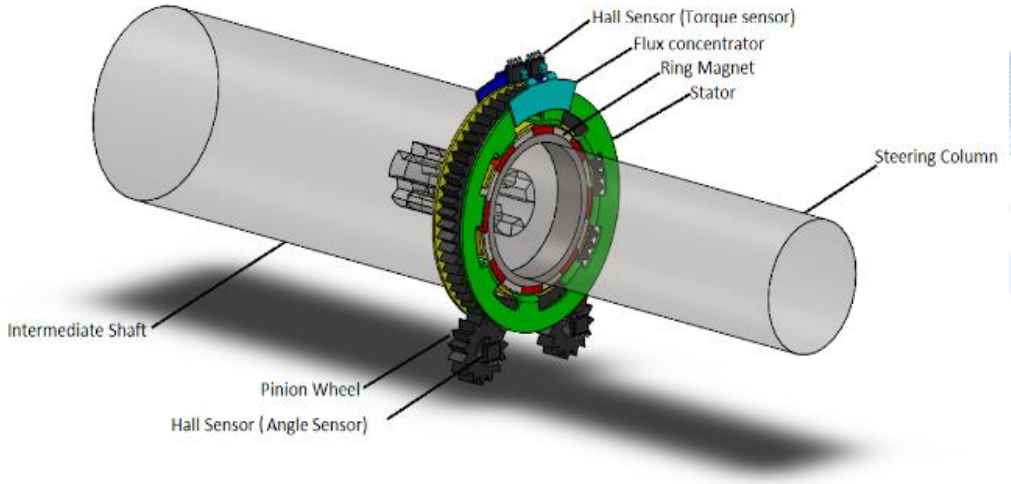
The **throttle position sensor** monitors how far open the throttle valve is open, which is determined by how far down the accelerator pedal has been pushed. The throttle position controls the amount of air that flows into an engine's intake manifold. When it is opened wide more air flows in, when it is nearly closed a small amount of air flows in. The position of the throttle and how quickly it is opening, is transmitted to the ECU, and that information is among the factors the computer uses to decide how much fuel is injected and the spark timing.



Steering Angle Sensor

The **steering angle sensor** (SAS) determines where the driver wants to steer, matching the steering wheel with the vehicle's wheels. Located within the steering column, the steering angle sensor always has more than one sensor packaged together in a single unit for accuracy, redundancy and diagnostics.





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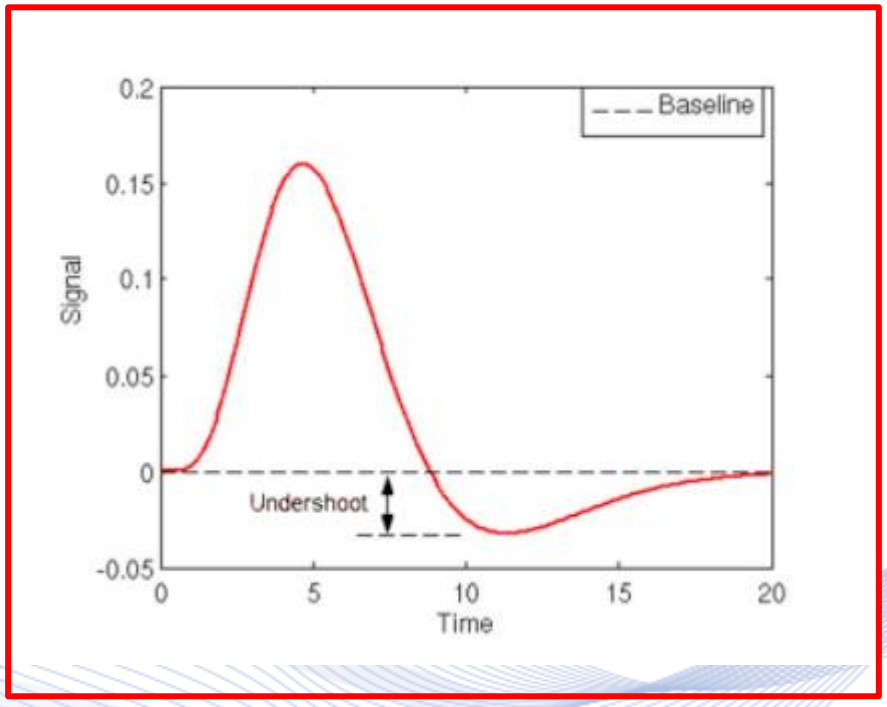
Accelerometers

AC accelerometers:

- Charge mode piezoelectric.
- Voltage mode piezoelectric.

DC accelerometers:

- Capacitive.
- Piezoresistive.



Piezoelectric sensors are widely used in Road Traffic Monitoring Systems.

Piezoelectric sensors

They produce electrical charge when pressure is applied.

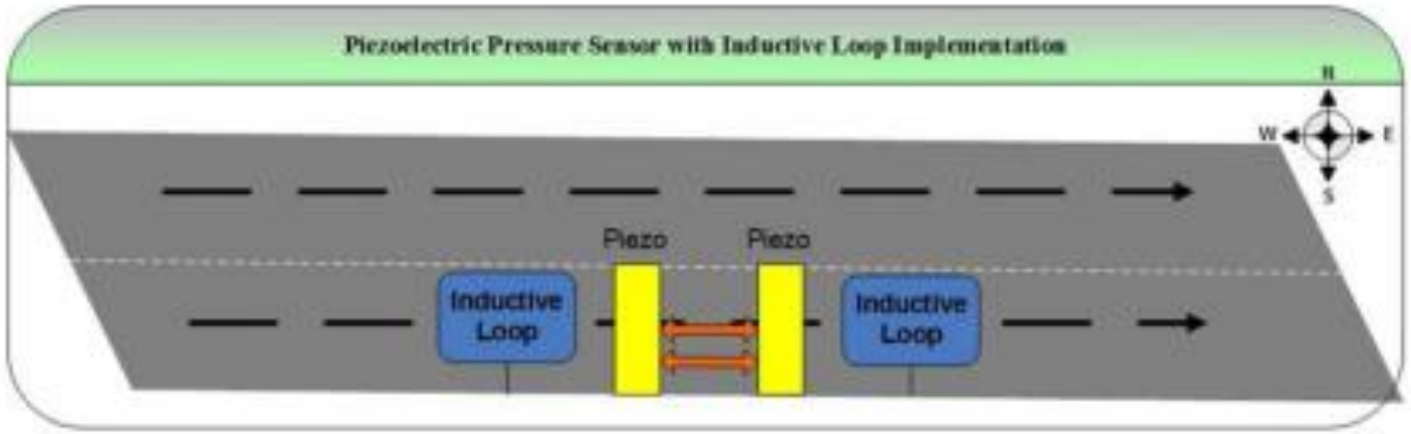
Pros:

- Precise vehicle classification.
- Accurate speed calculation.

Cons:

- Traffic disruption on installation, or maintenance.
- Sensitive to material temperature.

Accelerometers

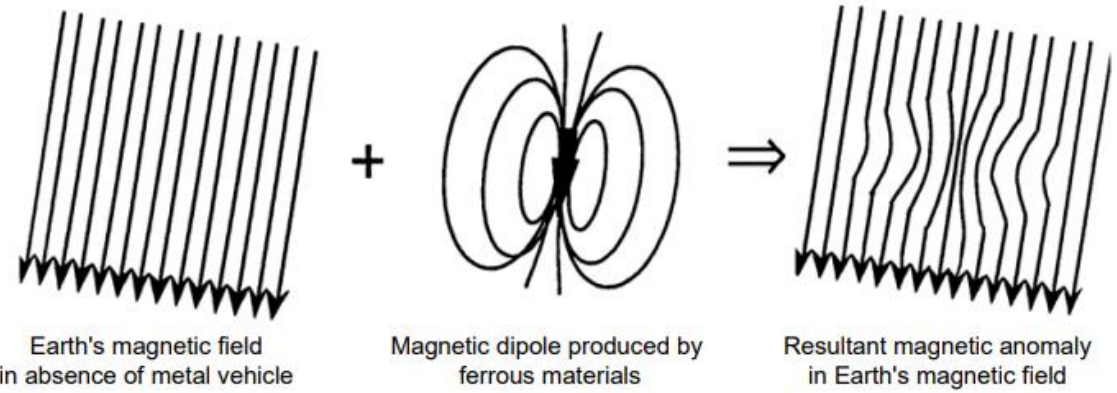


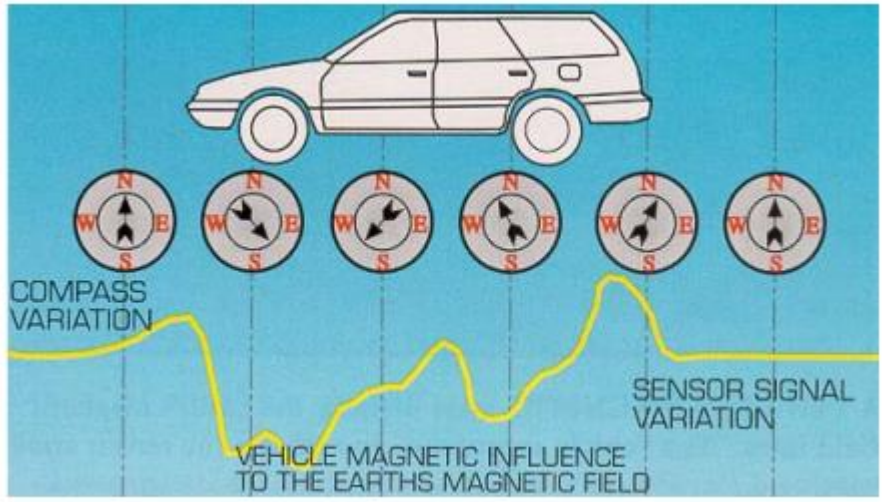
Weigh-In-Motion (**WIM**) technology system.

Magnetometers

Magnetometers can identify moving objects, by measuring Earth's magnetic field distortion.

- Minor pavement incursion.
- Cannot detect stopped vehicles.
- Limited information about vehicle characteristics.





Microwave radars

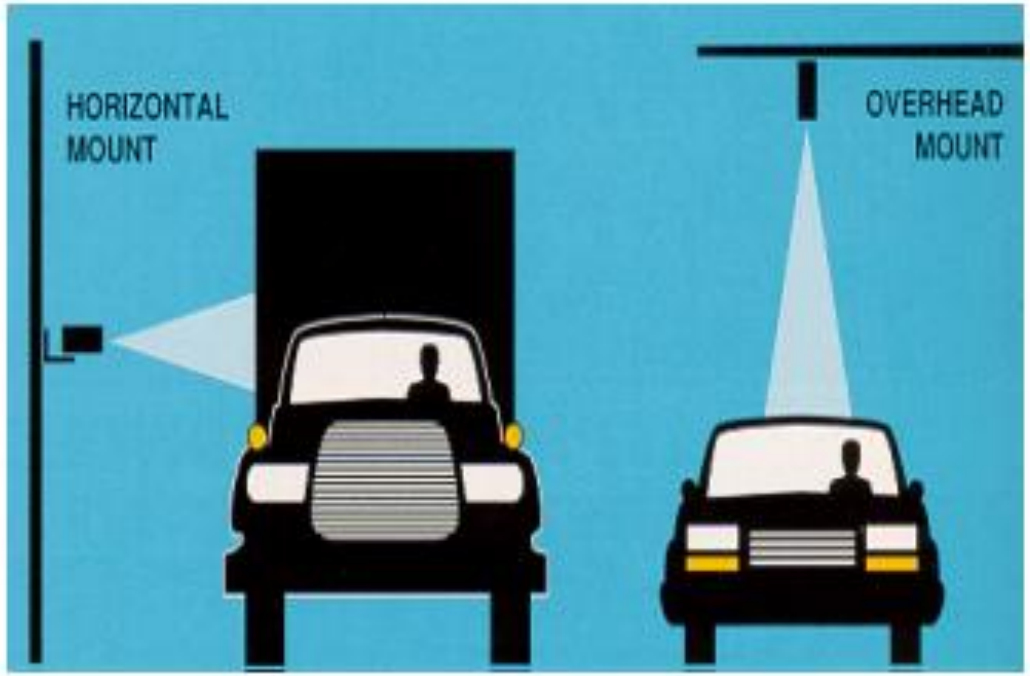
Passing vehicles reflect transmitted ***microwave radar*** energy.

Pros:

- Not affected by weather conditions.
- Multilane gathering data.
- Non need for pavement modification.

Cons:

- Cannot detect stopped vehicles.
- Not suited for road intersections.



Ultrasonic radars

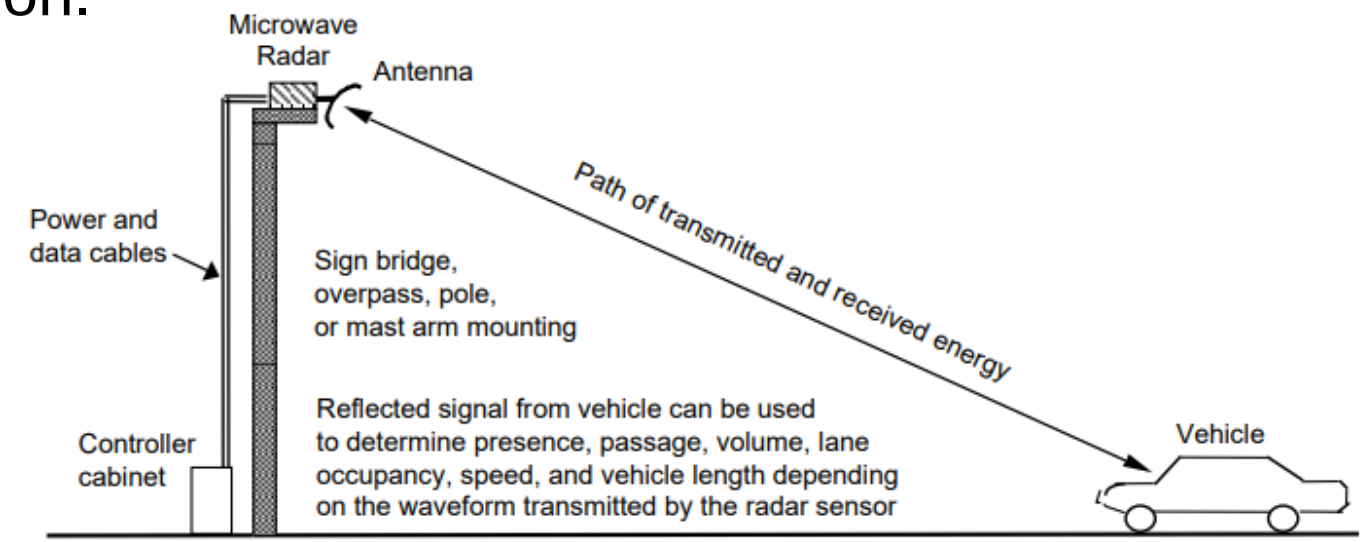
Passing vehicles reflect energy transmitted by ***ultrasonic radar***.

Pros:

- Not affected by weather conditions.
- Multilane gathering data.
- Non need for pavement modification.

Cons:

- Cannot detect stopped vehicles.
- Not suited for road intersections.



Acoustic sensing

Vehicle presence and speed is identified via detecting acoustic energy caused by vehicle interaction with road.

Pros:

- Multilane gathering data.
- Non need for pavement modification.

Cons:

- Cannot detect slow moving traffic.
- Weather conditions affect accuracy.

Infared light sensors

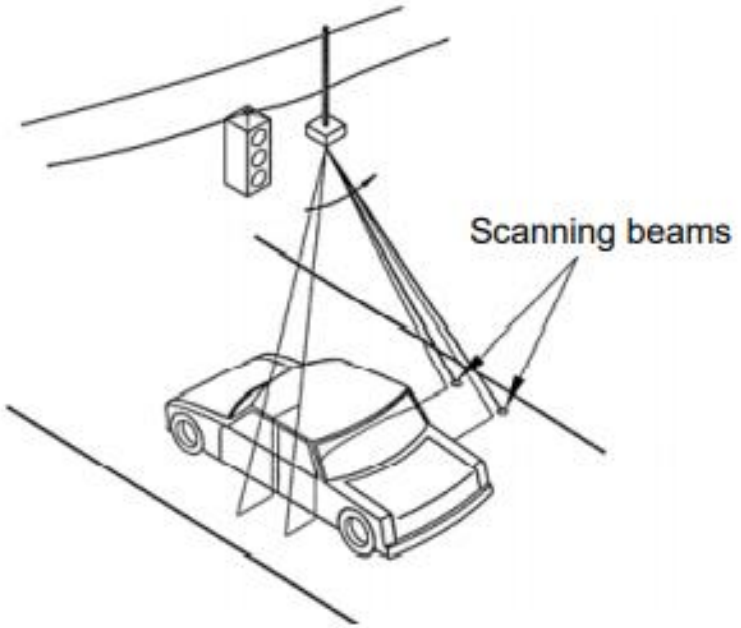
Passing vehicles reflects infrared light produced by laser diodes.

Pros:

- Multilane gathering data.
- Non need for pavement modification.

Cons:

- Not accurate, e.g., sensitive to sunlight.
- Very sensitive to weather conditions.



Video

Video is captured via:

- Stationary Cameras, e.g., CCTVs.
- Moving Cameras, e.g., UAVs.

Pros:

- Multilane gathering data
- No need for pavement modifications.
- Cost effectiveness.

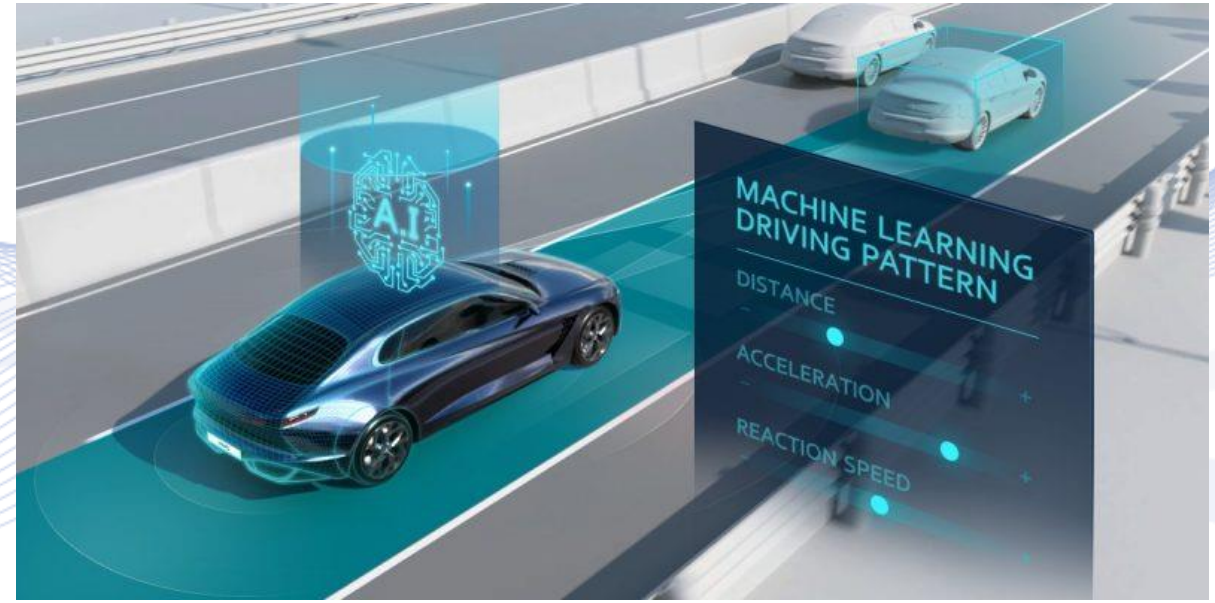
Autonomous Car Sensors

- Introduction
- Automation Levels
- Car Environment sensors
- 1D Signal Car Sensors
- Traffic sensors
- **Present Autonomous Car Companies**
- Conclusion

Present Auto Car Companies

Self-driving cars and **artificial intelligence** (AI) are often complimentary topics in technology, with every car manufacturer racing to develop their own artificial intelligence and self-driving technologies. Currently, several major companies are engaging in research and development of both semi and fully autonomous vehicles. Some companies that have past the research phase and are testing their cars in real world scenarios are:

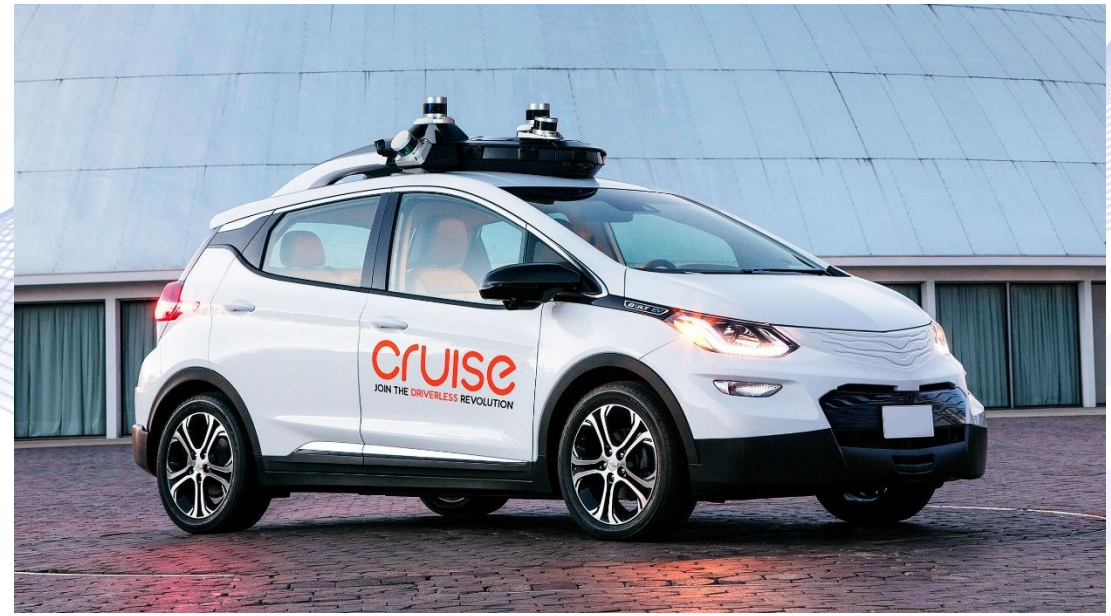
- Cruise
- Voyage
- Waymo
- Zoox
- Pony.ai



Cruise

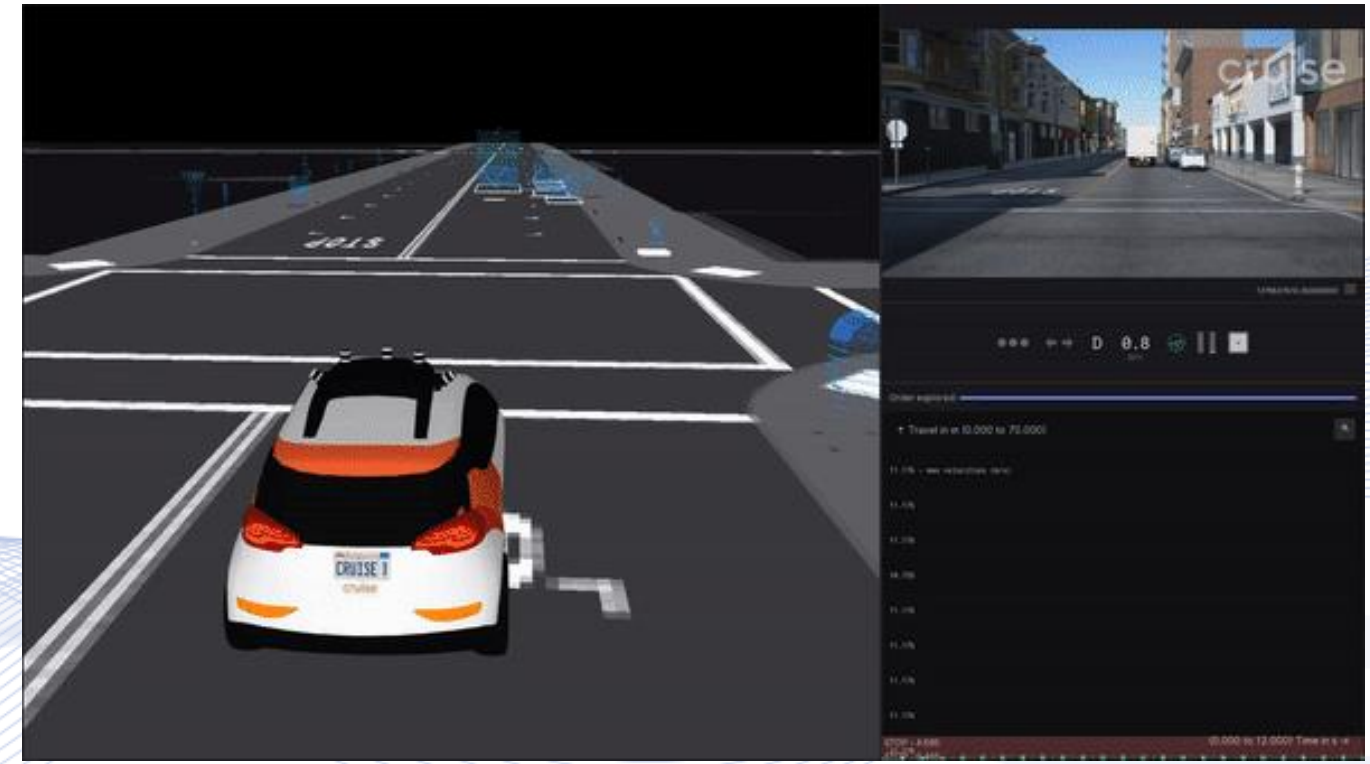
Cruise is an American self-driving car company founded in 2013 and acquired by GM in 2016. It uses thousands of tools and simulations with the petabytes of data that it daily collects to accelerate the learning process of its autonomous driving algorithms. Some of them are:

- Scene edit (2D testing)
- Webviz (data visualization)
- Starfleet (real-time operations)
- Cartographer (semantic mapping)



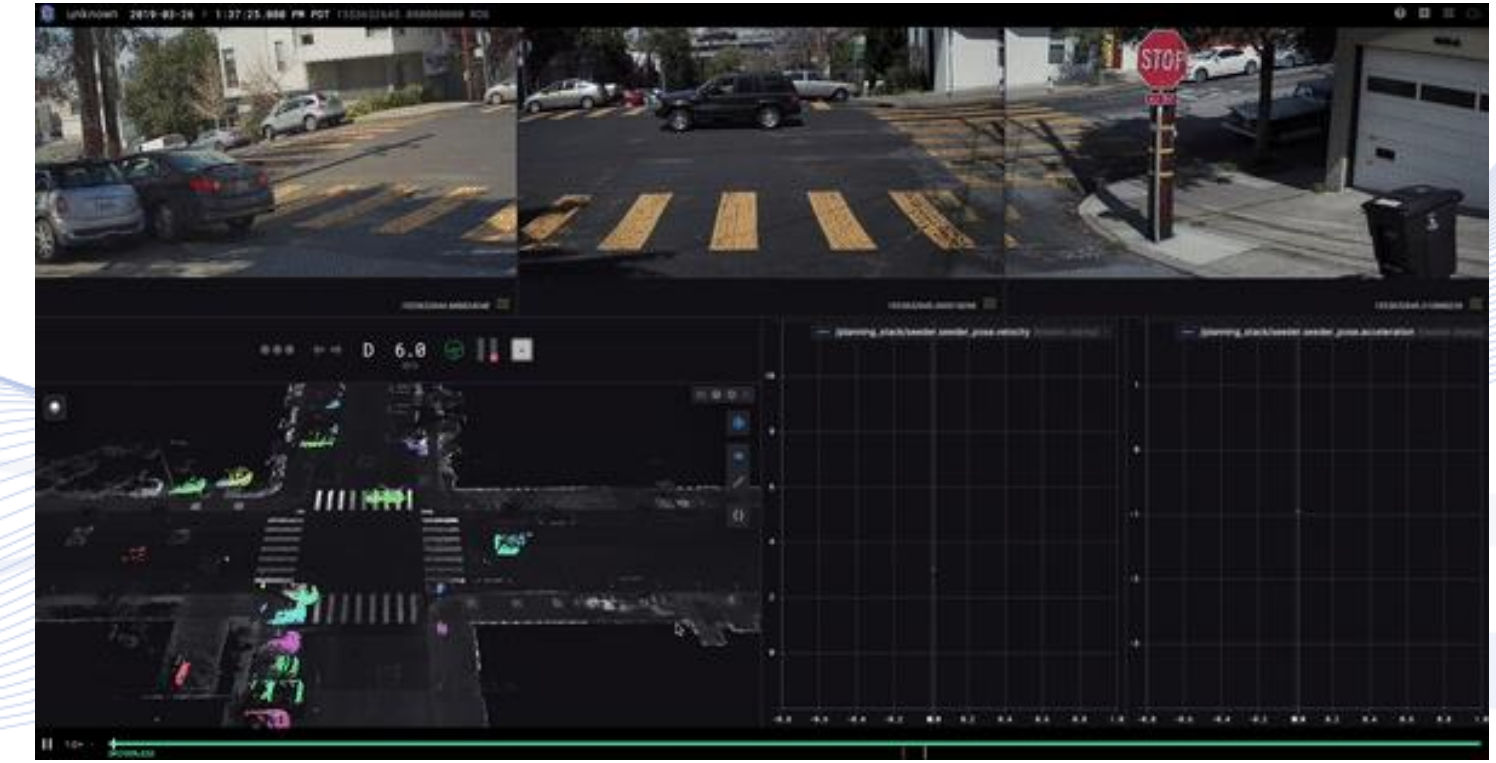
Cruise

Scene Edit creates visual 2D and 3D simulation tests for our Quality Assurance team. By eliminating the need to manually write these tests, Scene Edit provides real-time test feedback and shortens regression testing development cycles by 400%.



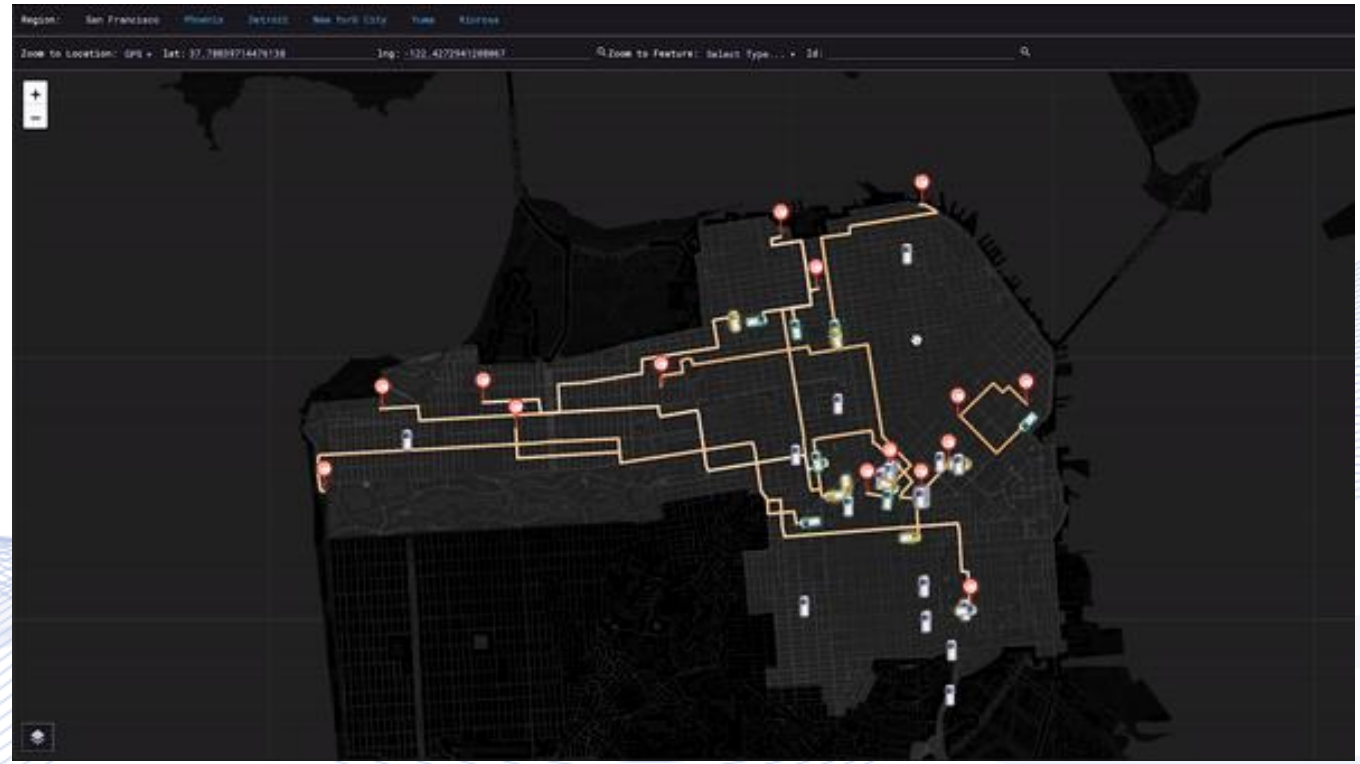
Cruise

Webviz visualizes thousands of obstacles and complex choices that the vehicles may encounter on the road. By consolidating over a dozen interactive tools into one web-based application, Webviz enables Cruise engineers to analyze vehicle performance and iterate quickly.



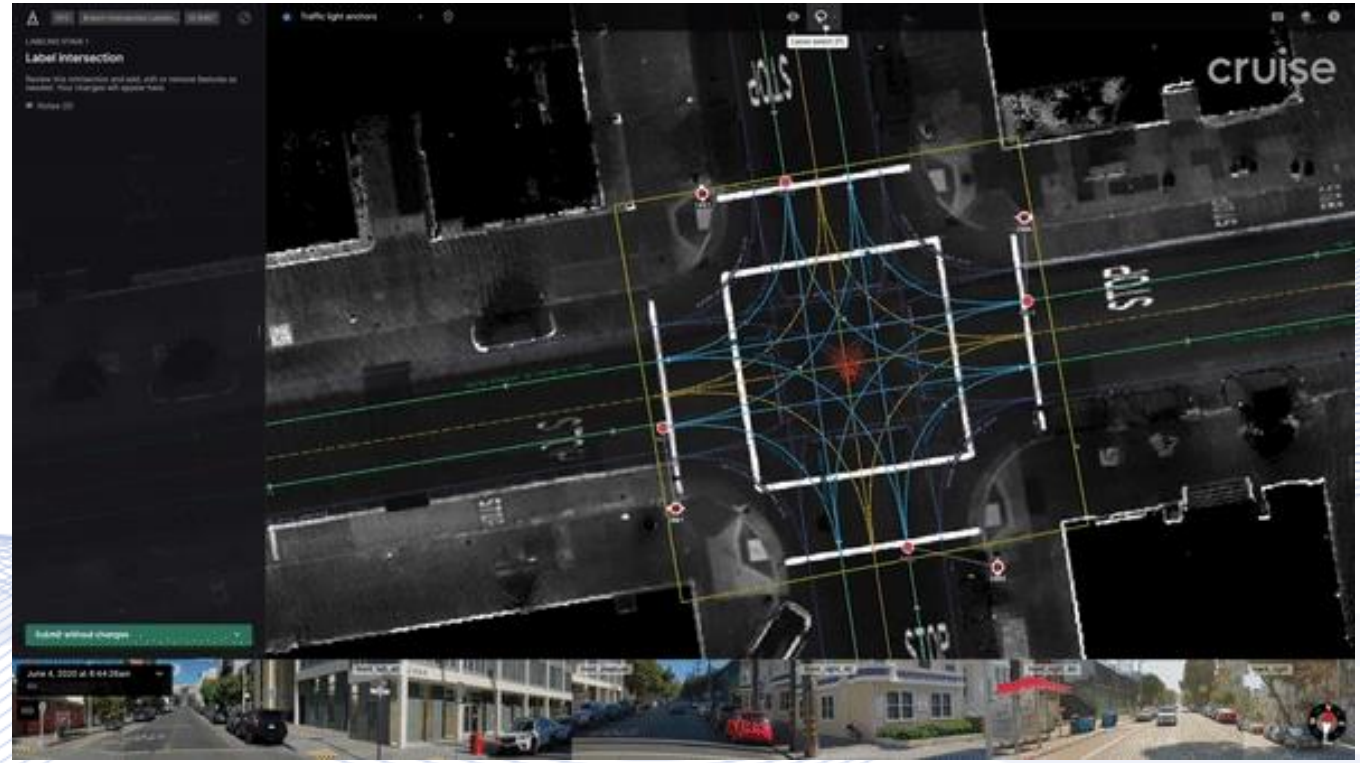
Cruise

Starfleet helps keep track of the vehicles in real-time and supports fleet operations at scale. Starfleet deploys code to vehicles remotely, assigns vehicle maintenance tasks, dispatches and monitors them on the road.



Cruise

Cartographer creates and maintains semantic maps of any urban environment. By mapping real-world features such as boundaries, lanes, and traffic controls, the AVs are set up for success with faster real-time analysis.



Voyage

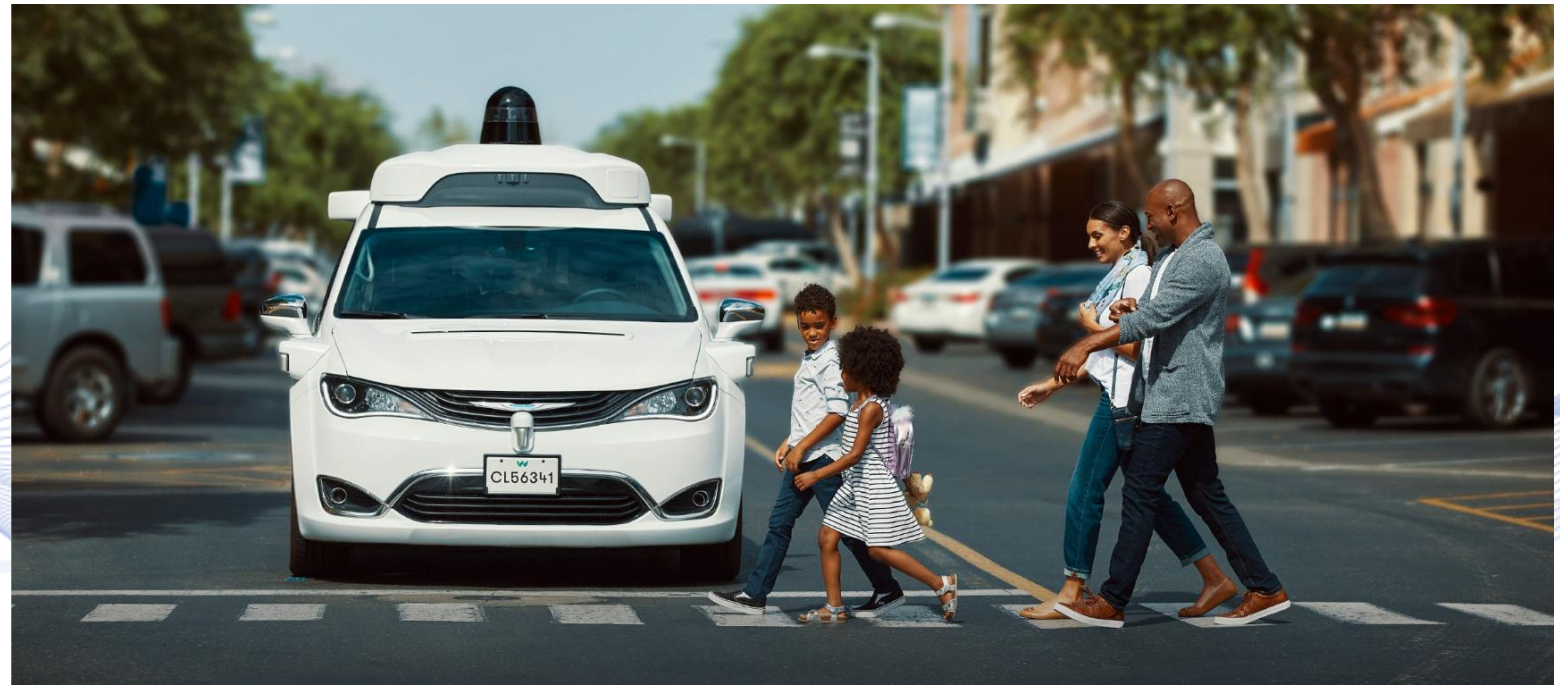
Voyage is a technology company building products for enabling the autonomous operation of self-driving vehicles that is headquartered in California and was founded in 2017. It oversees a fleet of low-speed autonomous vehicles providing trips to residents of several retirement communities. In 2021 Cruise, a majority-owned subsidiary of General Motors, acquired the self-driving startup. Both companies have tested their vehicles without a safety driver behind the wheel and aspire to launch full-fledged commercial robot taxi services.

Waymo

Waymo is an American autonomous driving technology development company, which began as the Google self-driving car project in 2009. In October 2020, the company expanded the service to the public, and it is the only self-driving commercial service that operates without safety backup drivers in the vehicle.

Waymo

Waymo One is the ride-hailing service that's currently the company is offering with fully autonomous rides for people in the East Valley of Phoenix, Arizona by just opening their app and hailing a car.



Waymo

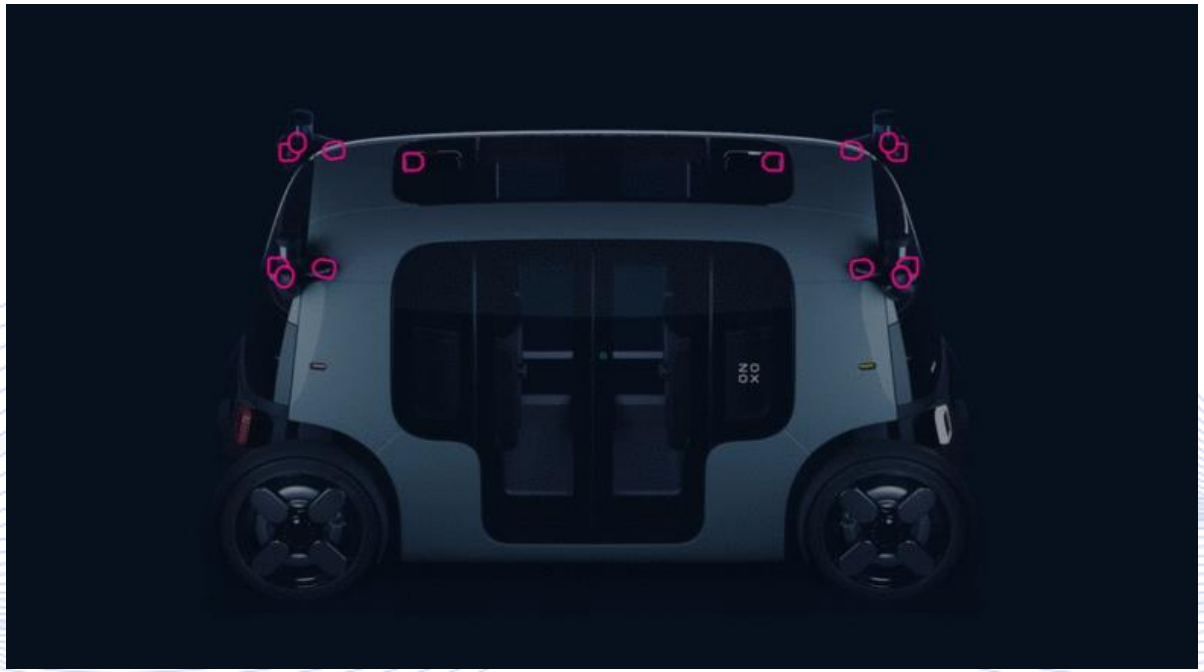
Everywhere in the world, most goods that we use and rely on get to their destination by truck. That's why the company with **Waymo Via** is focusing on mass product transportation with its fully autonomous trucks.

Zoox

Zoox is an American autonomous vehicle company founded in 2014 and acquired by Amazon in 2020. The company's approach is centered around the fact that a retrofitted vehicle is not optimized for autonomy. Zoox has applied the latest techniques in automotive, robotics and renewable energy to build a symmetrical, bi-directional battery-electric vehicle that solves for the unique challenges of autonomous mobility.

Zoox

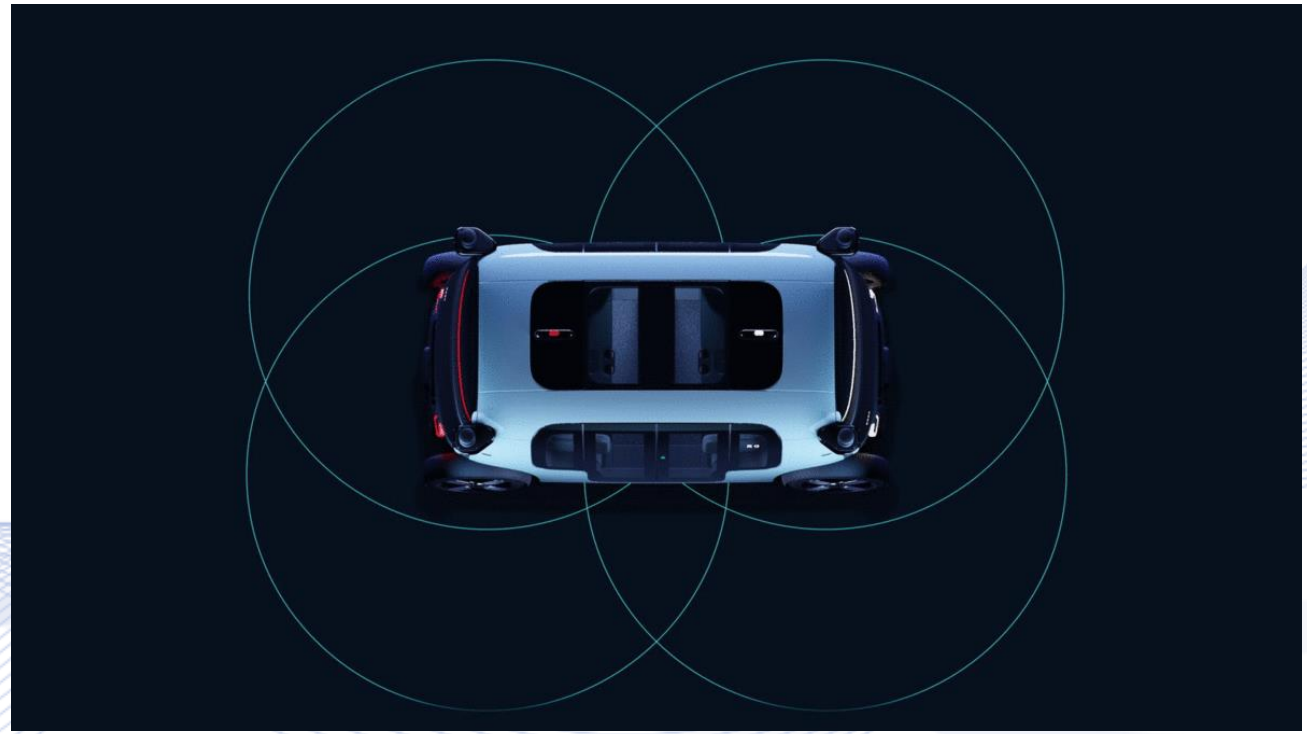
Zoox vehicles use unique **sensor architecture** combining cameras, lidars and radars to see their surroundings.



Cameras - **Lidars** - **Radars**

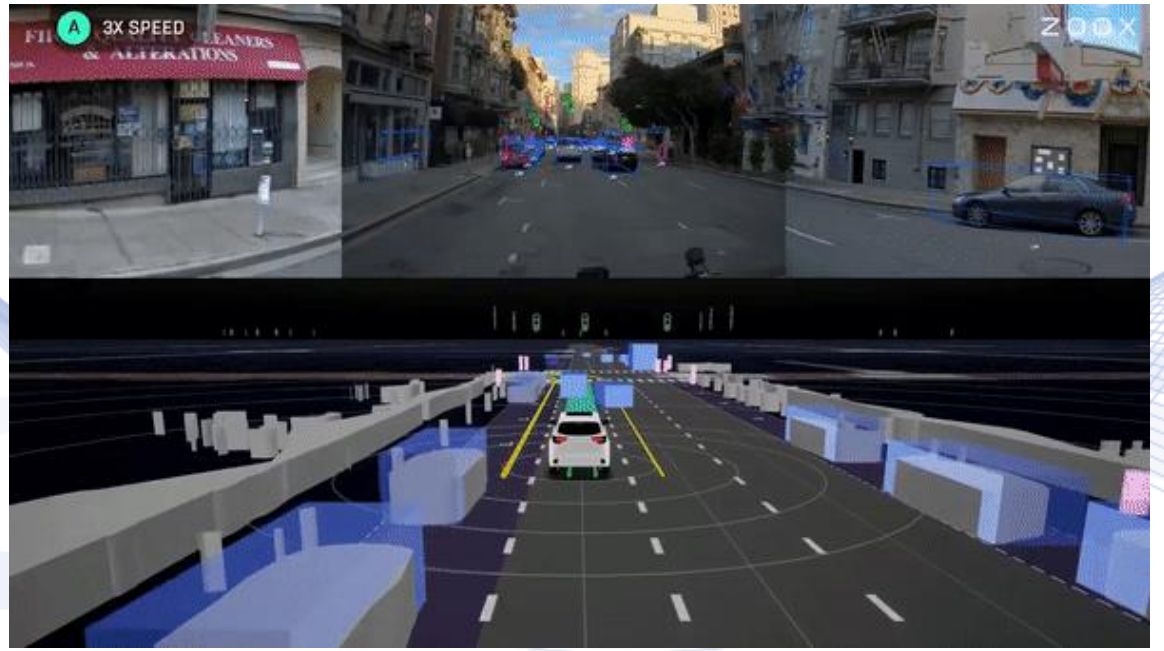
Zoox

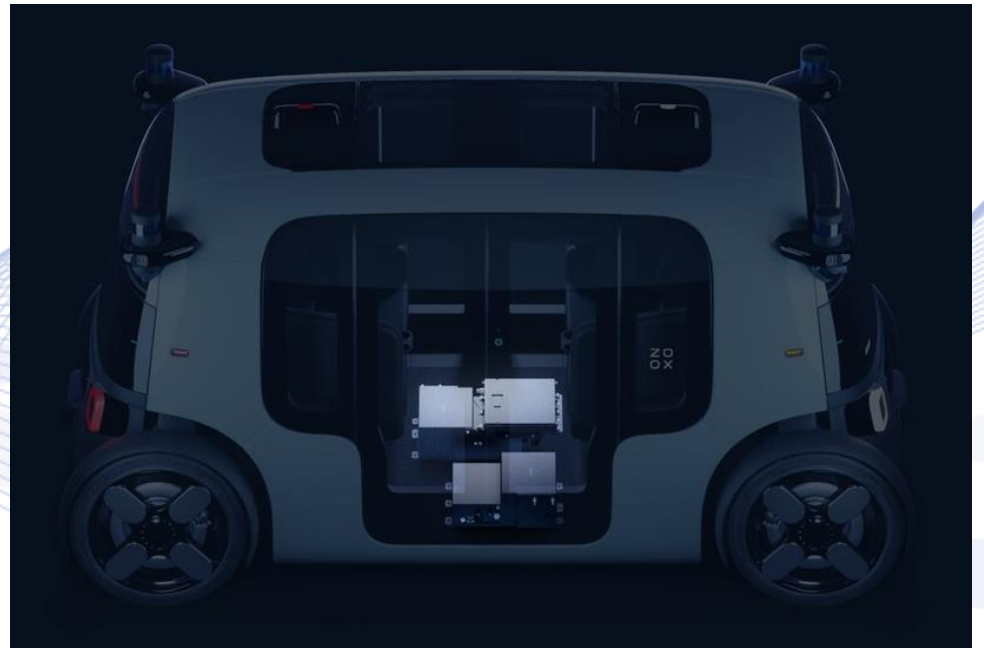
The placement of the sensors provides an overlapping field of view and **360° coverage**. This enables redundancy and for the vehicle to perceive in all directions equally well. The vehicle can see over 150 meters away in all directions and even around corners. That means that they can safely see what's coming long before it's anywhere close.



Zoox

Zoox vehicles are built with a **powerful compute system**, as well as redundant backups, that house our proprietary software. This means the vehicles can make quick decisions to continue to drive safely.





Pony.ai

Pony.ai is an autonomous vehicle technology company co-located in Silicon Valley, Beijing and Guangzhou. The company was founded in 2016 by two former developers for Baidu in Silicon Valley. Toyota is planning to invest $400 million in the company. They previously announced that they work together on testing self-driving cars on public roads in Beijing and Shanghai.

Pony.ai

They are developing safe and reliable autonomous driving technology globally. Having accumulated millions of kilometers in autonomous road testing in complex scenarios, they have a solid foundation to deliver autonomous driving systems at scale and address some of the toughest challenges in the safe deployment of autonomous vehicles.

Pony.ai

They have launched **autonomous mobility pilots** in multiple cities across the US and China, serving hundreds of riders everyday. These pilots have enabled us to build a strong technical and operational foundation to further expand and improve our service.

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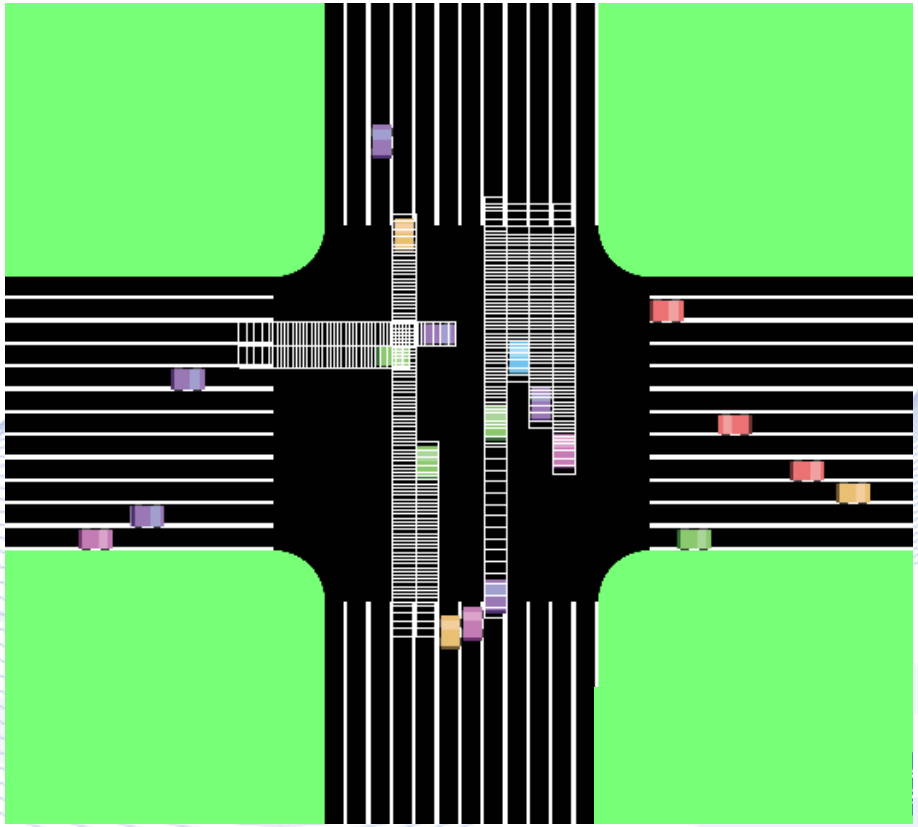
Conclusion

There seems to be a lot of potential for autonomous vehicles, be it transport or research. A sensor system needs to be developed and tested to ensure people about their safety, which will require from every sensor of the vehicle to be extremely reliable under any conditions. As more and more cars are getting autonomous at some level and can communicate too with each other, the safety factor will constantly increase.



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Q & A

Thank you very much for your attention!

More material in
http://icarus.csd.auth.gr/cvml-web-lecture-series/

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