Introduction to Autonomous Car Vision

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Artificial Intelligence &
Information Analysis Lab

Autonomous Car Vision

- Introduction
- Industry leaders
- Autonomous car system
- Open source datasets
- Applications
- Existing challenges
- Conclusion

Autonomous Car Vision

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Introduction

- The least reliable part of the car is the driver!
- More than **90% of road accidents worldwide, are caused primarily due to human errors** (IORAP).
- Around **1.25 million people die every year due to road accidents** (World Health Organization)
- **Death toll is projected to rise to 1.8 million by 2030** (WHO).

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Introduction

What is an autonomous car?

- A self-driving car also known as an **autonomous vehicle (AV), connected and autonomous vehicle (CAV)**, **driverless car**, **robo-car** is a vehicle that is capable of sensing its environment and moving safety with little or no human input (wikipedia).

Introduction

History:

- “Phantom autos”, the driverless vehicles of the 1920s. These cars were remote controlled. They could be operated from as far as five miles away.

Figure: Green Daily-Tribune, 1935 (Newspapers.com)

Introduction

History:

- The **first truly autonomous cars** appeared in 1980s with Carnegie Mellon University's **Navlab** and **AVL** projects funded by the United States' Defense Advanced Research Projects Agency (**DARPA**). By 1985, the AVL had demonstrated **self-driving speeds on two-lane roads** of 31 kilometres per hour with **obstacle avoidance added in 1986** and **off-road driving in day and nighttime conditions by 1987**.

Introduction

- With several **driving assistance techniques** being implemented and **sensors** being placed, the car provides a **safe environment** for the driver in order to **avoid crash or damage**.

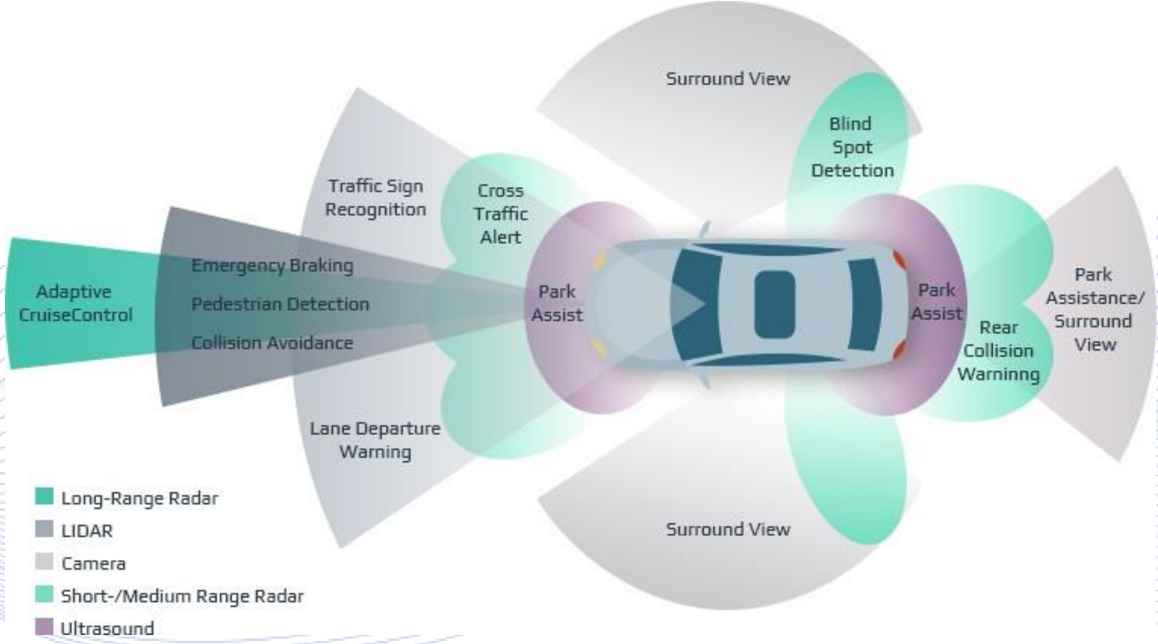

Figure: Autonomous car sensors. https://www.intellias.com/sensor-fusion-autonomous-cars-helps-aoid-deaths-road/

Introduction

Autonomous cars are now able to

- understand their environment and what's relevant information (**perception**),
- construct or update a map of an unknown environment while simultaneously keeping track of their location in it (**Localization & Mapping - SLAM**),
- plan their mission or trajectory and behavior (**planning & control**) as well as
- **predict** and estimate the motion of other objects in the surrounding space.

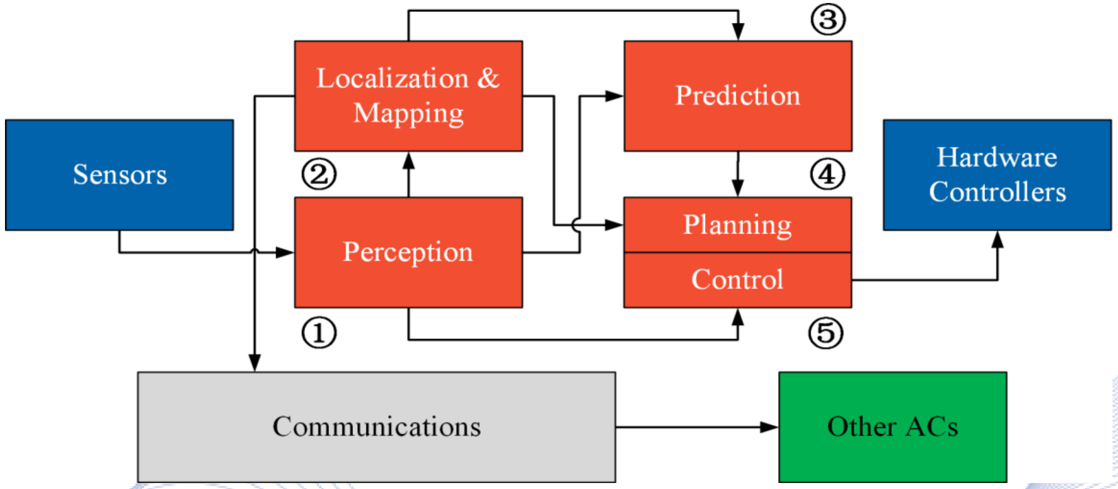

Figure: HKUST autonomous car system architecture [1].

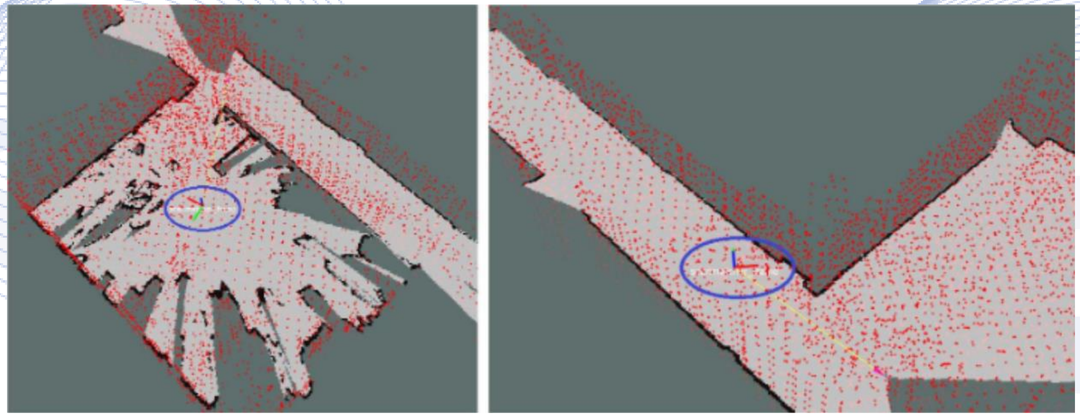

Figure: Kim, Pileun, Jingdao Chen, and Yong K. Cho. "SLAM-driven robotic mapping and registration of 3D point clouds." *Automation in Construction* 89 (2018): 38-48.

Introduction

- The need for safety calls for deployment and utilization of **driving assistance**. Started with adding basic safety measures to making the car a bit ‘smarter’ by adopting advanced driving assistance systems (**ADAS**) and now somehow ‘intelligent’ by enhancing the use of full automation.

Table: SAE Levels of Driving Automation.

Level	Name	Driver	DEM2	DDTF3
0	No automation	HD4	HD	HD
1	Driver assistance	HD & system	HD	HD
2	Partial automation	System	HD	HD
3	Conditional automation	System	System	HD
4	High automation	System	System	System
5	Full automation	System	System	System

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Industry leaders

- The global autonomous vehicle market size is projected to be valued at $54.23 Bn in 2019 and is projected to garner $556.67 Bn by 2026, registering a CAGR of 39.47% from 2019 to 2026 [1].
- A second report states that the global self-driving car market is expected to expand at a CAGR of 36.2% leading to global revenue of $173.15 Bn by 2023 [2].
- A third report forecasts that by 2050, the autonomous vehicle industry could be worth a staggering $7 trillion [3].

[1] https://www.alliedmarketresearch.com/autonomous-vehicle-market

[2] https://www.marketwatch.com/press-release/self-driving-car-market-global-industry-trends-share-size-and-forecast-report-by-2023with-cagr-of-362-2019-09-03

[3] https://www.forbes.com/sites/danielaraya/2019/01/29/the-challenges-with-regulating-self-driving-cars/#10140e89b260

Industry leaders

Market Segmentation:

The autonomous vehicle market is segmented based on three key items, **level of automation** (0-5), **component** (hardware, software, service), **application** and **region**.

Industry leaders

Which country is doing best?

According to 2019 Autonomous Vehicles Readiness Index [4], the **Netherlands** together with **Singapore** are current world leaders in autonomous car **development**. The **United States** ranked fourth in 2019.

[4] https://assets.kpmg/content/dam/kpmg/xx/pdf/2019/02/2019-autonomous-vehicles-readiness-index.pdf

Industry leaders

Which country is doing best?

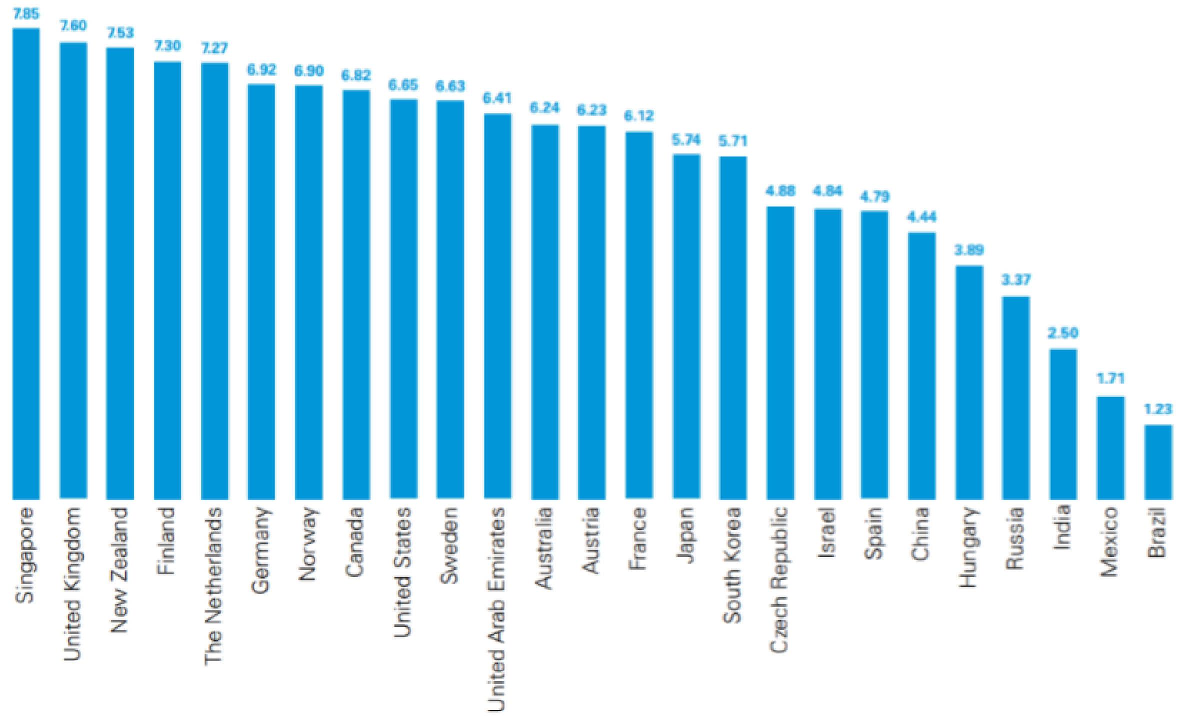

Figure: Policy and legislation.

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Industry leaders

Which country is doing best?

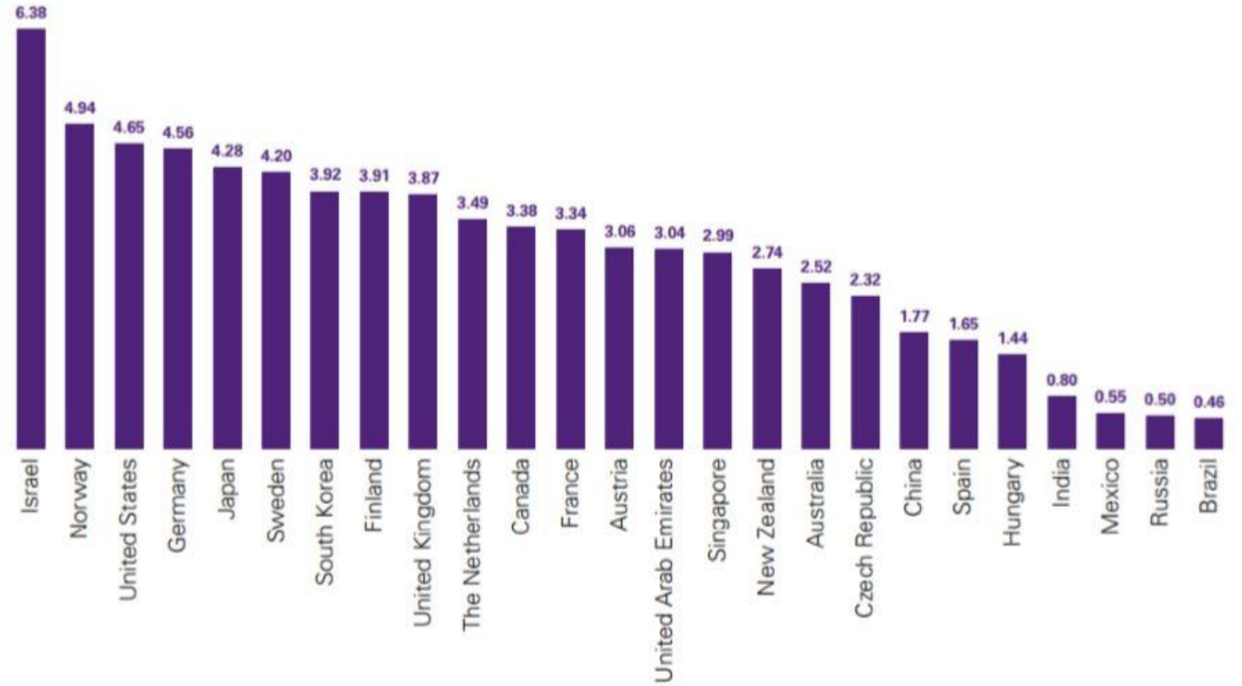

Figure: Technology and innovation

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Industry leaders

Which country is doing best?

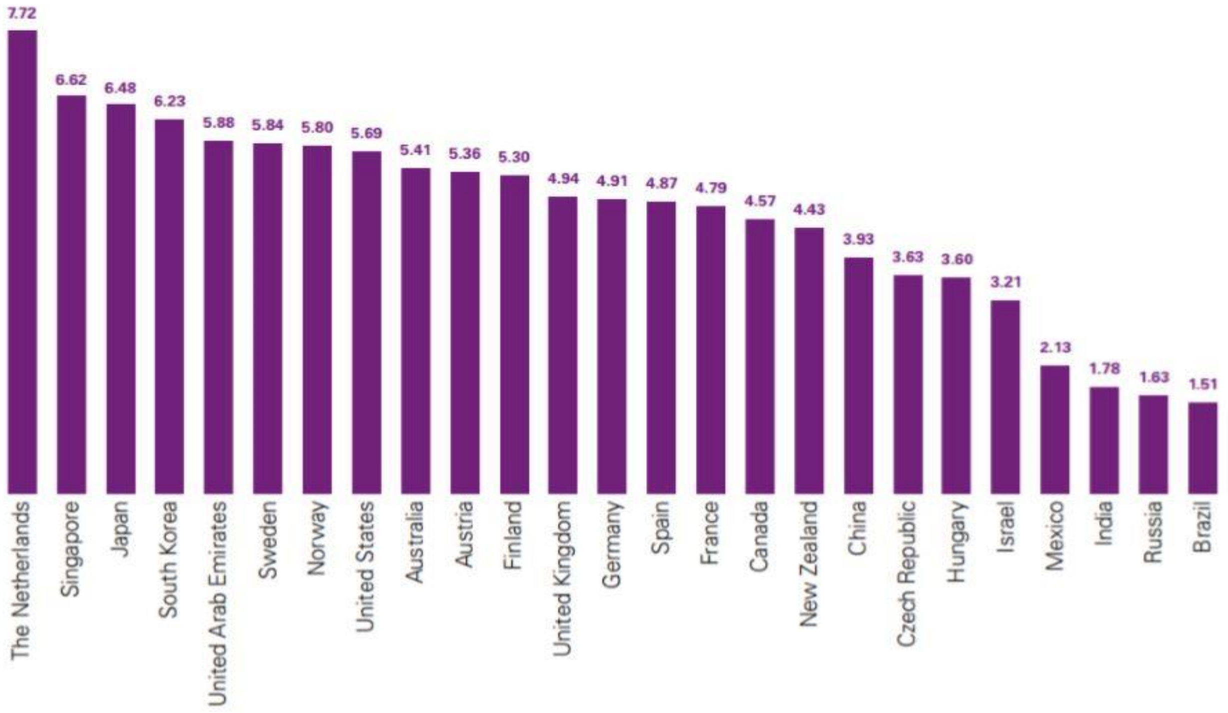

Figure: Infrastructure

Industry leaders

Which country is doing best?

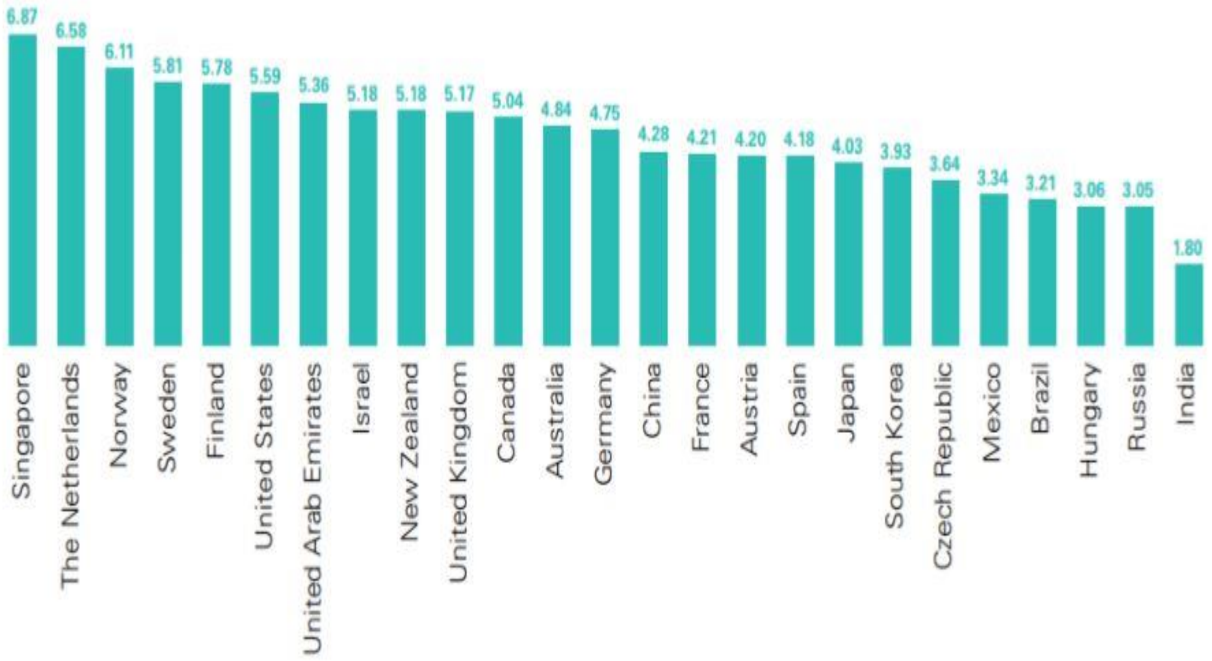

Figure: Consumer acceptance

Industry leaders

Key automobile industry players:

Industry leaders

Key technology providers:

Industry leaders

Key service providers:

UBER

lyft

ZOOX

WAYMO

Industry leaders

Which companies are developing autonomous cars?

Figure: The state of the art autonomous cars; (a) Waymo (b) Uber; (c) Apollo.

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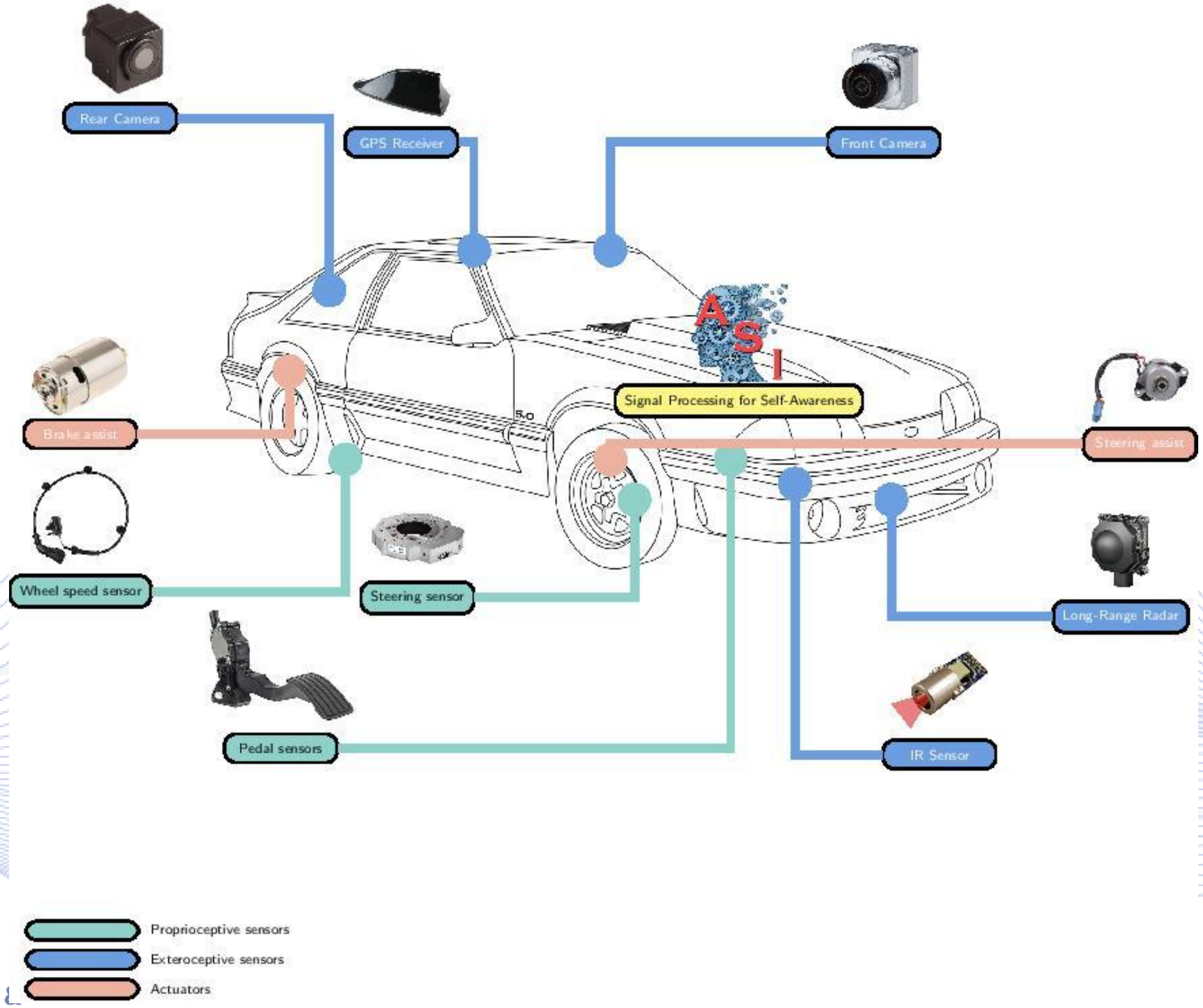
Autonomous car architecture

Several popular autonomous car system architectures:

- **Stanley** (Grand Challenge): sensor interface, perception, planning & control, user interface, vehicle interface, global services.
- **Junior** (Urban Challenge): sensor interface, perception, navigation, user interface, vehicle interface, global services.
- **Boss** (Urban Challenge): mission, behavioral and motion planning.
- **Tongji**: perception, decision & planning, control and chassis.

Autonomous car architecture



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Autonomous car architecture

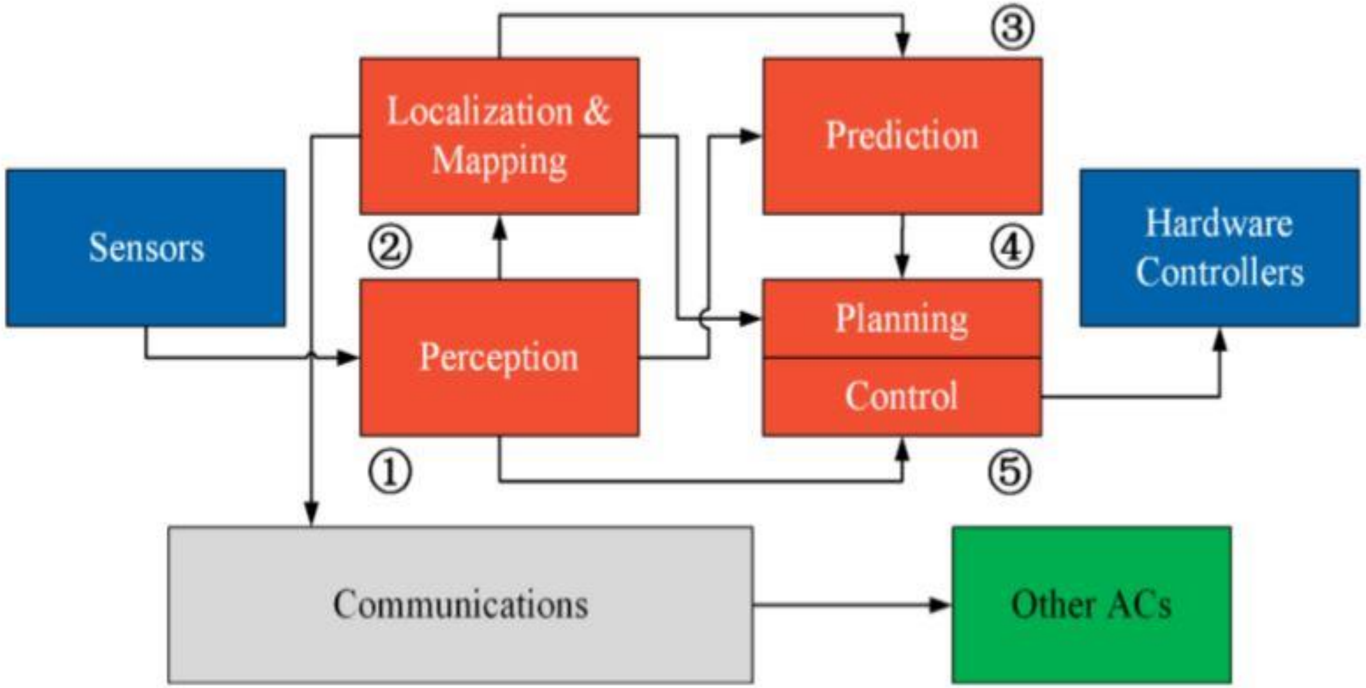
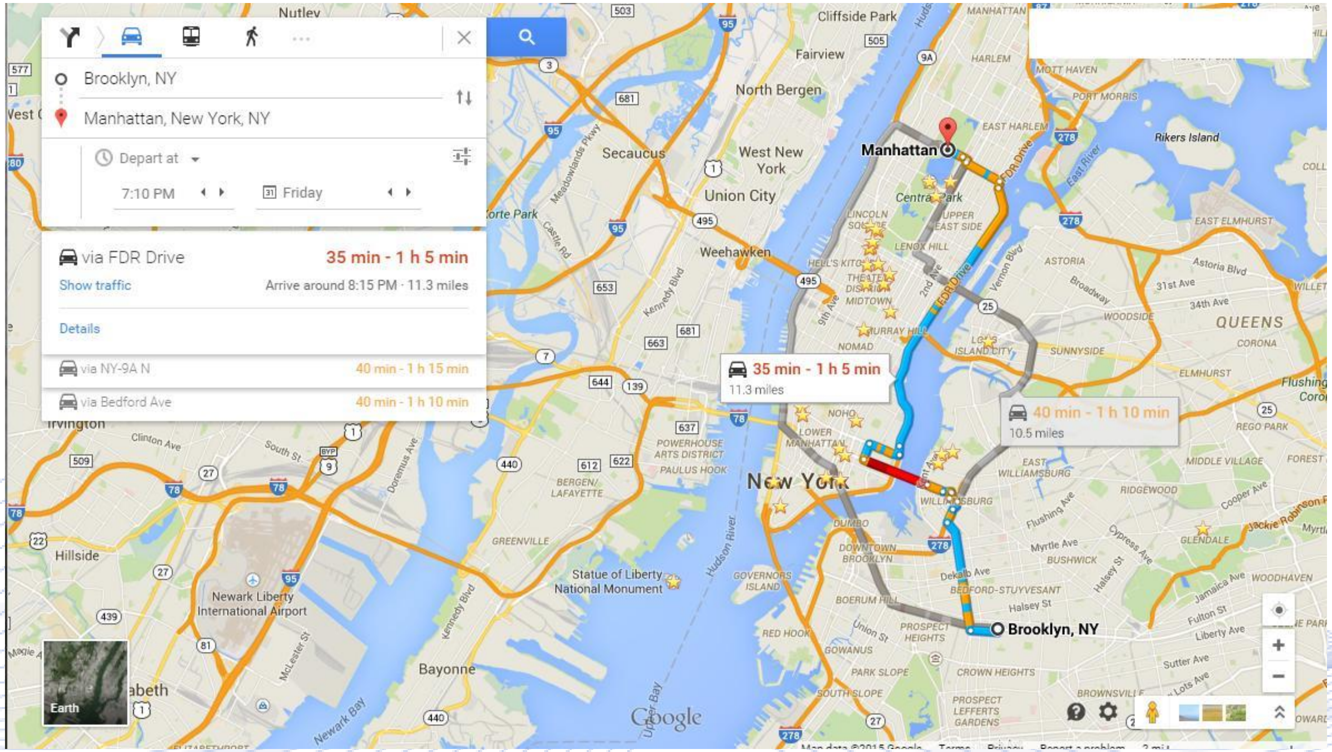


Figure: Autonomous car system architecture

Autonomous car mission planning

- **Autonomous car mission planning**
  - Find the best (2D) trajectory from start to destination
  - Planning constraints:
    - Road map (e.g., Google maps)
    - Regulatory restrictions (one way streets)
    - Traffic load
  - Use of semantic (2D) maps

Autonomous car mission planning



Google maps path planning.

Autonomous car hardware

- Hardware includes various sensors, e.g., **camera**, **lidar** and **radar**, and hardware **controllers**, e.g., **torque steering motor**, **electronic brake booster** etc.

- In this lecture, we mainly discuss sensors.

Autonomous car hardware

The autonomous car sensors are generally used to **acquire 2D/3D environment data**. Each sensor is chosen as a trade-off between **sampling rate**, field of view (**FoV**), **accuracy**, **range**, **cost** and **overall system complexity** [5].

[5] https://autonomous-driving.org/2019/01/25/positioning-sensors-for-autonomous-vehicles/

Cameras

- Cameras are **passive** sensors.
- Cameras capture 2D images by collecting light reflected on the 3D environment objects.
- Camera data is usually subject to the environmental conditions, e.g., weather (rain, fog, snow, etc.) and illumination.
- Computer vision and machine leanring algorithms are generally used to extract useful information from captured images/videos.

Camera mounting positions

1. Front camera

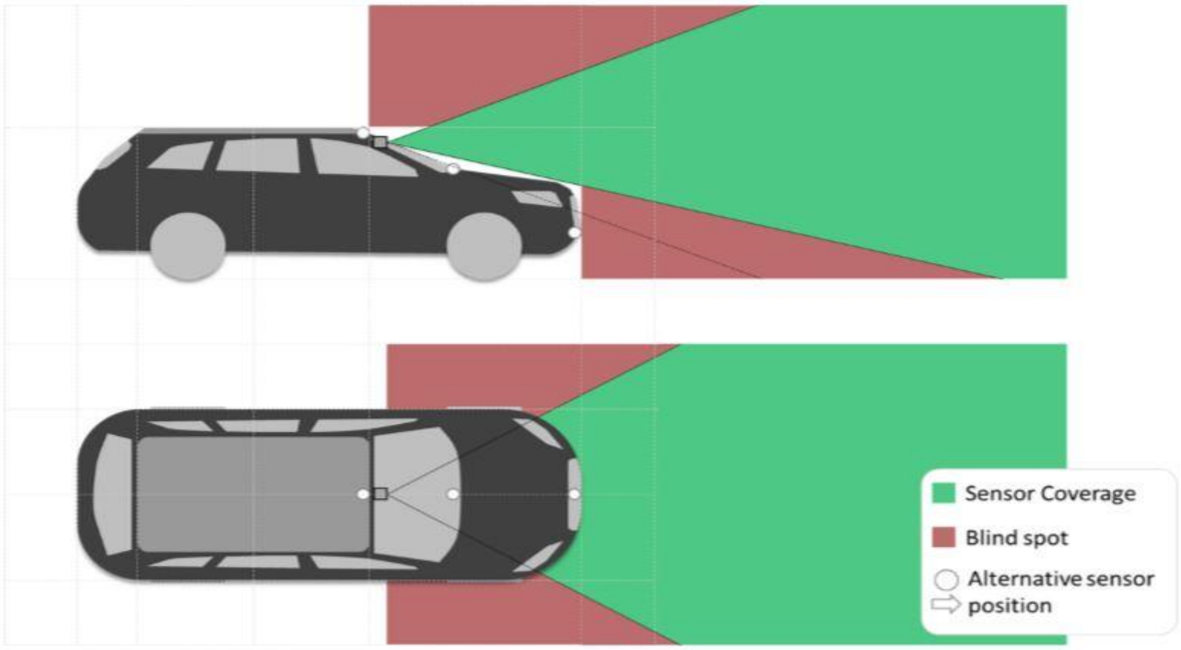


Figure: Front camera.

Camera mounting positions

Front camera

Variations:

- Front cameras are typically mounted between the rear mirror and the windshield. The windshield protects the camera and is cleaned by the wipers.
- Alternatively, front cameras can be installed inside the vehicle between the dashboard and the windshield, or outside of the vehicle on the bumper or at the front roof edge center.
- Stereo cameras can provide distance estimation.

Camera mounting positions

Front camera advantages

- Front cameras benefit from vehicle front lights at night.
- Enables ADAS features, like lane departure warning and lane change assistant.
- If installed behind the windshield: protection from rain and dirt.

Drawbacks:

- Vertical FoV is limited by vehicle’s hood. Hence small objects in front of the vehicle are occluded (unless camera is mounted on front bumber)
- Insufficient overall coverage for urban autonomous driving, if not

Camera mounting positions

360-degree coverage by roof-mounted wide-angle cameras.

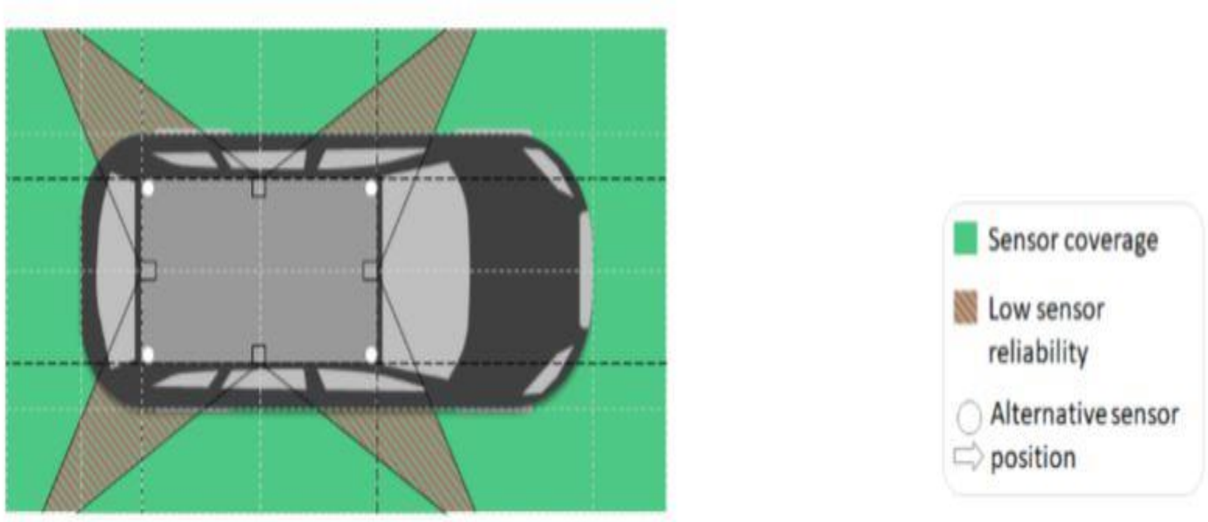


Figure: 360-degree coverage by roof-mounted wide-angle cameras.

Camera mounting positions

360-degree coverage by roof-mounted wide-angle cameras.

Variations:

- Cameras can be tilted to better cover the close environment around the vehicle.
- Cameras can be mounted on the corners of the vehicle instead of the roof edge centers, or as a central "camera tower".

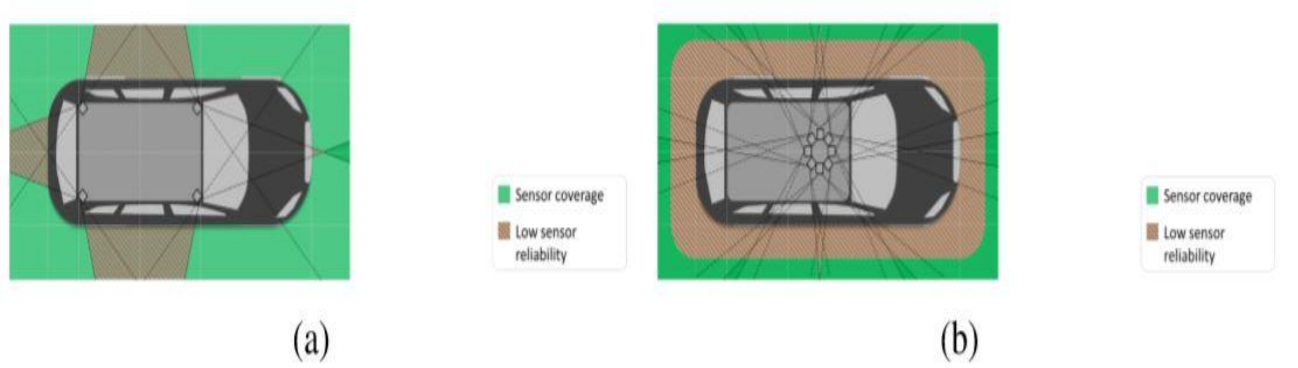


Figure: Another two common ways of mounting cameras apart from the "cameras at the roof edge centers"; (a) camera at the roof corners; (b) central camera tower.

Camera mounting positions

360-degree coverage by roof-mounted wide-angle cameras. Advantages:

- 360 degree coverage.
- It enables top view to support parking.

Drawbacks:

- Fish-eye cameras are subject to severe lens condition
- Camera resolution will be spread over a large area, leaving a comparably low resolution per degree. This effectively limits the range of object detection.

Camera mounting positions

Wide-angle camera for traffic light detection.

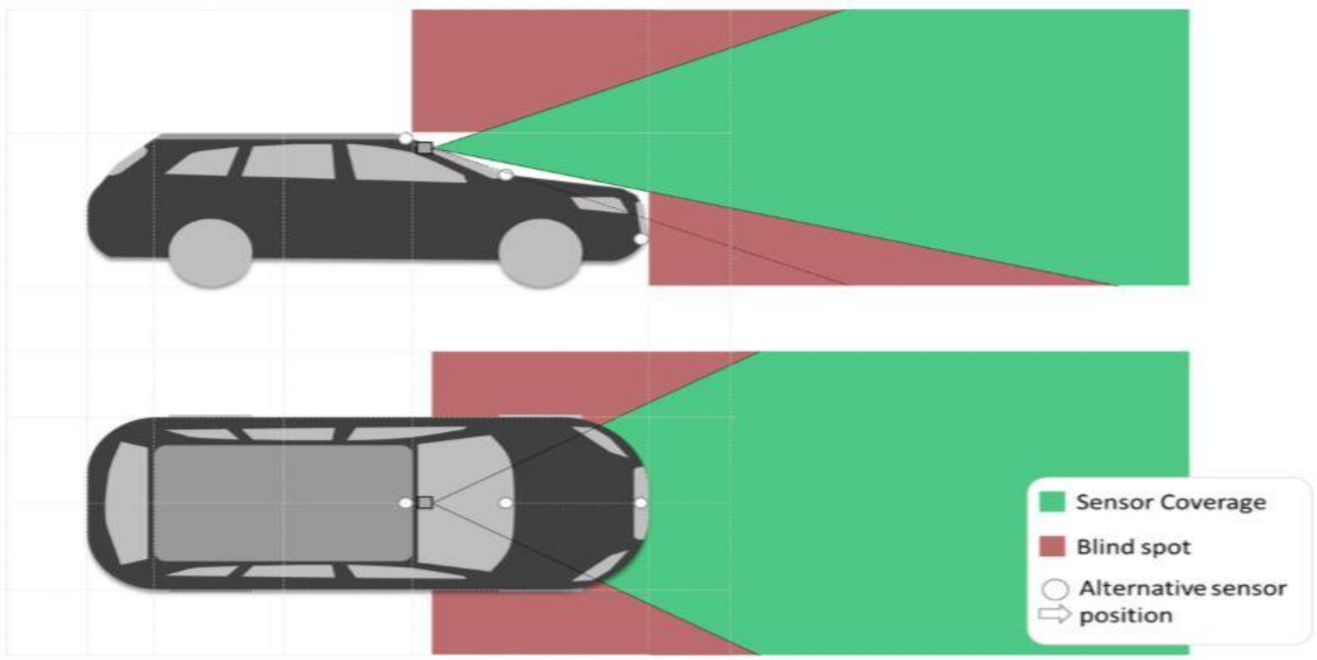


Figure: Wide angle camera for traffic light detection.

Camera mounting positions

Wide angle camera for traffic light detection.

Front camera and surround view camera systems are usually unable to detect objects that are close and elevated, such as traffic lights, because of their limited vertical FoV. This can be solved by adding a wide-range camera mounted at the front roof edge center. Depending on the positioning of traffic lights in the target environment, it may be necessary to tilt these cameras upwards.

Lidars

Lidars are active sensors.

- Lidar illuminates a target with pulsed laser light and measures the source distance to the target, by analyzing the reflected pulses.
- Due to its high 3D geometry accuracy, Lidar is generally used to create high-definition 3D world maps.

Lidar mounting positions

Single lidar on roof center.

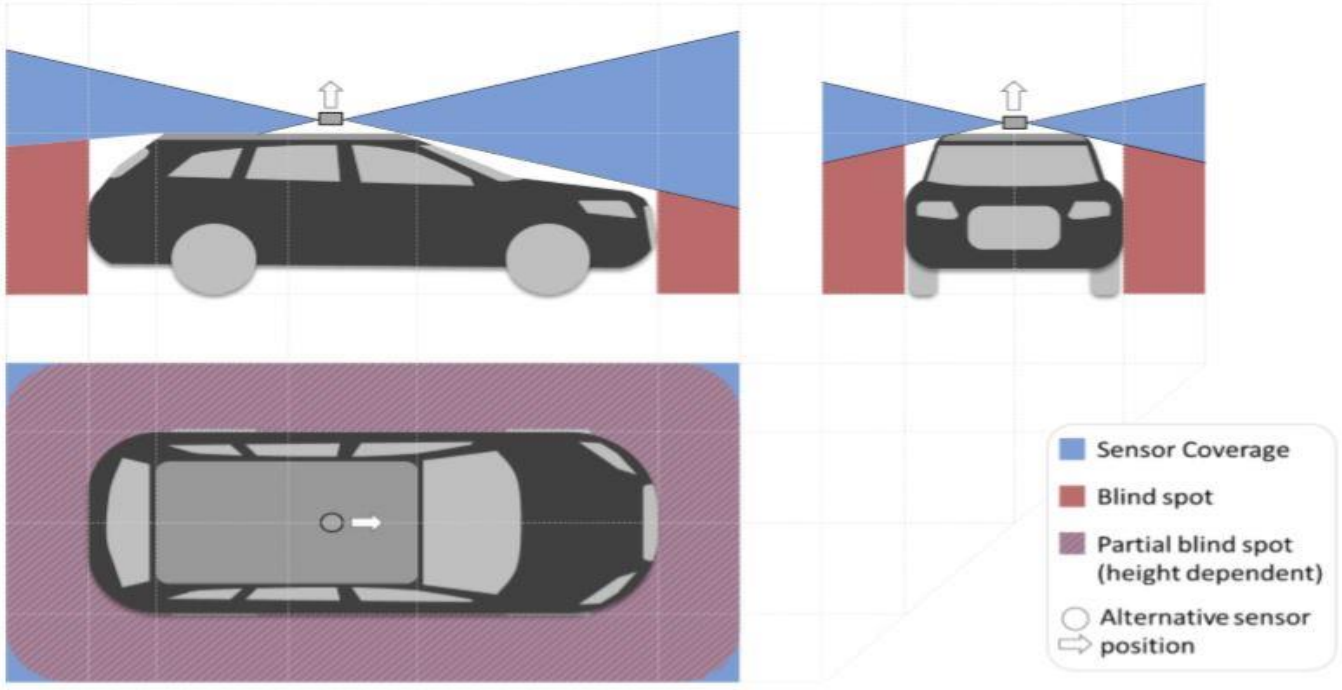


Figure: Single lidar on roof center.

Lidar mounting positions

Single lidar on roof center.

Variations:

- Sensor can be elevated to reduce blind spot by occluding roof.
- Sensor can be moved from the roof center to the roof front edge, which improves from perception while decreasing rear perception.

Lidar mounting positions

Single lidar on roof center.

Advantages:

- Simple setup, no effort to synchronize and align multiple point clouds.
- 360 degree coverage with one sensor.
- Good overview, ability to look over other traffic participants.

Drawbacks:

- Blind spot for low objects in all directions, particularly to the rear.
- Sensor must be elevated from roof to leverage full vertical FoV, the high position causes mechanical challenges in case of abrupt deceleration and makes it impossible to enter areas with low ceiling.

Lidar mounting positions

Mul*tiple lidars on the roof.*

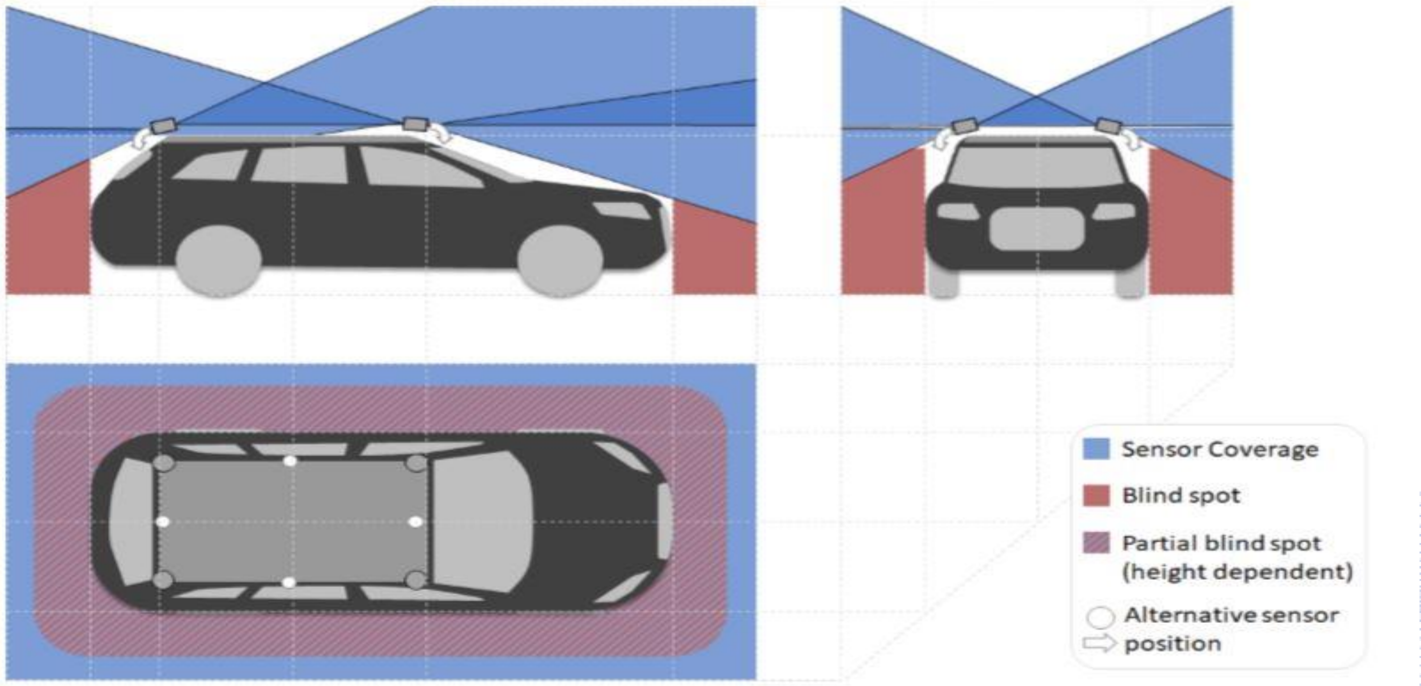


Figure: Multiple lidars on the roof.

Lidar mounting positions

Multiple lidars on the roof.

Variations:

- Sensors can be tilted to decrease blind spots.
- Sensors can be mounted on the edges of the vehicle roof or complemented by additional sensors on the roof.

Lidar mounting positions

Multiple lidars on the roof.

Advantages:

- No occlusion by vehicle roof clouds.
- 360 degree coverage.
- Tilted sensors reach optimal coverage among roof mounted configurations.

Drawbacks:

- Higher complexity in terms of integration and point cloud fusion compared to single sensor.
- Tilting of the sensors is limited by their vertical FoV. Too few tilting results in blind spots near the vehicle while too much tilting limits coverage on elevated objects.

Lidar mounting positions

Front lidar.

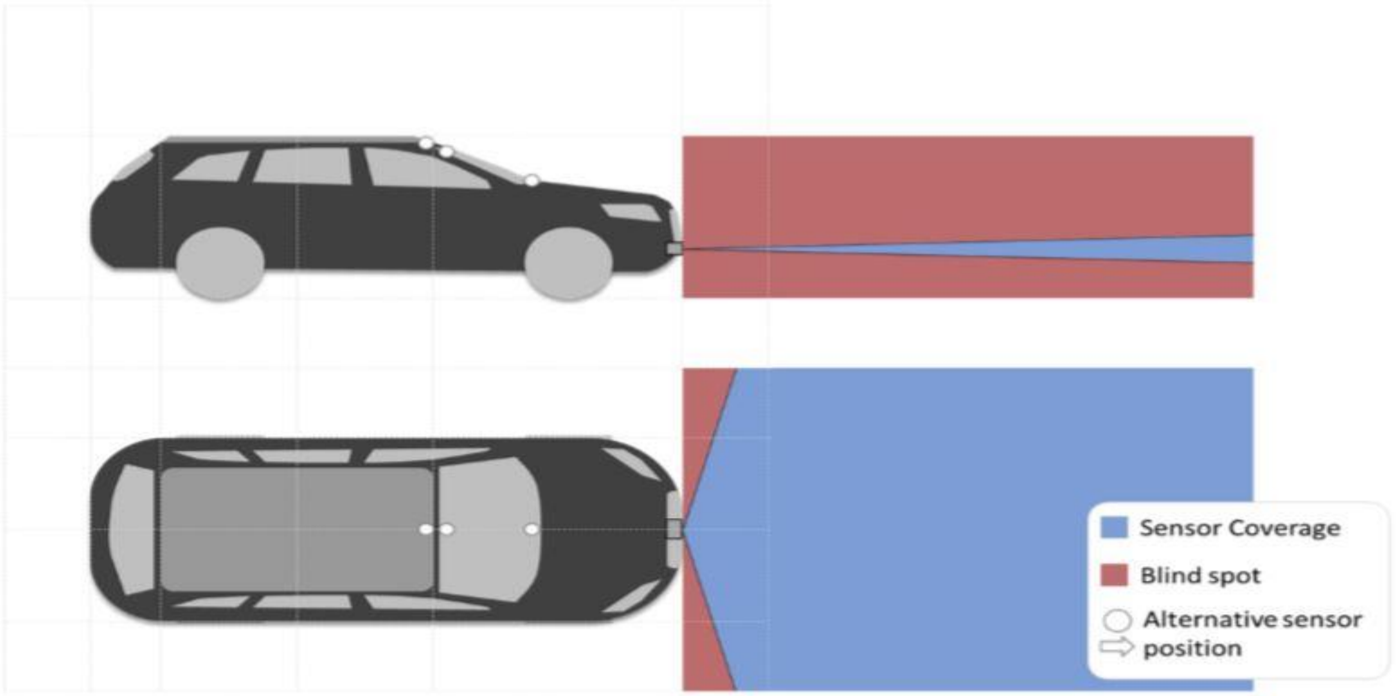


Figure: Front lidar.

Lidar mounting positions

Front lidar.

Variations:

- Lidars with bigger vertical FoV enable steeper slopes.
- Higher mounting points behind windshield or at the front roof edge center allow to look over other traffic participants and low obstacles at the cost of missing low obstacles.

Lidar mounting positions

Front lidar

Advantages:

- Simple setup. Good integration into vehicle.
- On flat surfaces: Lidar beams are almost parallel to the road surface; hence no road surface reflections are returned. This allows to interpret the returns directly as a distance to obstacles.
- Good for detection of vehicles in the front on highways (ACC).

Drawbacks:

- On slopes; sensor will return ground plane as an obstacle for ascending roads and no returns for descending roads.
- Insufficient overall coverage for urban AD if not combines with other sensors.

Lidar mounting positions

Side view lidars.

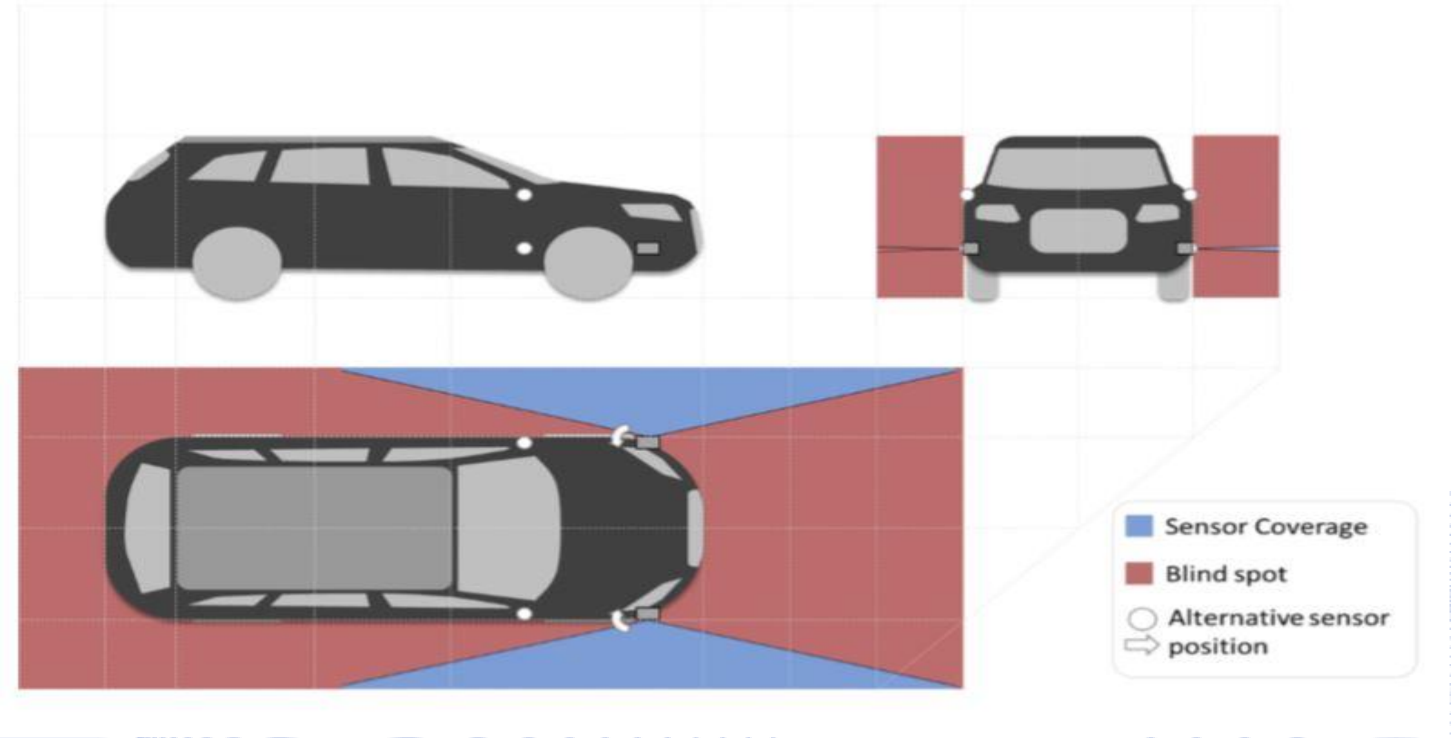


Figure: Side view lidar.

Lidar mounting positions

Side view lidars.

Variations:

- Higher horizontal FoV and vertical FoV lidars enable full coverage of vehicle sides.
- Different positions: position behind front wheel case may simplify integration, position below side mirror allows to look over low obstacles.

Lidar mounting positions

Side view lidars.

Advantages:

- Enables Crossing with occlusion scenario. The vehicle can detect cross-traffic at intersections without entering and potentially blocking the traffic.

Drawbacks:

- Sensor with low vertical FoV will have issues with slopes.
- Protruding 360 degree lidars on the vehicle's sides provide 180 degree coverage.

Other types of 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 time between transmitting an ultrasonic signal and receiving its echo.
- ***Global positioning system*** (***GPS***) provides time and geolocation information for autonomous cars.
- ***Inertial measurement unit*** (***IMU***) measures an autonomous car specific force, angular rate and orientation, using a combination of accelerometers, gyroscopes and sometimes magnetometers.

Autonomous car perception

- The perception module analyzes the raw sensor data and outputs an environment understanding to be used by the autonomous cars. This process is similar to human visual cognition.
- Using sensor data and perception output, the localization and mapping module can not only estimate autonomous car location, but also build and update a 3D world map. This topic became very popular since the concept of simultaneous localization and mapping (SLAM) was introduced in 1986.

Autonomous car perception

- Perception tasks include: object (lane, pedestrial, vehicle, traffic light signage, etc.) detection & tracking, depth/disparity estimation & 3D geometry reconstruction, etc.
- The state-of-the-art perception technologies can be broken into two categories: computer vision-based and machine learning-based ones.

Object detection & tracking

Lane detection involves lane marking detection and free space detection.

(a) (b)

Figure: Lane detection; (a) lane marking detection; (b) free space detection.

Object detection & tracking

Pedestrian detection can be either bounding box-level or instance/pixel-level [6].

(a) (b)

Figure: Pedestrian detection; (a) 2D bounding box-level detection; (b) instance/pixel-level detection.

[6] https://www.cis.upenn.edu/jshi/ped_html/

Object detection & tracking

Vehicle detection include car, truck, bus detection.

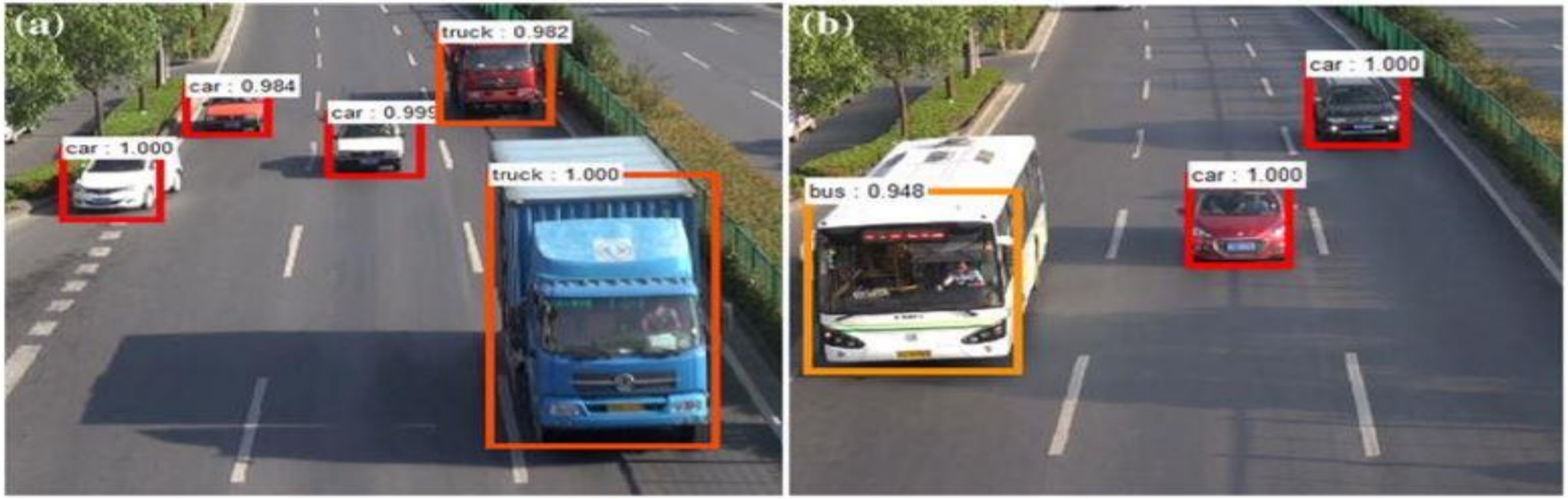


Figure: Vehicle detection.

Object detection & tracking

Traffic light and signage detection also involves signage classification.

Figure: Traffic light and signage detection.

Depth/disparity estimation & 3D geometry reconstruction

Depth estimation can be achieved using either a single movable camera or an array of synchronized cameras [7].

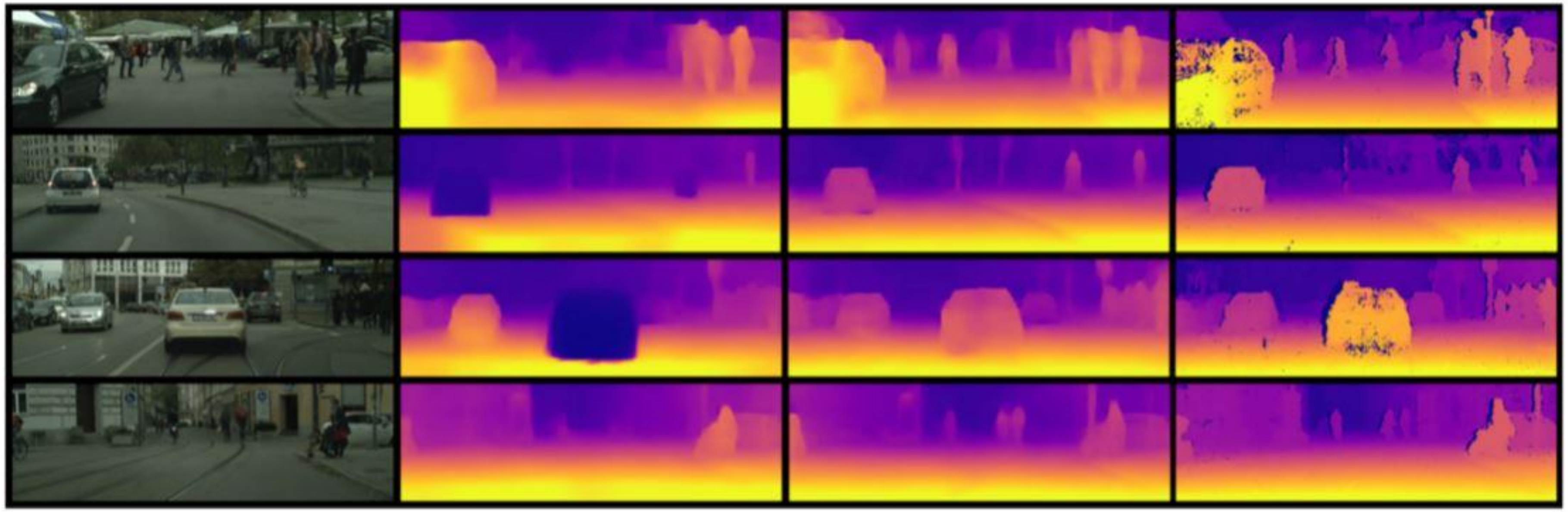


Figure: Monocular depth estimation.

[7] https://ai.googleblog.com/2018/11/a-structured-approach-to-unsupervised.html

Depth/disparity estimation & 3D geometry reconstruction

Depth estimation can be achieved using either a single movable camera or an array of synchronized cameras [7].

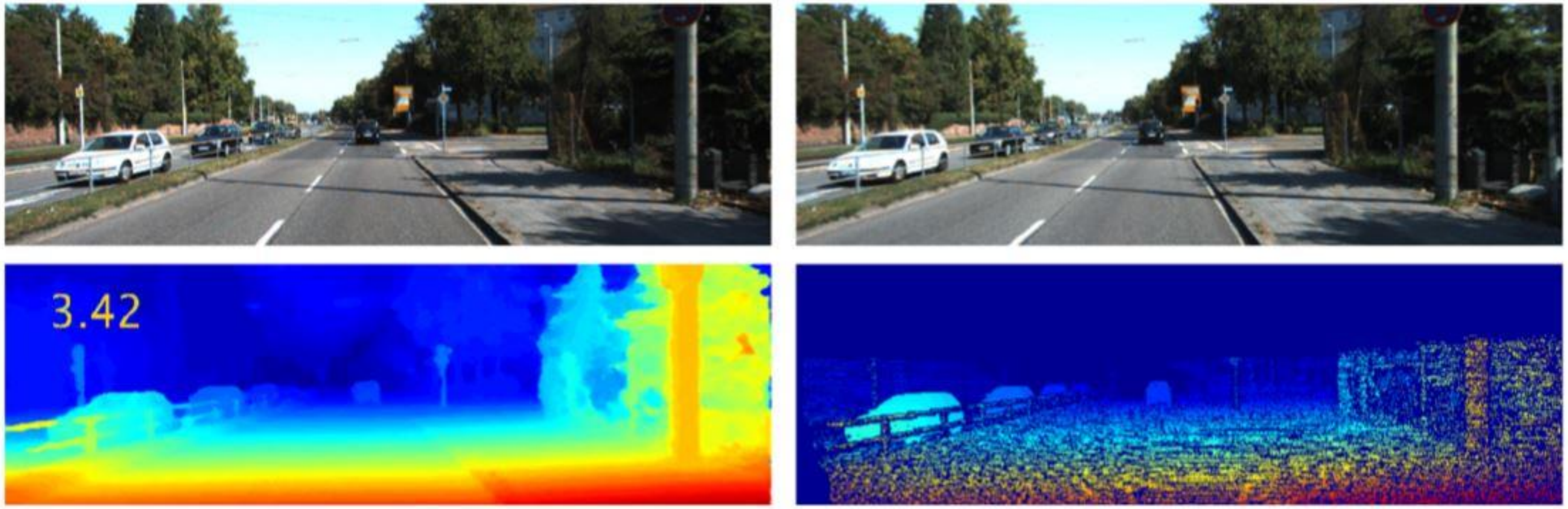


Figure: Disparity map estimation.

Localization & Mapping

- The state-of-the-art SLAM systems are generally classified as filter-based and optimization-based.
- The filter-based SLAM systems are derived from Bayesian filtering.
- The optimization-based SLAM approaches can be divided into two main branches: bundle adjustment (BA) and graph SLAM.
- According to the used sensor(s), SLAM systems can be classified as: Lidar-based, Lidar-IMU-based, visual and visual-IMU ones.

Deep Learning in autonomous cars

The most popular deep learning models used in autonomous car technology include:

- End-to-end learning
- Deep Neural Networks (DNNs)
  - Convolutional Neural Networks (CNNs)
  - Transformer networks
  - Deep Reinforcement Learning.

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Open source datasets

- ***KITTI***: stereo vision, optical flow, depth estimation, odometry, object detection & tracking, road detection and pixel/instance-level semantic image segmentation.
- ***6D-vision***: stereo vision, optical flow, ego-motion estimation, pedestrian recognition and semantic image segmentation.
- ***ApolloScape***: scene parsing, car instance, lane segmentation, self-localization, trajectory estimation, object detection/tracking and stereo vision.
- ***Cityscapes***: pixel/instance-level semantic image segmentation.
- ***Other datasets***: KAIST Urban, BDD100K, Mapillary, Nuscenes, EISATS, etc.

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Applications

- Civil and privately owned self-driving vehicles to optimize daily time management and reduce time spent driving;
- Self-driving trucks for “automated runs” and to reduce human resources;
- ***Mobility as a Service*** (***MaaS***) and car-sharing to minimize upfront costs and the need for parking space.
- Carpooling and taxi or bus services to eliminate driver’s costs paid by the commuters.
- Self-driving vans for leisure.

Applications

The autonomous driving technology can be implemented in any types of vehicles, such as delivery vans, taxis, coaches, tour buses, etc.

(a) (b) (c)

Figure: Self-driving delivery vans; (a) Volvo self-driving van; (b) TuSimple self-driving van; (c) Tesla self-driving van.

Applications

The autonomous driving technology can be implemented in any types of vehicles such as delivery vans, taxis, coaches, tour buses, etc.

(a) (b) (c)

Figure: Self-driving taxis; (a) Didi self-dring taxi; (b) Nutonomy self-driving taxi; (c) Voyage self-driving taxi.

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Existing challenges

- The perception modules cannot perform well in poor weather and/or illumination conditions or in complex urban environments.
- Most perception methods are generally computationally-intensive and cannot run in real time on embedded and resource-limited hardware.
- Supervised learning has been extensively used. However, data labeling is an extremely labor-intensive task.
- The use of current SLAM approaches still remains limited in large-scale experiments, due to its long-term unstability.
- “when can people truly accept autonomous driving and autonomous vehicles?” is a still good topic for discussion and poses serious ethical issues.

Existing challenges

- Road infrastructure quality as a necessity for self-driving cars.
- Policy & Regulations.
- Consumer acceptance: consumer perception of the safety of autonomous cars has stalled being the biggest roadblock to the development of self-driving vehicles.
- Data collection and privacy: Concerns about biometric data being collected by self-driving car manufacturers and sent to other parties.
- Internet of cars and cybersecurity: Hack of automated cars could cause collisions and gridlock, hindering emergency services.

Existing challenges

- Car insurance: Who is paying in the case of an accident?

- Ethics issues: Classical AI ethics questions:
- “If we are about to have a car accident killing two pedestrians, how an autonomous car will decide which one to kill?”
- “If we are about to have acar accident killing a pedestrian or the car driver, how an autonomous car will decide which one to kill?”

Q & A

Thank you very much for your attention!

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

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