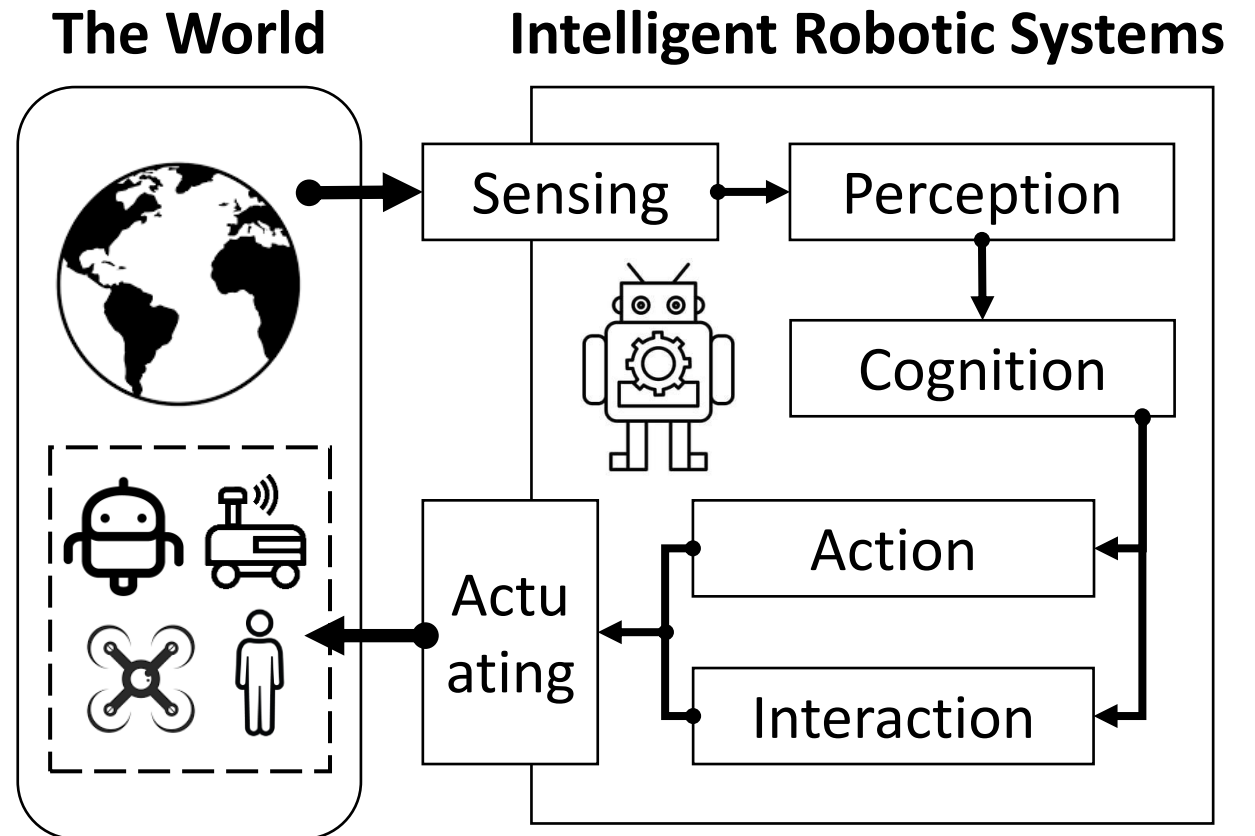


COMPSCI-603: Robotics

Sensing and Actuating

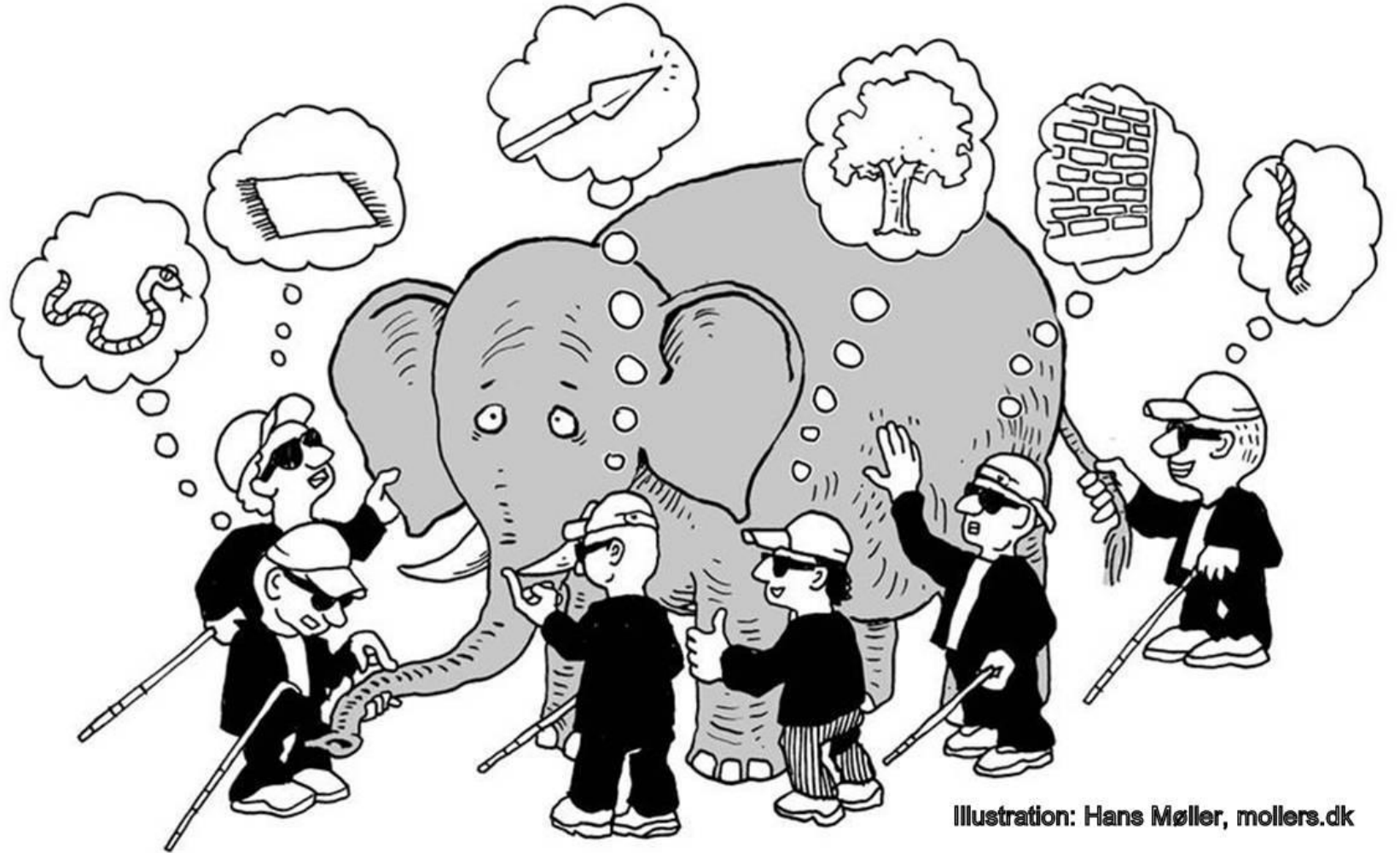
(Brief Overview)

Robotic Systems



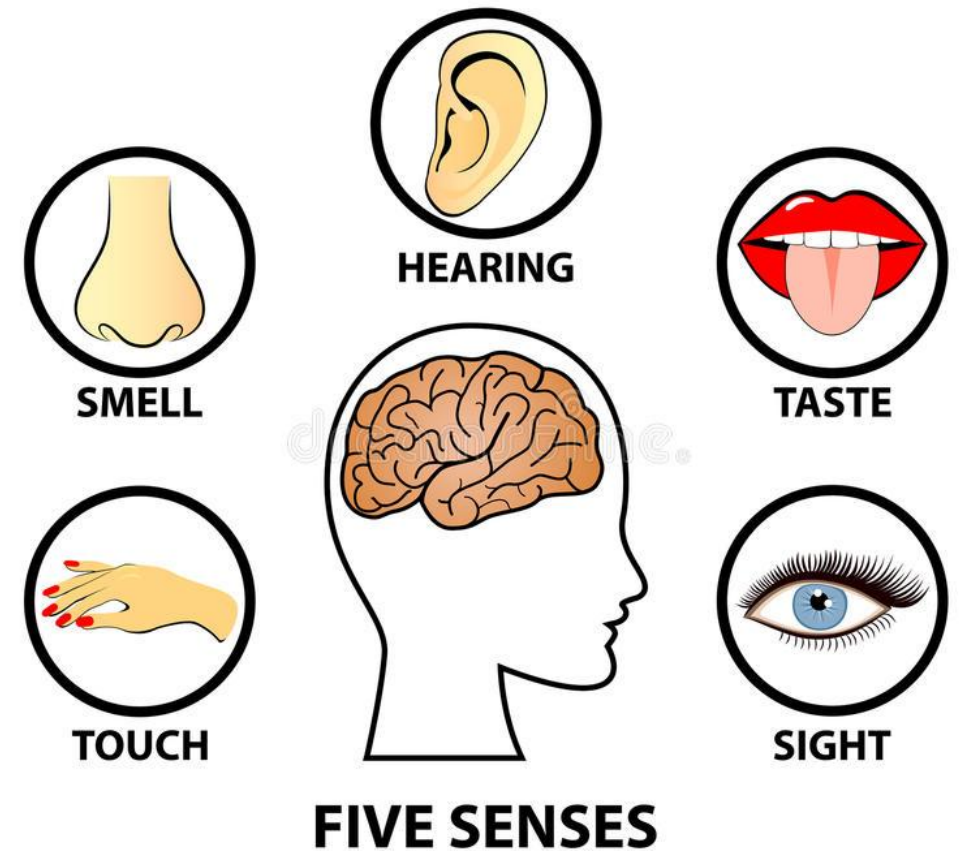
Robot Sensing

- What is the purpose of sensing for robots?



Sensors

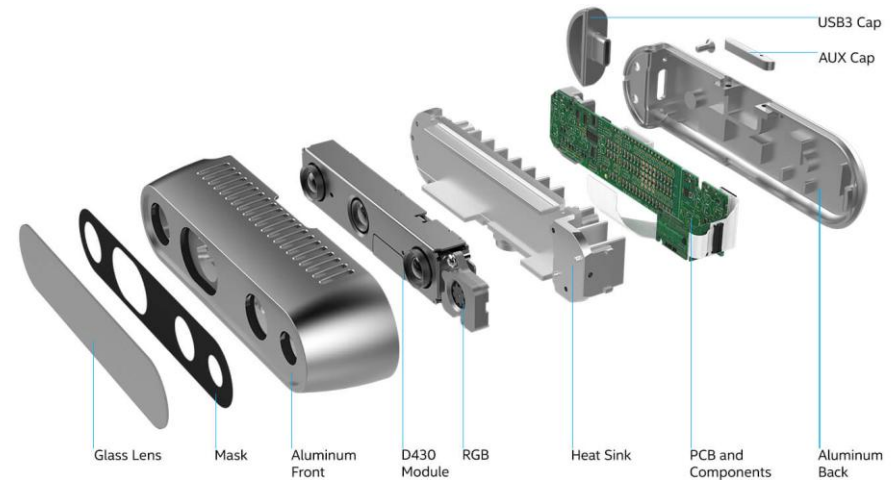
- Sensors are electronic devices that measure physical quantities.
- Sensors are a necessary physical component of the *perception* system of a robot.
- Sensors do not provide state, but measurement or observation
- Examples:
 - Contact: switch
 - Distance: radar
 - Location: GPS



Reference: Roland Siegwart, Illah Reza Nourbakhsh and Davide Scaramuzza. "Introduction to Autonomous Mobile Robots", Chapter 4, MIT Press, 2011.

Sensor Types

- From the perspective of energy emission:
 - Passive: receive energy only.
 - Vision → Camera
 - Hearing → Microphone
 - Active: emit energy and measure its response.
 - Radar, sonar
 - LiDAR
 - Structured light
 - Touch



Sensor Types

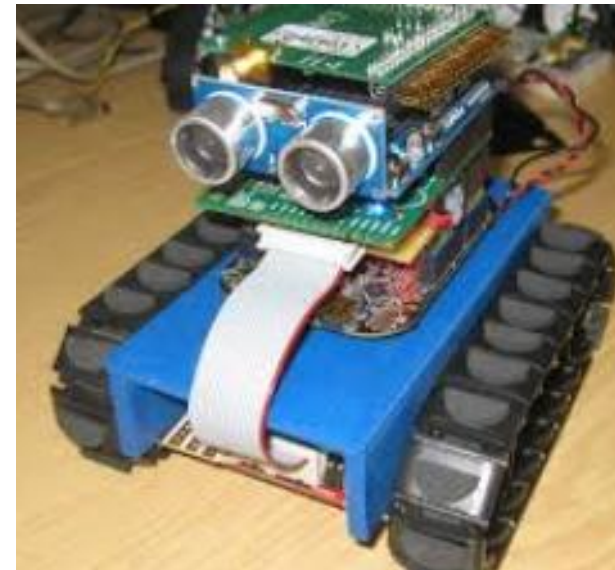
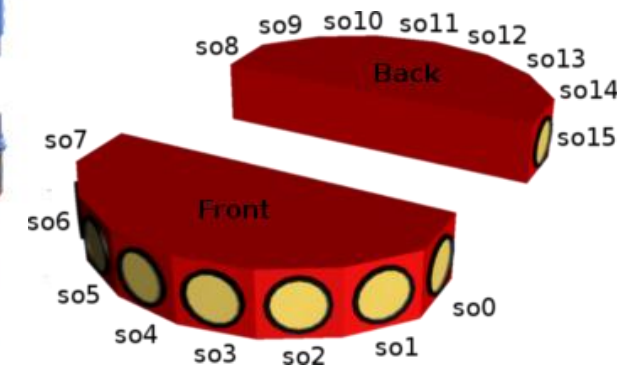
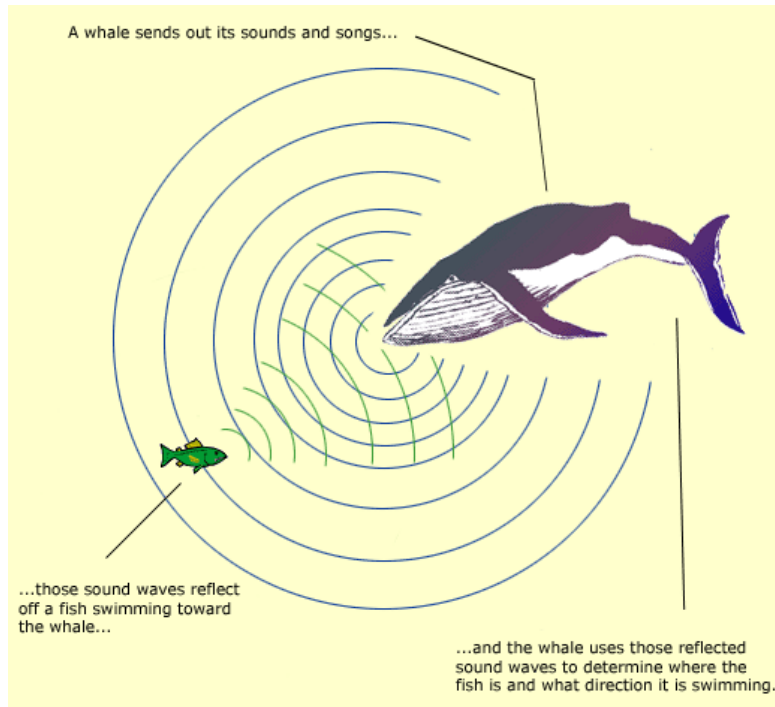
- From the perspective of information sources:
 - Proprioceptive sensors: measure values internally to the robot, e.g., for robot state estimation.
 - Battery status
 - Motor rotation
 - CPU temperature
 - Exteroceptive sensors: obtain observations of the external environment, e.g., for situational awareness.
 - Distance
 - Visual images
 - Thermal readings

Common Proprioceptive Sensors

- Odometry sensor (to estimate change in position over time): motor/wheel encoders.
 - Inertial sensor (to estimate velocity): gyroscope, accelerometer.
 - Heading sensor: compass.
 - Tilting angle sensor: inclinometer.
-
- Inertial measurement unit (IMU): an electronic device that uses a combination of accelerometers, gyroscopes, and sometimes magnetometers to measure orientation in space.

Common Exteroceptive Sensors

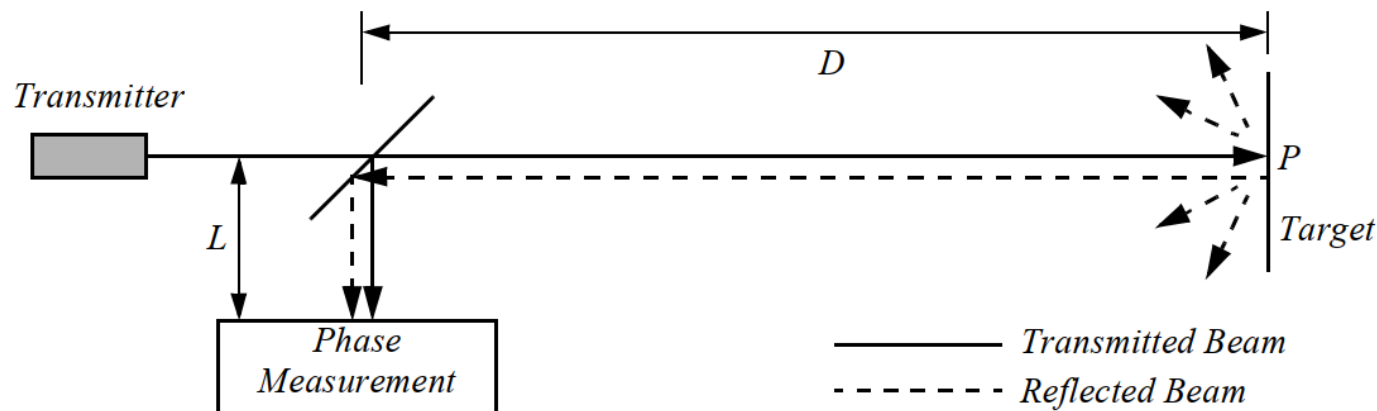
- Sonar: uses a transducer to generate a sound pulse and then listens for echo.



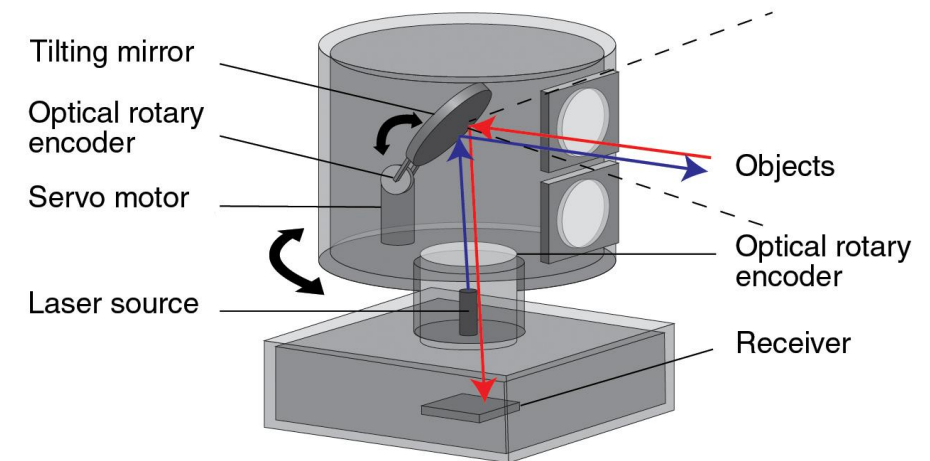
Common Exteroceptive Sensors

- Laser range sensor
 - Measures large range distance, so called range sensors.
 - Uses propagation speed of electromagnetic waves.
 - Thus, is also called Light Detection And Ranging (LiDAR).

$$\text{Distance} = (\text{Speed of Light} \times \text{Time of Flight}) / 2$$



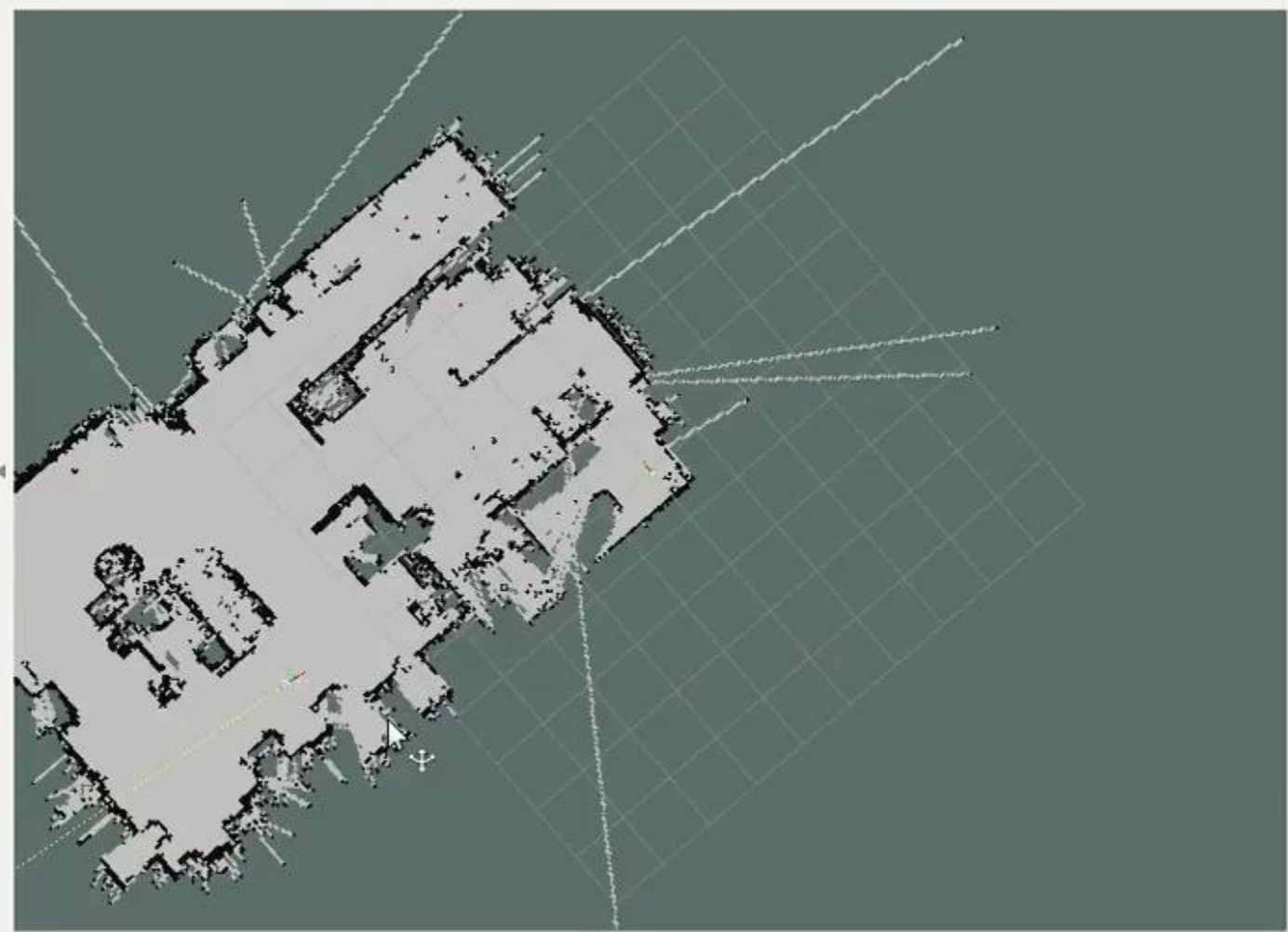
RPLiDAR



Displays

- Global Options
 - Fixed Frame: map
 - Background ...: 48; 48; 48
 - Frame Rate: 30
- Global Statu...
 - Fixed Frame: OK
 - Grid:
 - Image:
 - Status: Ok
 - Image Topic: /camera/rgb/image...

Add Remove Rename



Views

Type: Orbit (rviz) Zero

Current View	Orbit (rviz)
Near Clip ...	0.01
Target Fra...	<Fixed Frame>
Distance	18.0931
Yaw	2.4354
Pitch	1.5698
Focal Point	0; 0; 0

Save Remove Rename

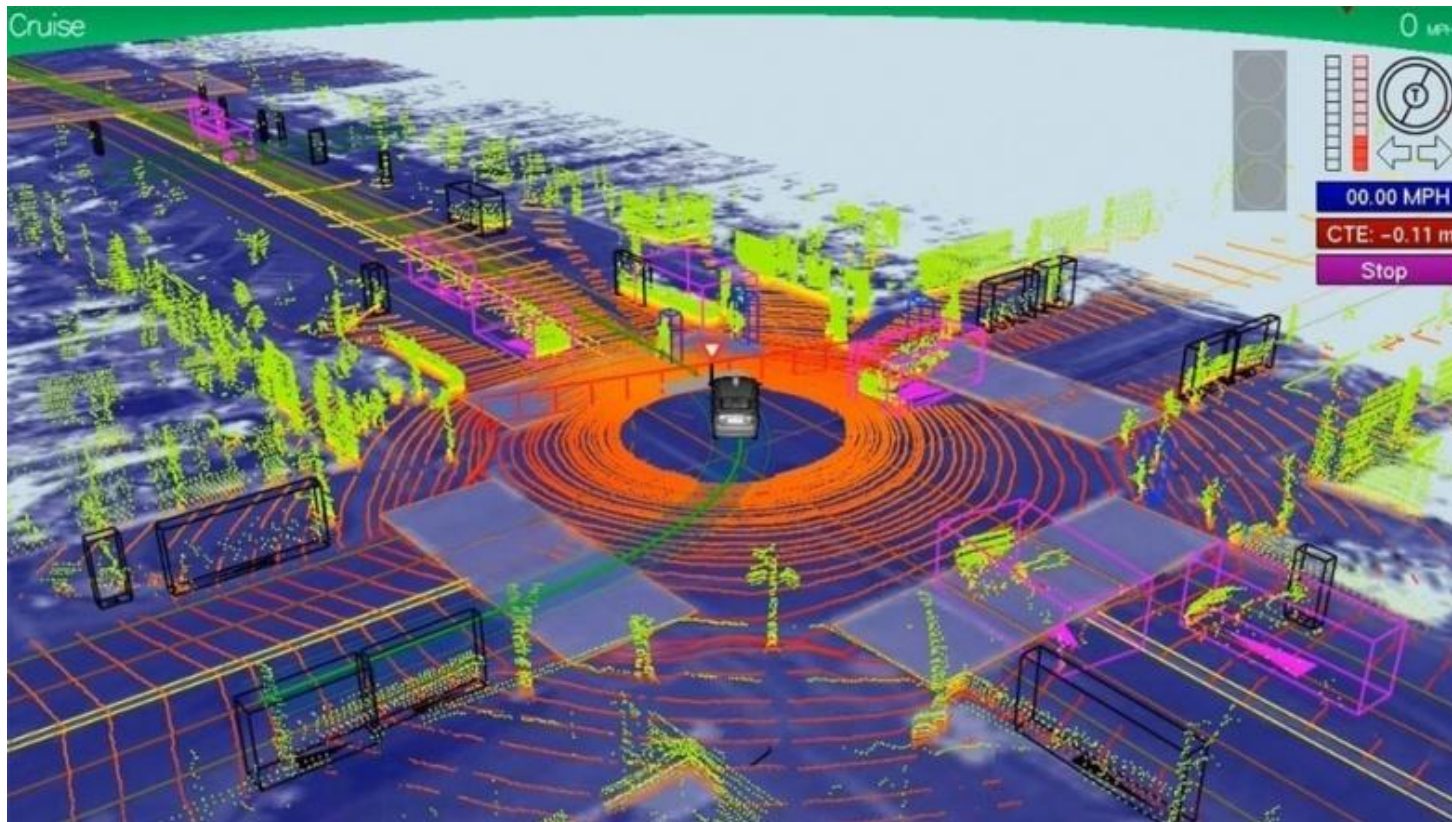
Time

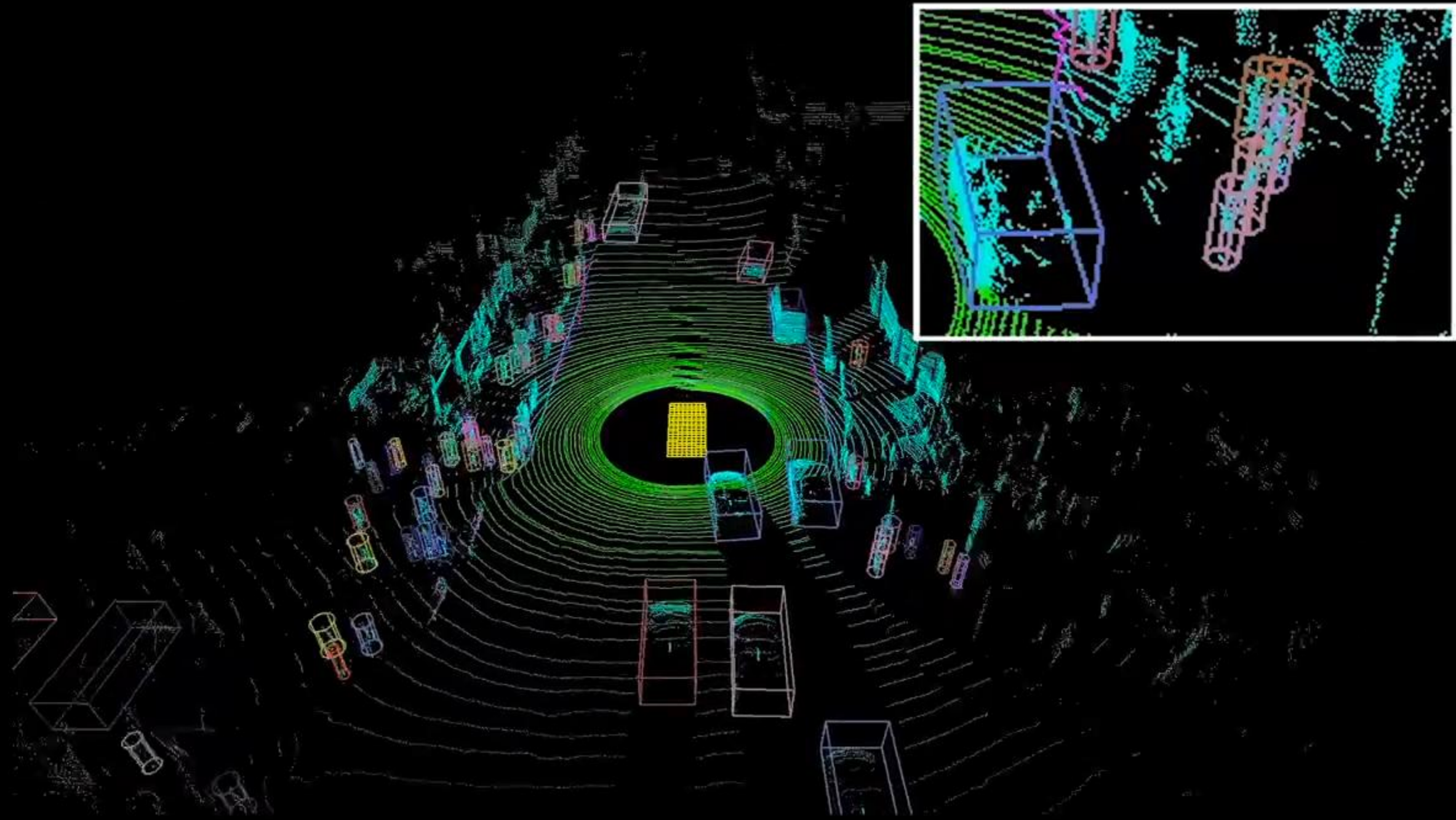
ROS Time: 1457281976.48 ROS Elapsed: 476.41 Wall Time: 1457281976.52 Wall Elapsed: 476.41 Experimental

Reset Left-Click: Rotate. Middle-Click: Move X/Y. Right-Click/Mouse Wheel: Zoom. Shift: More options. 30 fps

Common Exteroceptive Sensors

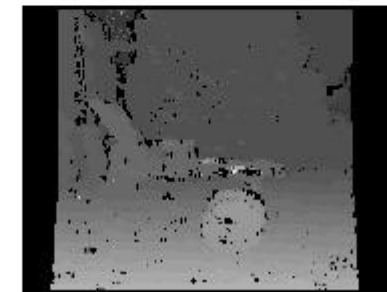
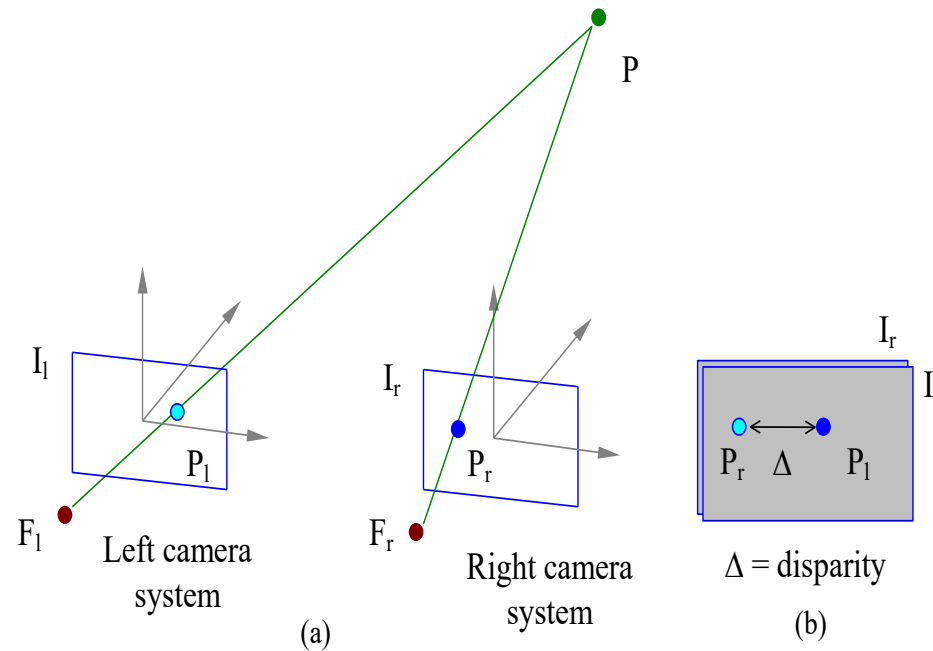
- 3D LiDAR: use multiple laser beams to expand the vertical field of view.





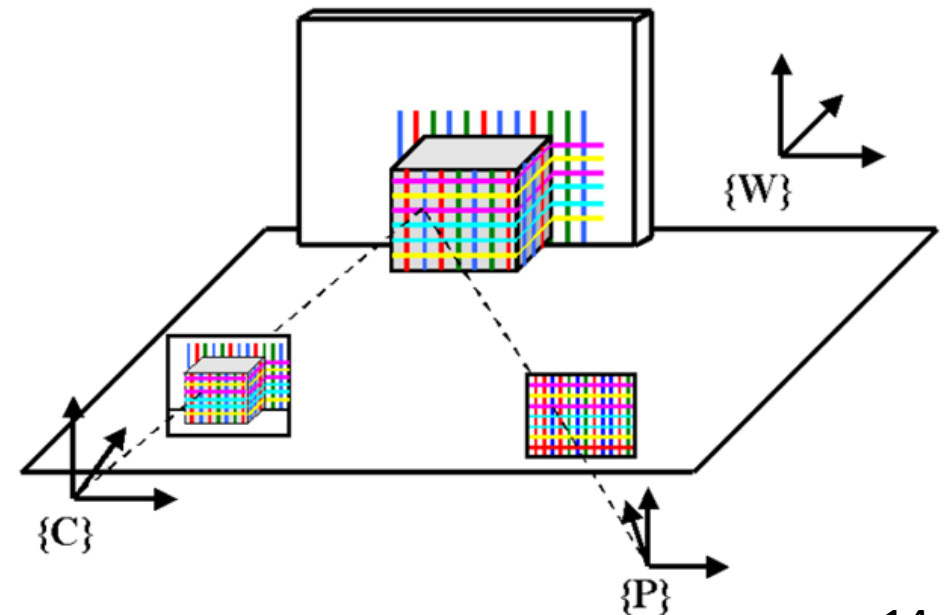
Common Exteroceptive Sensors

- Stereo camera: two (or more) cameras looking at the same scene from different perspectives provide a mean for determining three-dimensional shape and position.



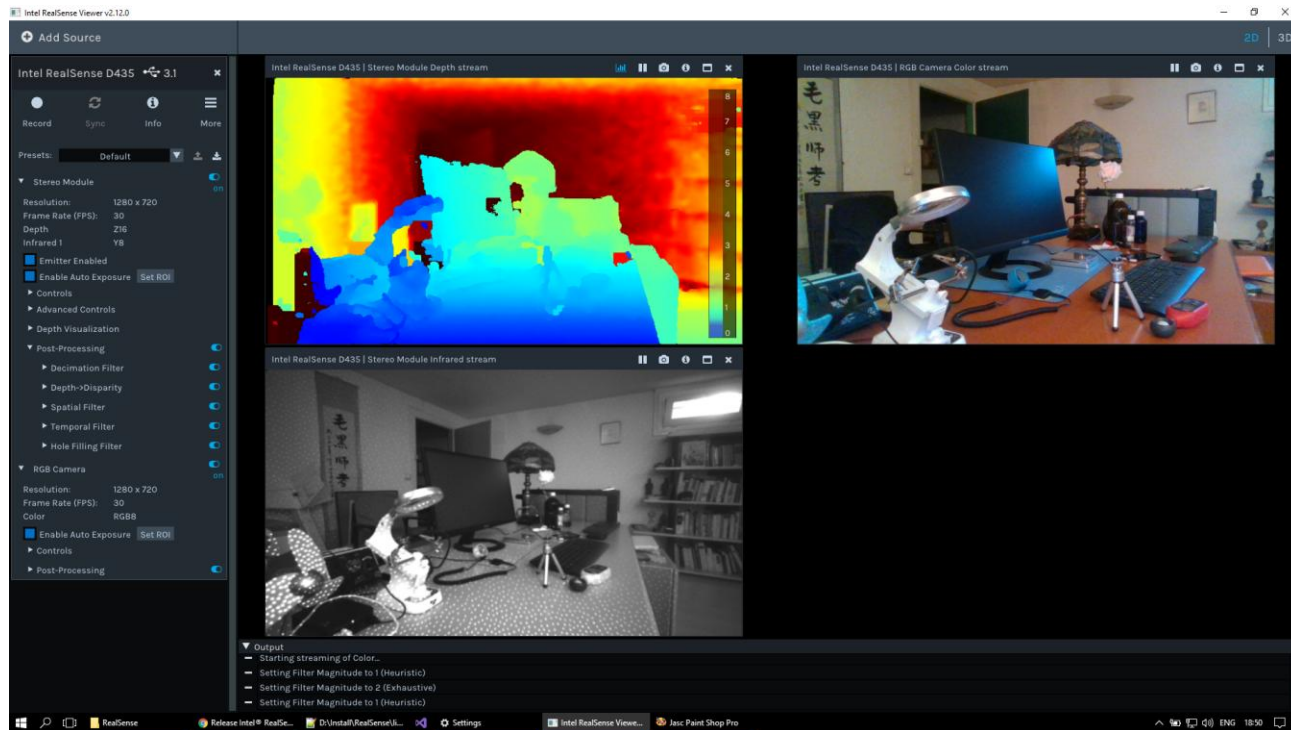
Common Exteroceptive Sensors

- Structured light sensor (color-depth sensors):
 - Projects a known pattern onto the scene.
 - Measures the similarity of sensed and projected patterns to find correspondence.
 - Uses triangulation to estimate distance.

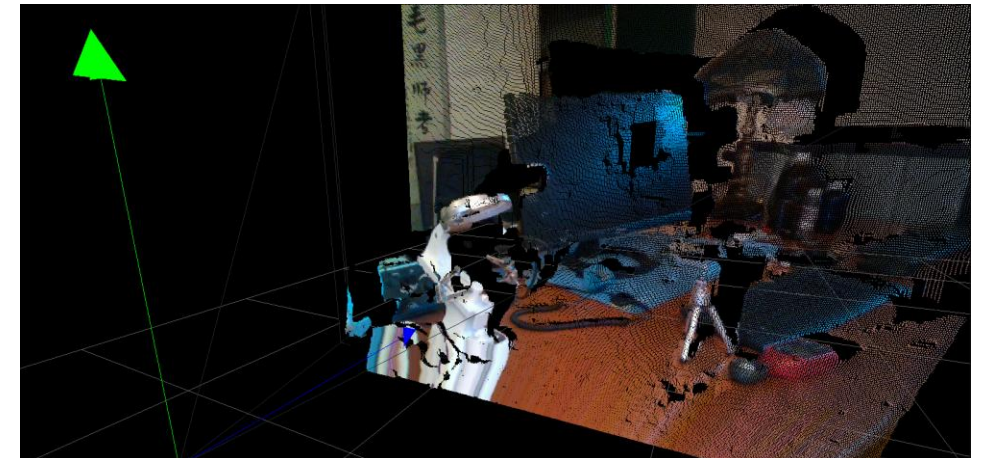
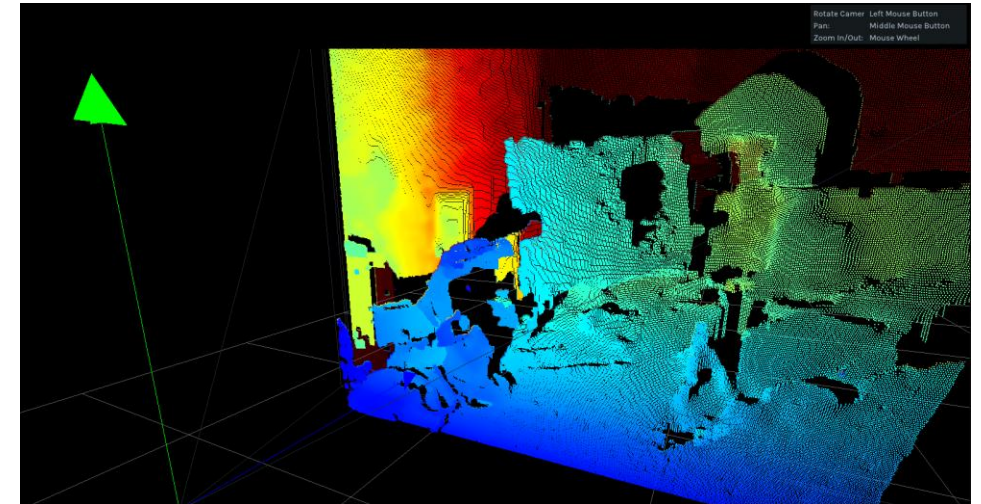


Common Exteroceptive Sensors

- Structured light sensor:
 - <https://github.com/IntelRealSense/librealsense/releases>



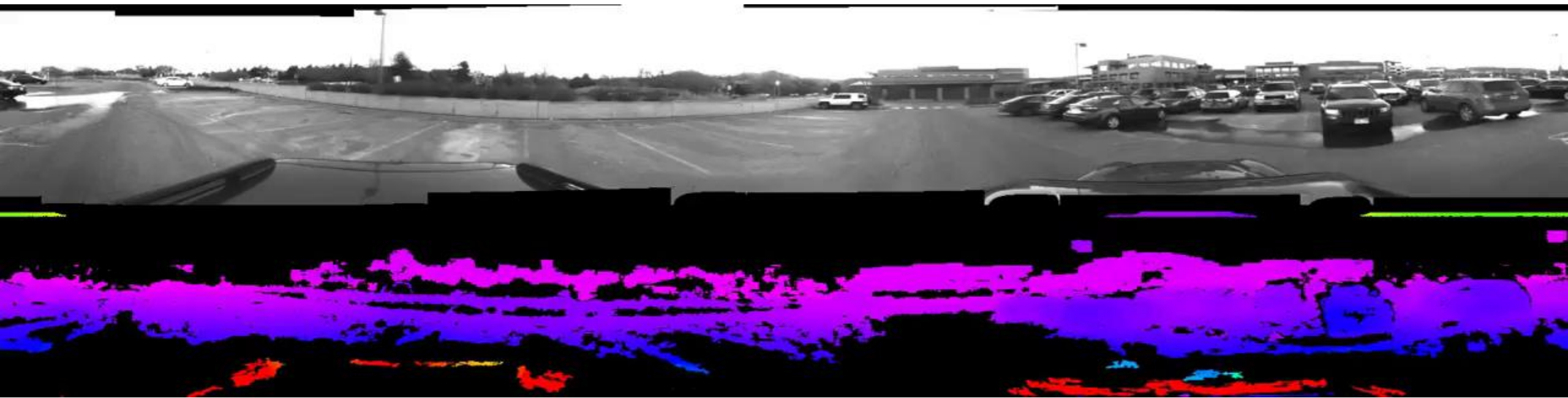
Reference: "Intel RealSense D435 review" by Maurice's Musings.














































Common Exteroceptive Sensors

- Omnidirectional stereo camera:

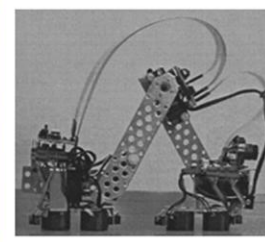
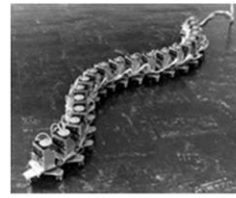


Sensor Performance Metrics

- Resolution: minimum difference that can be measured between two adjacent values.
- Frequency: the maximum speed with which a sensor can provide a stream of readings.
- Response: variation of output signal as function of the input signal (more linear is usually better).
- Accuracy/error: deviation between sensor's output and the true value.
 - Systematic errors: deterministic, caused by factors that can often be modeled and corrected (e.g., through calibration).
 - Non-systematic errors: non-deterministic, sometimes can be described in probabilistic terms (e.g., wheel slip may cause errors in encoder readings).
- Many other metrics: dependability, dynamic range, sensitivity, etc.

Actuating	Flying	Swimming	4+ Legged	2 Legged	4+ Wheeled	2 Wheeled	Arms	Head
Defense								
Industry								
Security								
Medical								
Transport		Yole Development Report, “Sensors for drones and robots: market opportunities and technology revolution,” 2016						
Commercial								
Consumer								

Actuating: Mobile Robots



Tracked

Articulated Body

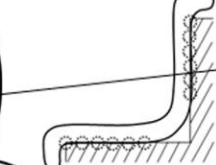
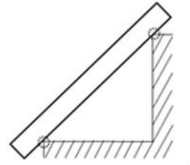
Hybrid
(Articulated Body)

Bridging

Conforming

Hybrid
(Legged)

Wheeled

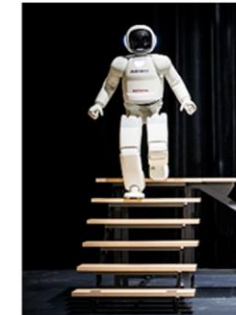


Jumping Over



Legged

Legged



Chun Fan Goh, Akshay Hinduja, Divish Ajmani, Robin Song, Lei Zhang, and Kenji Shimada. "Designing a mobility solution for fully autonomous welding of double-hull blocks." Journal of Mechanisms and Robotics 11, no. 4. 2019.

Actuating: Soft Robots

iSprawl



Soft gripper



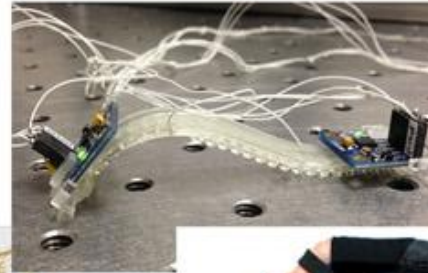
OCTOPUS



Universal gripper



Tuft Softworm



Inflatable robotic arm



X-RHex



Soft robotic fish



PoseiDrone



Origami robot



Rehabilitation glove



Octobot

Mostly stiff
Few selectively compliant elements

Entirely soft

Cecilia Laschi, Barbara Mazzolai, and Matteo Cianchetti. "Soft robotics: Technologies and systems pushing the boundaries of robot abilities." *Science robotics* 1, no. 1. 2016.

Real-World Robots

- Autonomous driving

HOW UBER'S FIRST SELF-DRIVING CAR WORKS

Top mounted **LIDAR** beams 1.4 million laser points per second to create a 3D map of the car's surroundings.

There are **20 cameras** looking for braking vehicles, pedestrians, and other obstacles.

A **colored camera** puts LiDAR map into color so the car can see traffic light changes.

Antennae on the roof rack let the car position itself via GPS.



LiDAR modules on the front, rear, and sides help detect obstacles in blind spots.

A **cooling system** in the car makes sure everything runs without overheating.

SOURCE: Uber

BUSINESS INSIDER

The self-driving car's sensors

Just like a person has five senses, Google's self-driving car has a variety of gadgets that detect nearby objects so it can avoid them.



Laser
Provides a 360-degree view around the car and helps determine its location.

Microphone
Can detect sirens of approaching emergency vehicles.



Videocameras
With one on each of the car's four corners and another on its roof, they help the car recognize objects around it.

Global Positioning System software
Helps car determine its location.

Position sensor
Located in the wheel hub, this sensor helps determine car's location from wheel rotations.

Orientation sensor
Located in car's interior, it acts like the car's inner ear, sensing motion and balance.

Radar
Measures speed of cars ahead.



How the car operates

- 1 Any object the vehicle's sensors spot is interpreted by software to determine if it's a pedestrian, cyclist, vehicle or something else.
- 2 Using what it's learned from previous driving, the software makes predictions about what objects will do next.
- 3 The software analyzes the information to decide whether it is safe to accelerate, turn or hit the brakes.



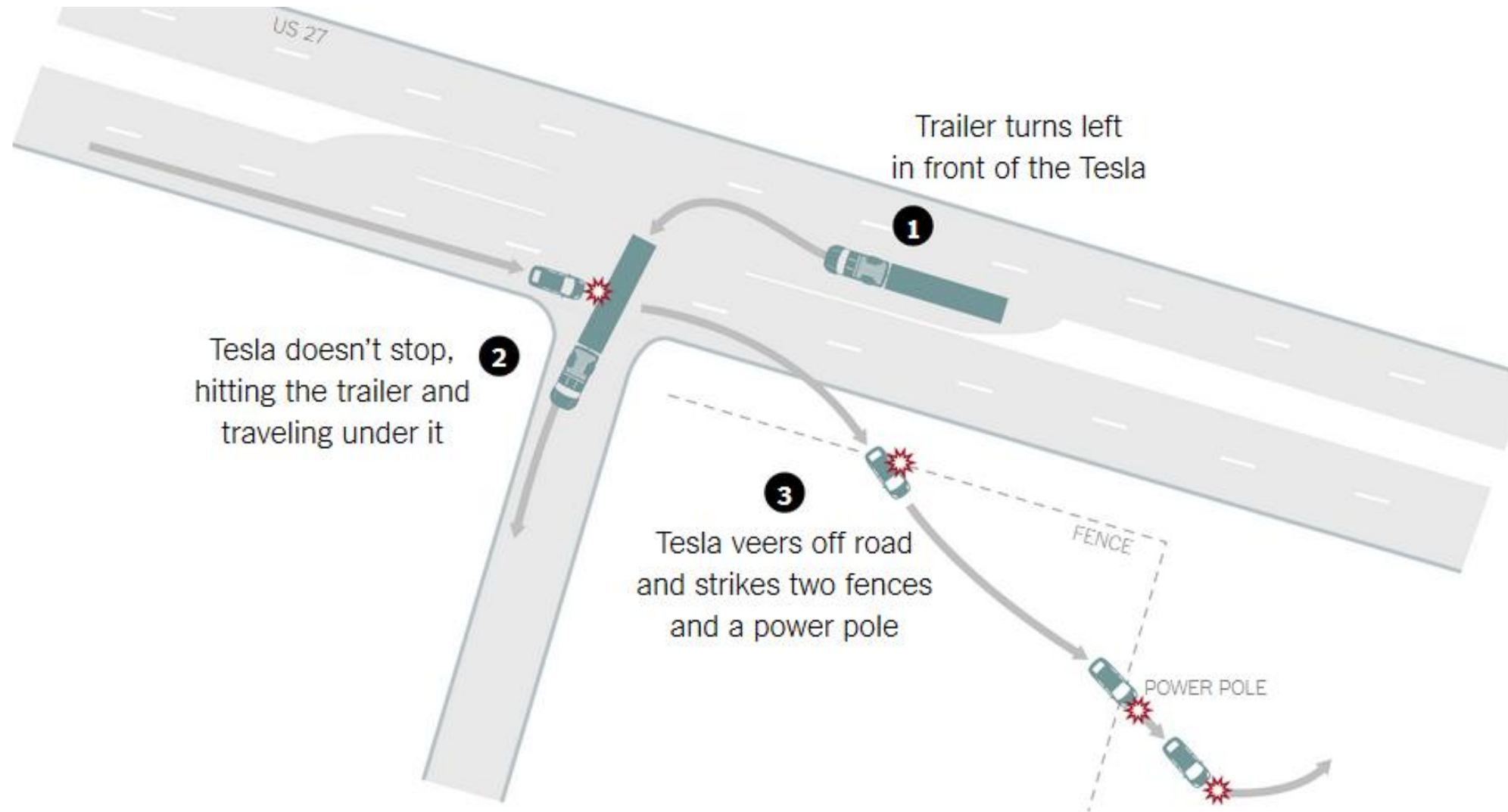
How the car sees the world

This computerized image is what Google researchers monitoring sensor data see as they ride in the vehicle.

- Other vehicle
- Pedestrian
- Cyclist
- Objects that warrant caution
- A crosswalk, indicating the car needs to stop
- A traffic signal, warning of upcoming railroad tracks
- Path where Google's car intends to go

Source: Google
Graphic: Tribune News Service

- On May 7, 2016, a Tesla Model S crashed in northern Florida into a truck that was turning left in front of it.



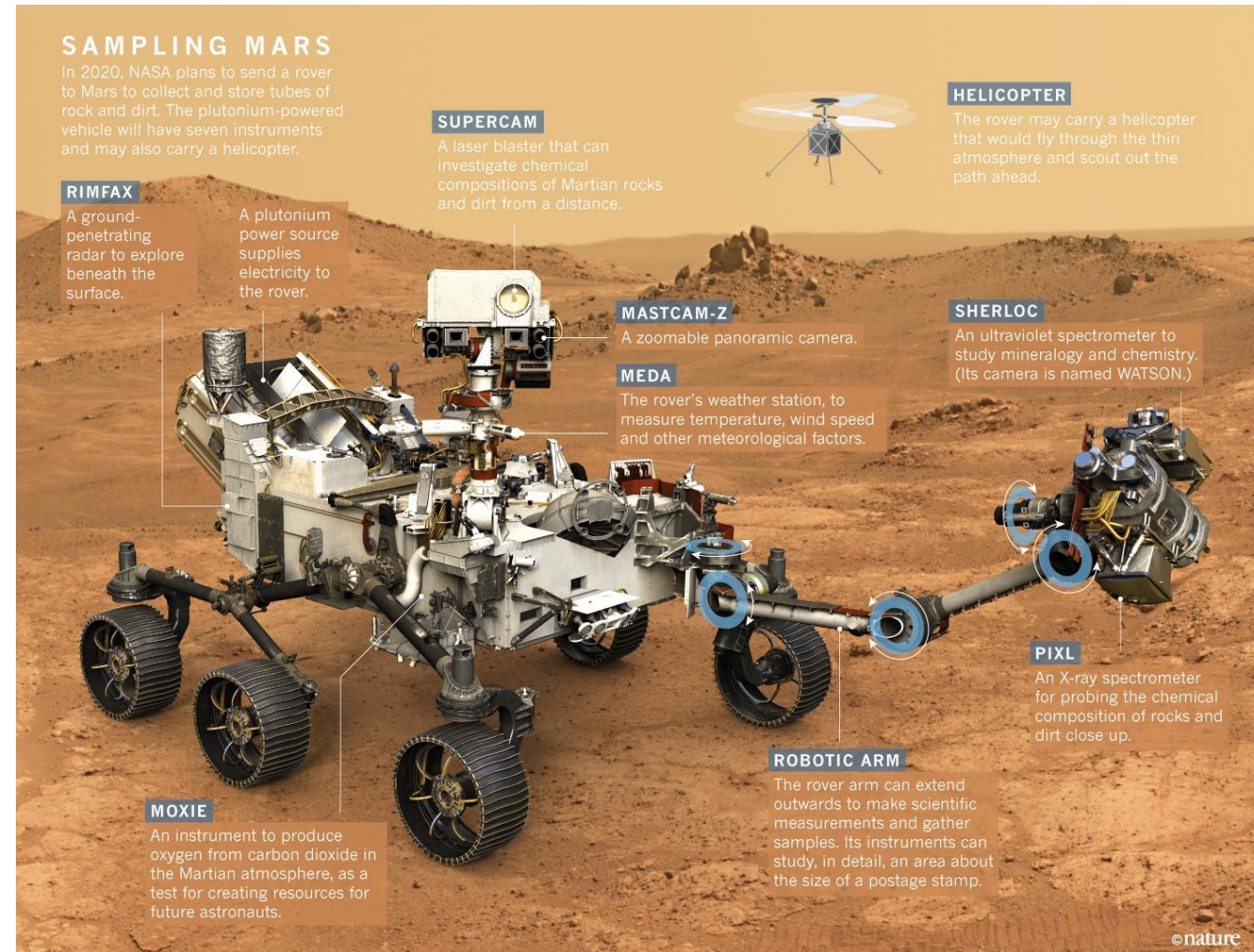
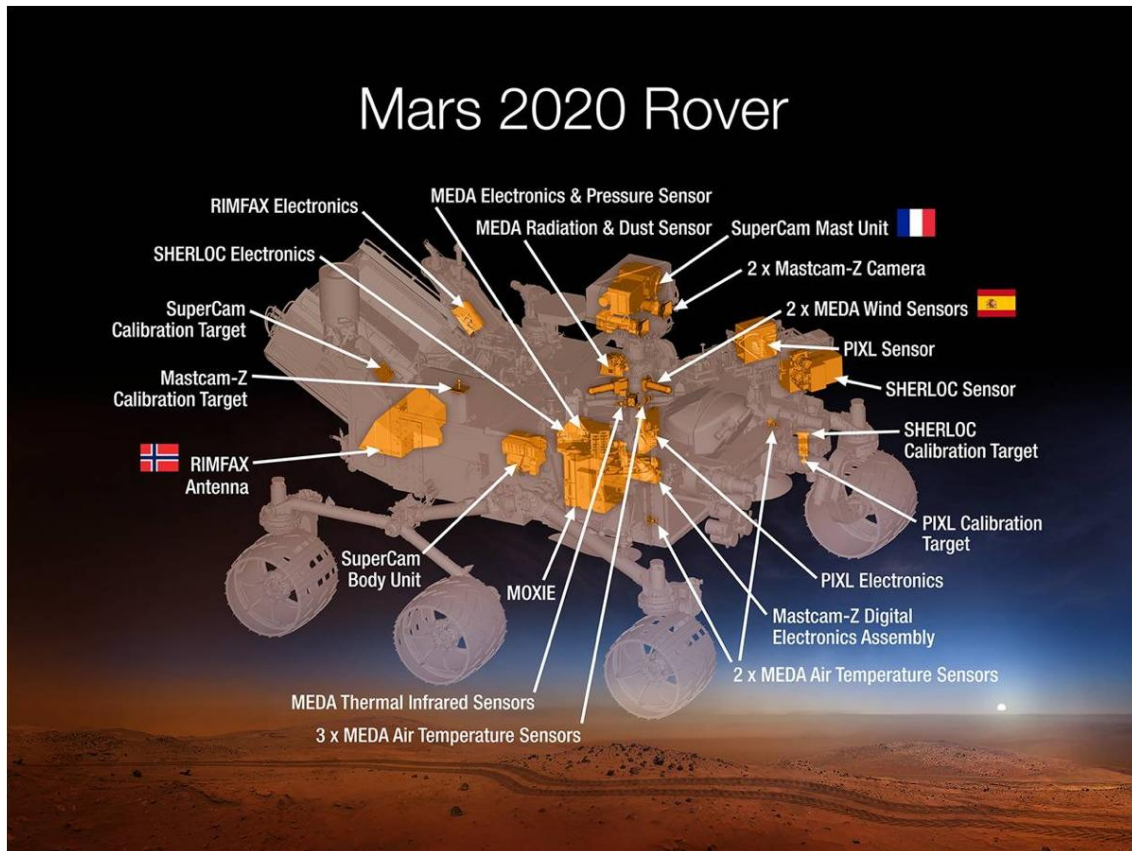
- In December 2025, Tesla FSD successfully completes full coast-to-coast drive with zero interventions



- **Zero-Intervention Milestone:** David Moss completed a ~2,732-mile journey in a Model 3 without touching the steering wheel or pedals.
- **Trip Details:** The trip took 2 days and 20 hours (68 hours total) from Los Angeles to Myrtle Beach, SC.
- **Technology & Route:** The car used FSD V14.2.2.3, demonstrating advanced real-time AI, rather than just map memorization.
- **Infrastructure:** The trip relied on the Tesla Supercharger network for autonomous charging, including parking at stations.

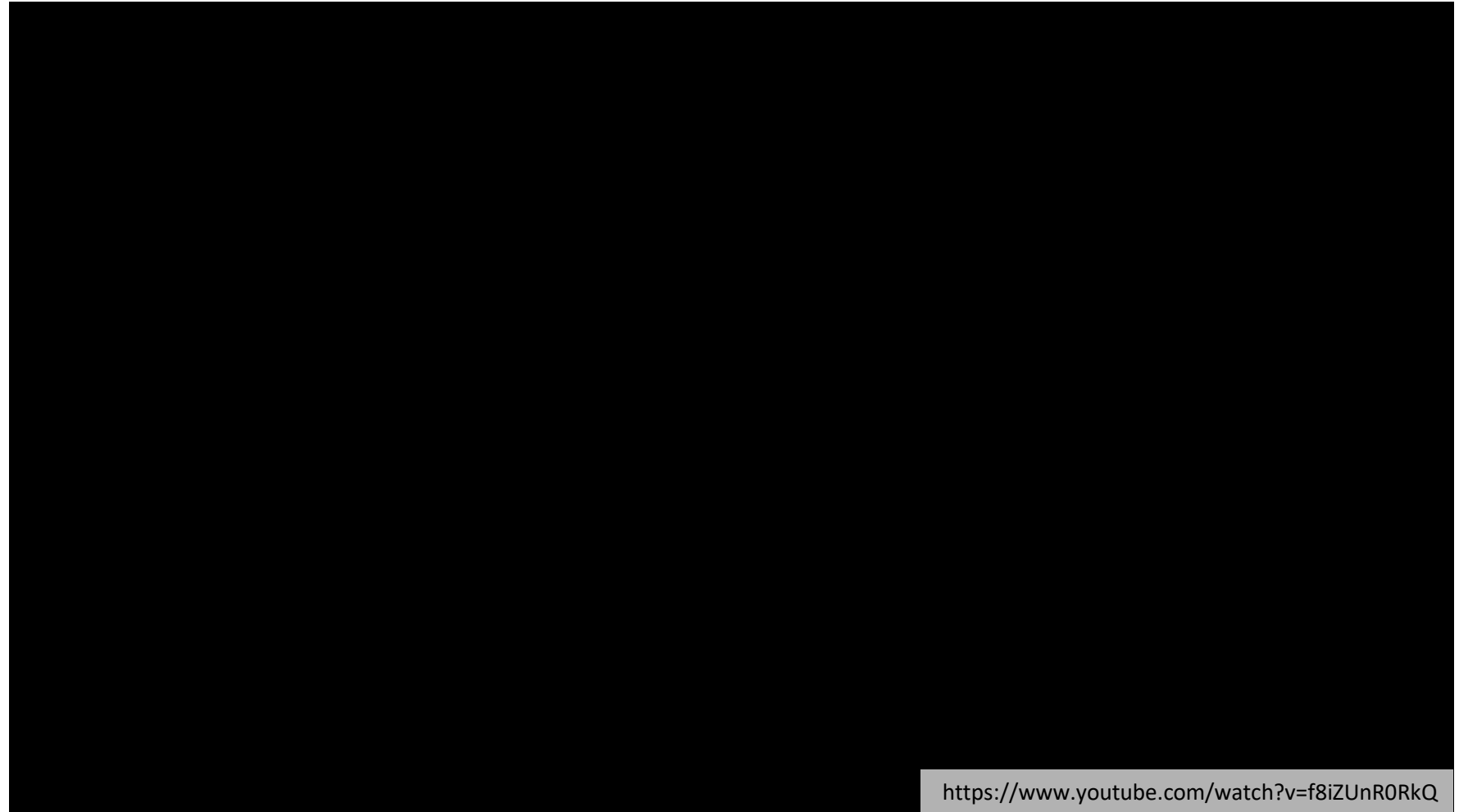
Real-World Robots

- Mars Rover



Real-World Robot Design

- How will you design a security robot that can patrol public buildings and streets?



Real-World Robots

- Security Robots

NEWS

Tech

Tech

Robot 'drowns' in fountain mishap

18 July 2017



MELISSA MORALES

The Knightscope K5 robot tumbled into the fountain by accident

A security robot in Washington DC suffered a watery demise after falling into a fountain by an office building.

300-pound mall robot runs over toddler

by Matt McFarland @mattmcfarland

July 14, 2016: 3:58 PM ET



THIS SECURITY ROBOT RAN OVER A TODDLER

A security robot tackles toddler

Social Surge - What's Trending

Eiffel Tower could get a makeover

These 8 men are richer than 3.6 billion people combined

South Korean prosecutors seek to arrest Samsung heir

