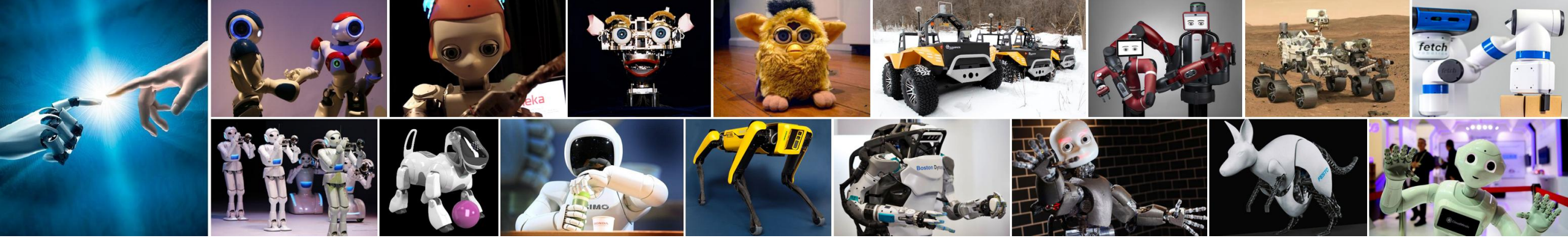
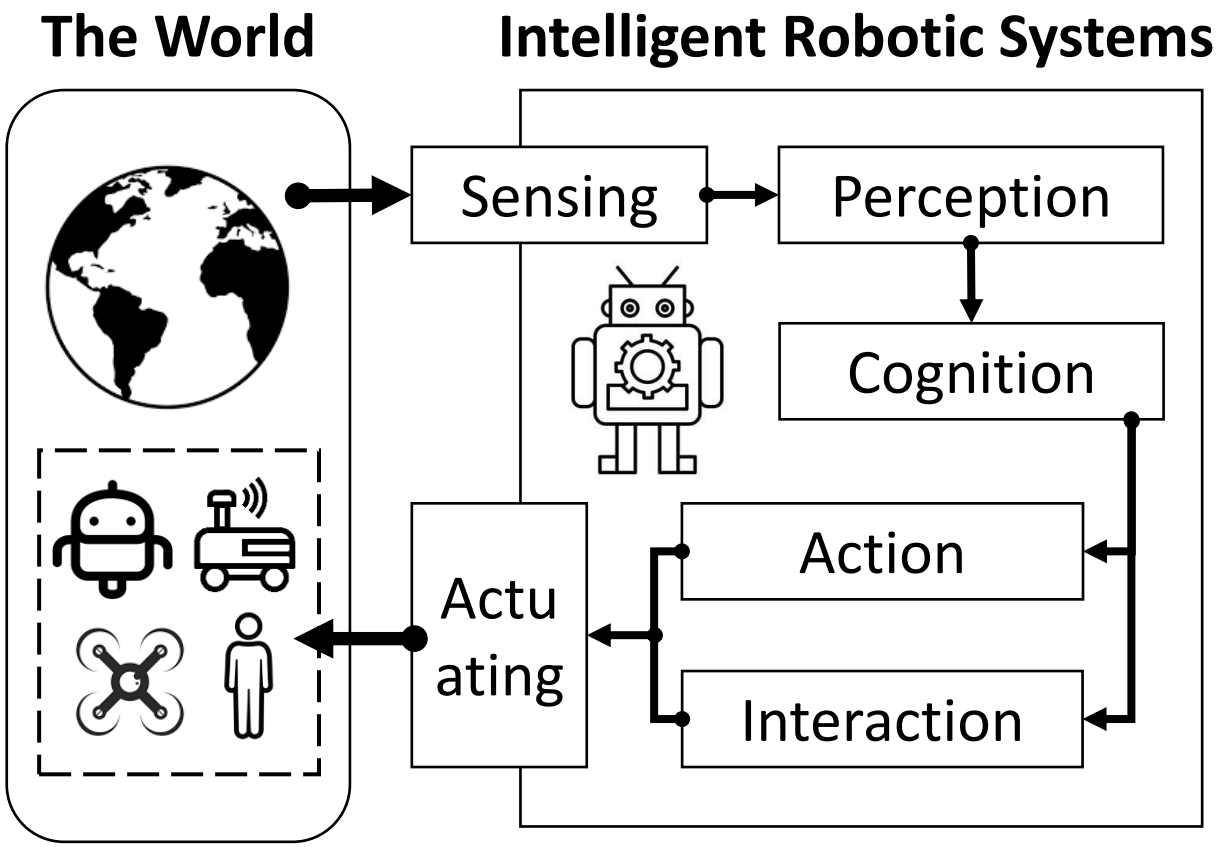


COMPSCI-603: Robotics

Sensing and Actuating

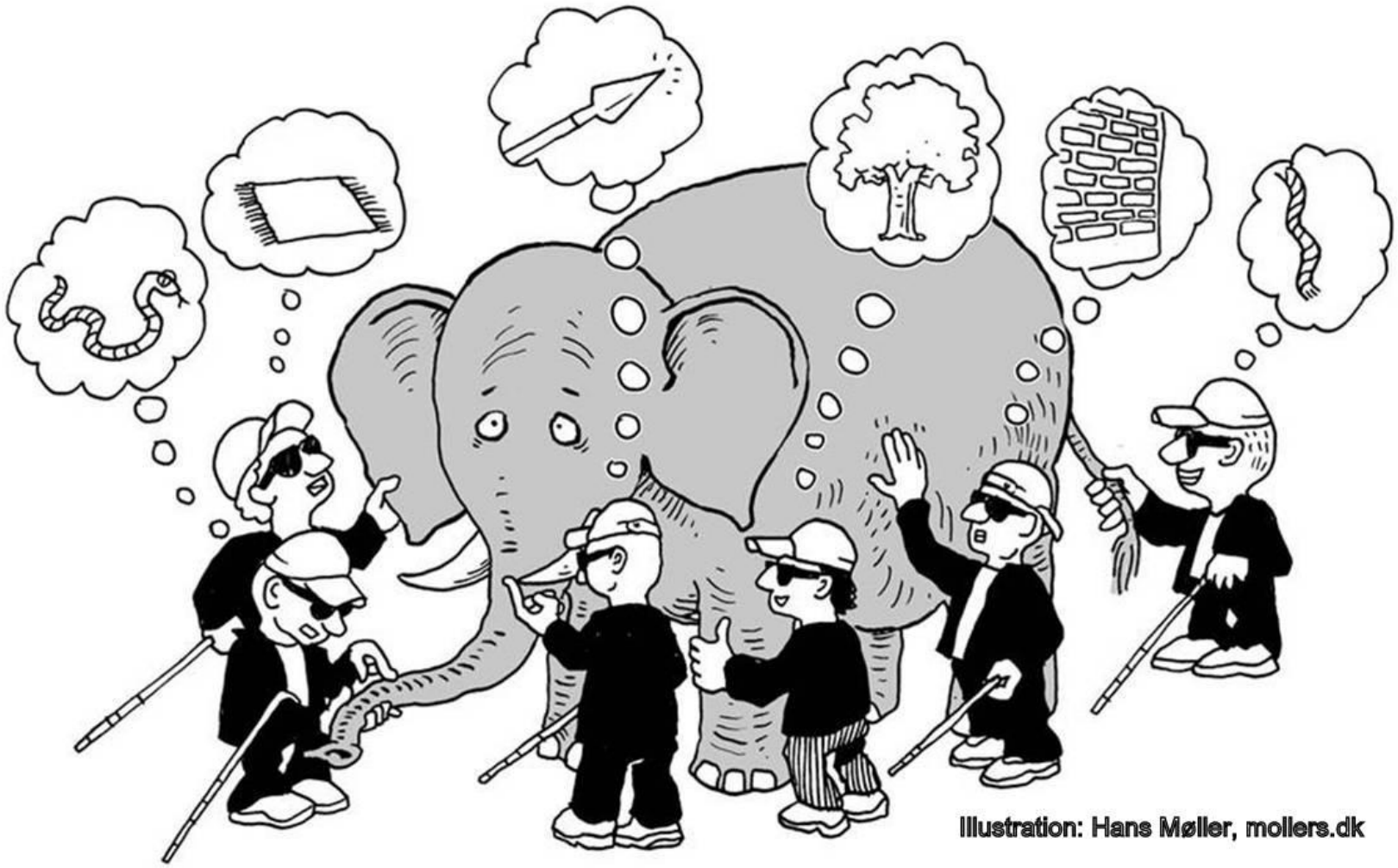
(Brief Overview)

Robotic Systems



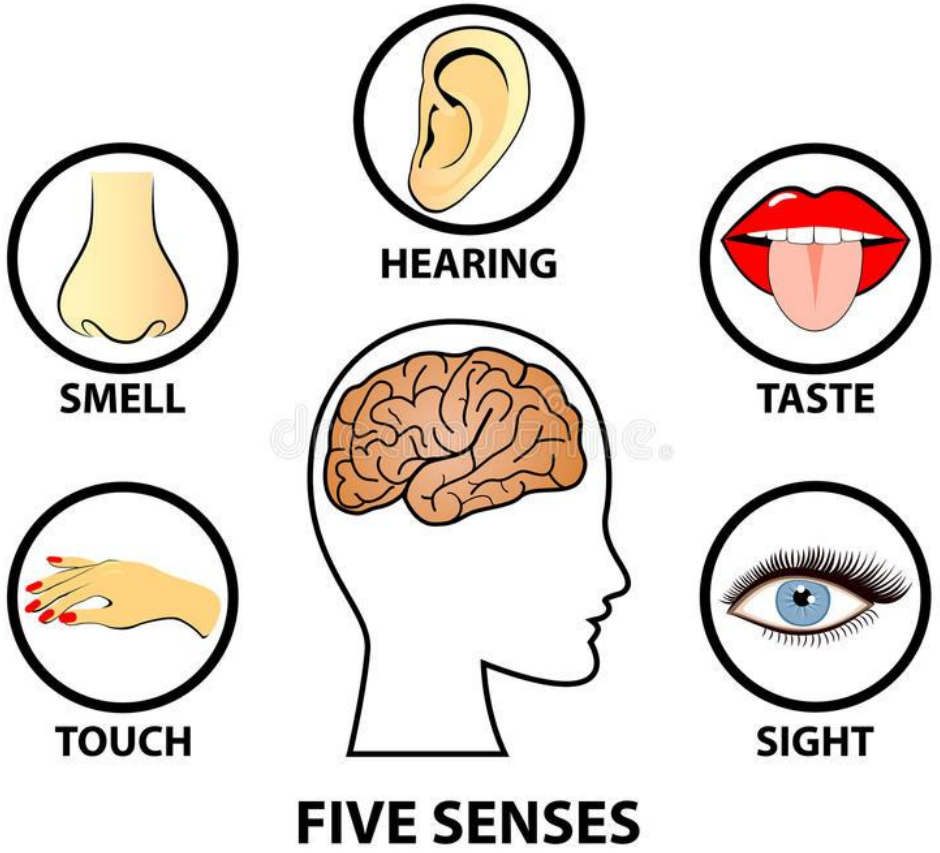
Robot Sensing

- What is the purpose of sensing for robots?



Sensors

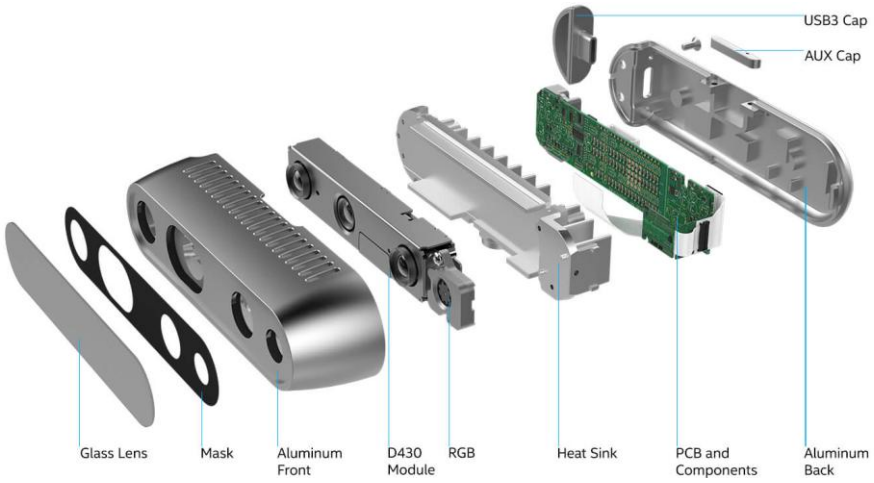
- Sensors are electronic devices that measure physical quantities.
- Sensors are a necessary physical component of the *perception* system of a robot.
- Sensors do not provide state, but measurement or observation
- Examples:
  - Contact: switch
  - Distance: radar
  - Location: GPS



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

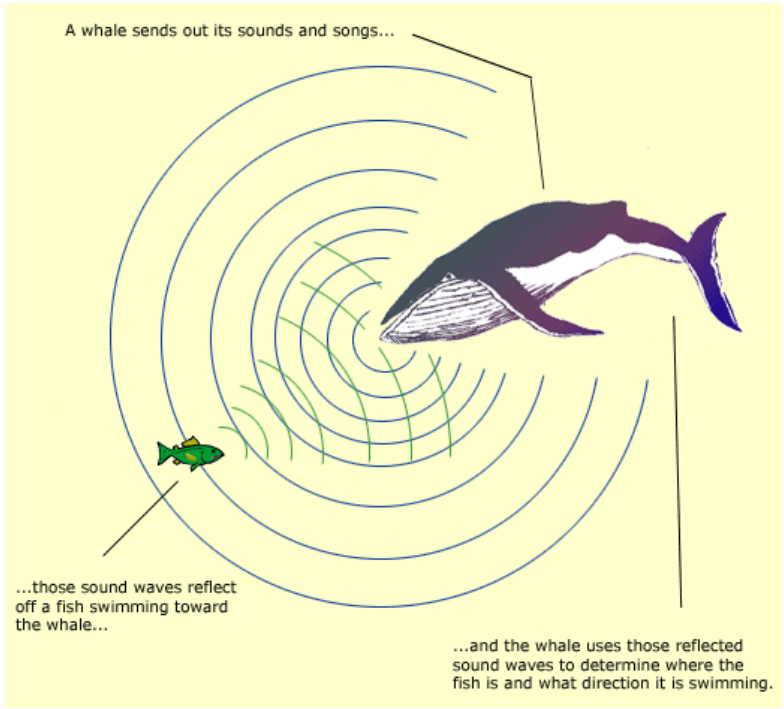
Common Proprioceptive Sensors

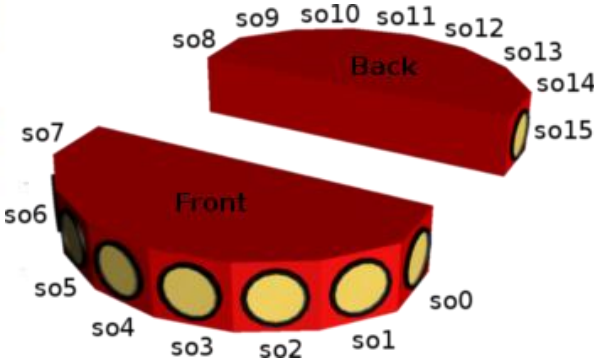
- Odometry sensor (to estimate change in position over time): motor/wheel encoders.
- Inertial sensor (to estimate velocity): gyroscope, accelerometer.
- Heading sensor: compass.
- Tilting angle sensor: inclinometer.

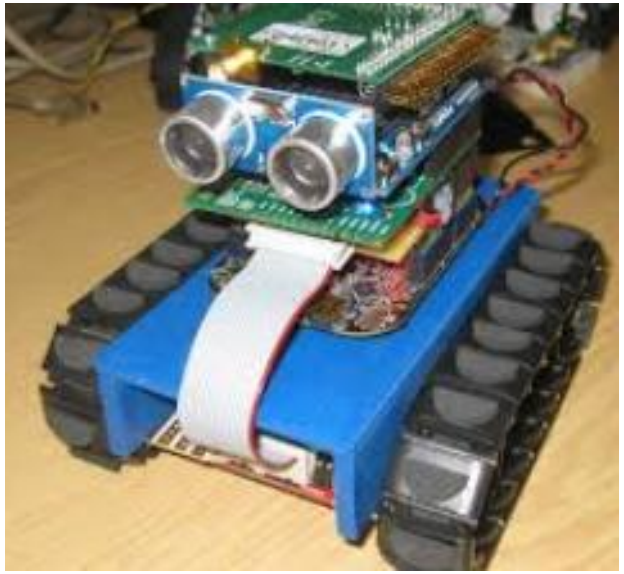
- Inertial measurement unit (IMU): an electronic device that uses a combination of accelerometers, gyroscopes, and sometimes magnetometers to measure orientation in space.

Common Exteroceptive Sensors

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





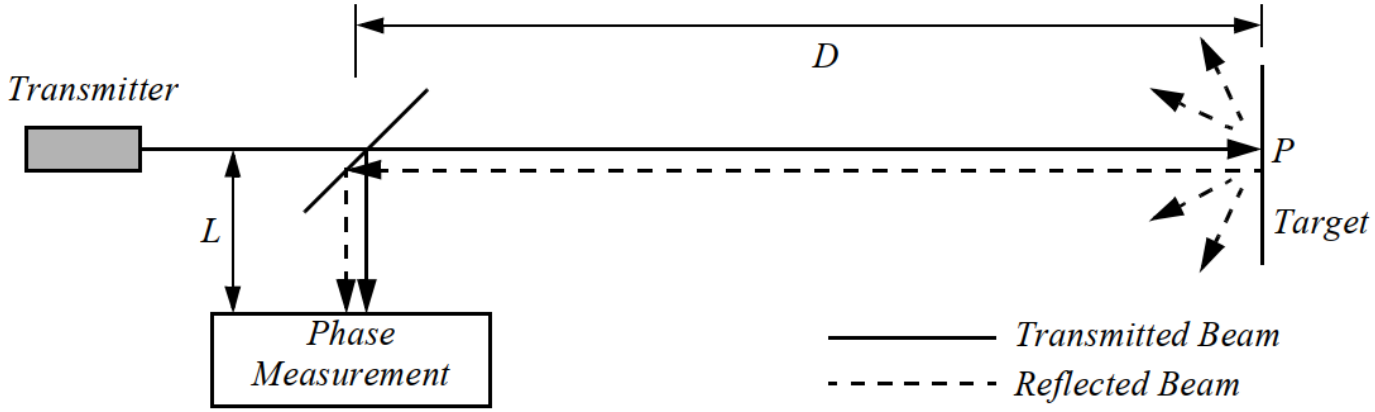


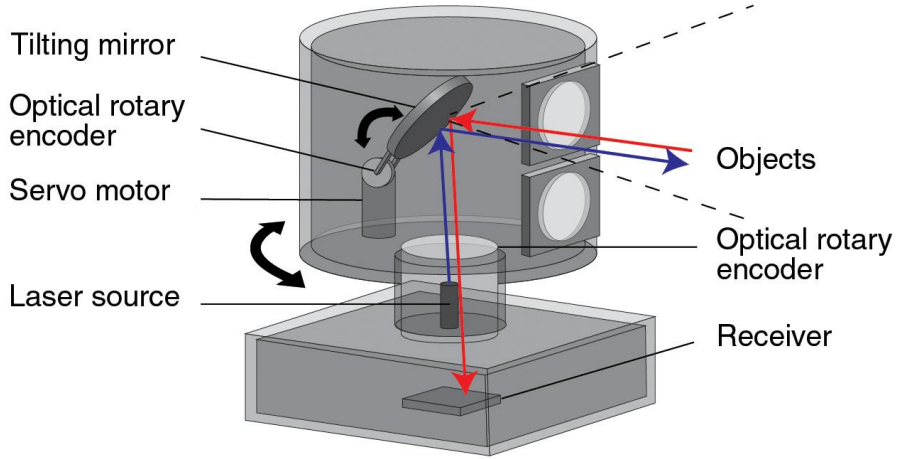
Common Exteroceptive Sensors

- 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).

RPLiDAR

Distance = (Speed of Light x Time of Flight) / 2





Applications Places

demo.rviz* - RViz

File Panels Help

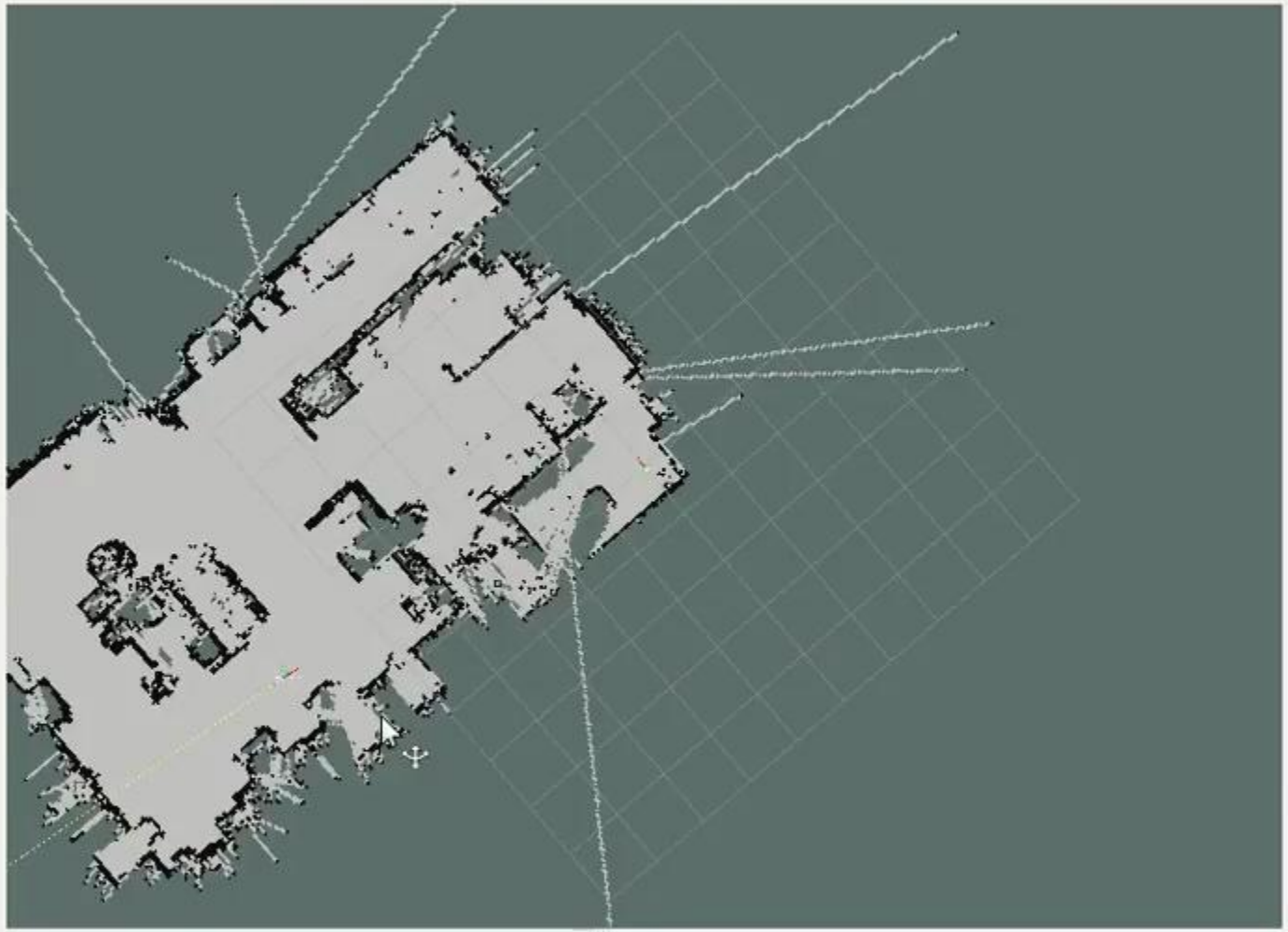
Interact | Move Camera | Select | Focus Camera | Measure | 2D Pose Estimate | 2D Nav Goal | Publish Point

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

Image



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

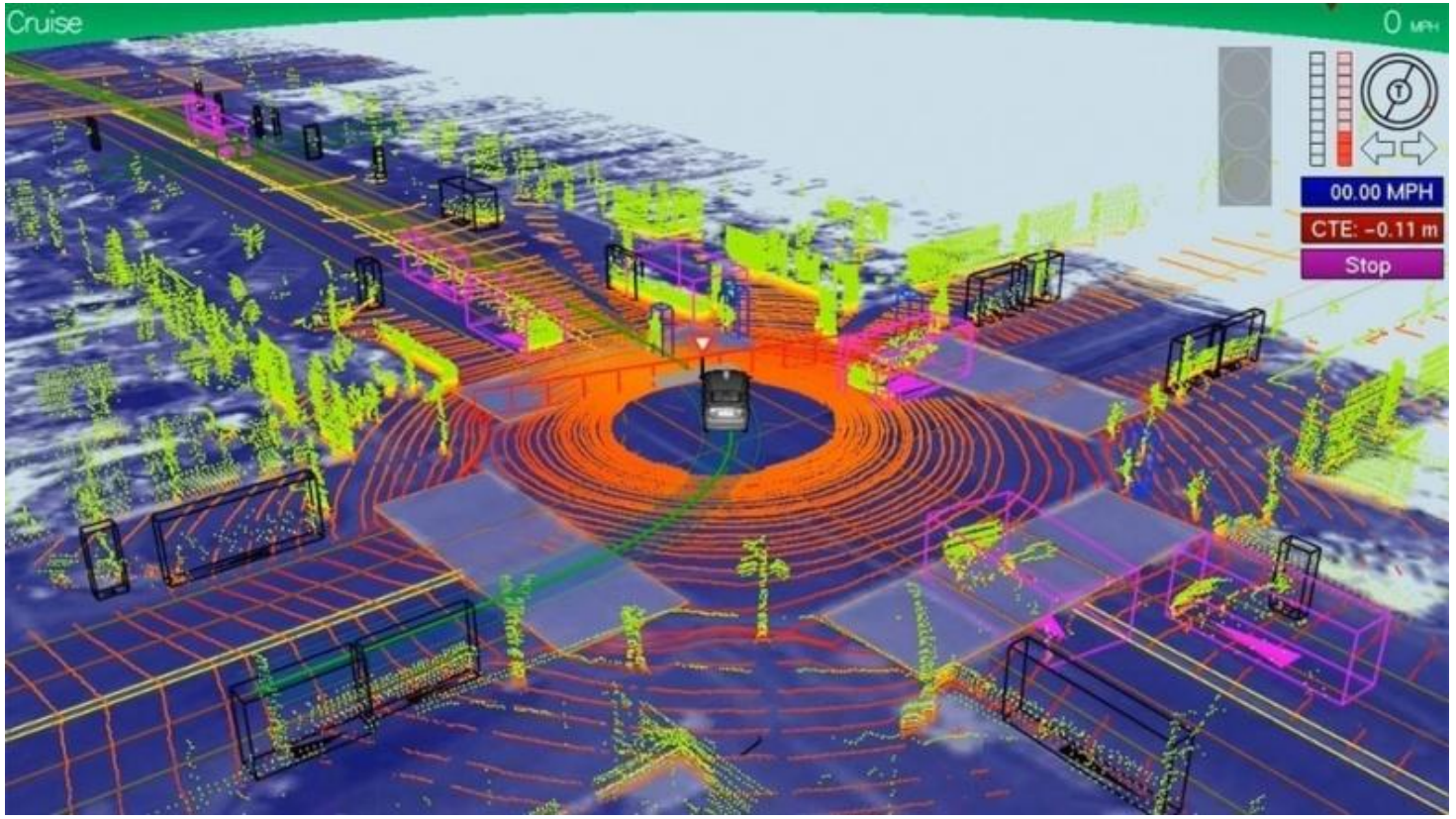
Reset **Left-Click:** Rotate. **Middle-Click:** Move X/Y. **Right-Click/Mouse Wheel:**: Zoom. **Shift:** More options. 30 fps

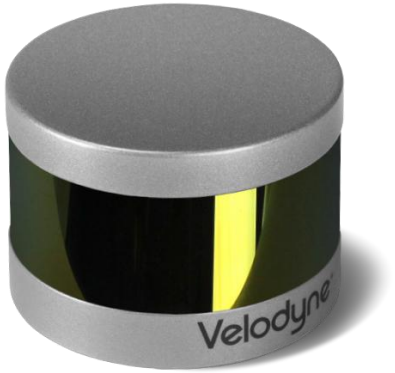
demo@demo-ThinkP... | demo.rviz* - RViz

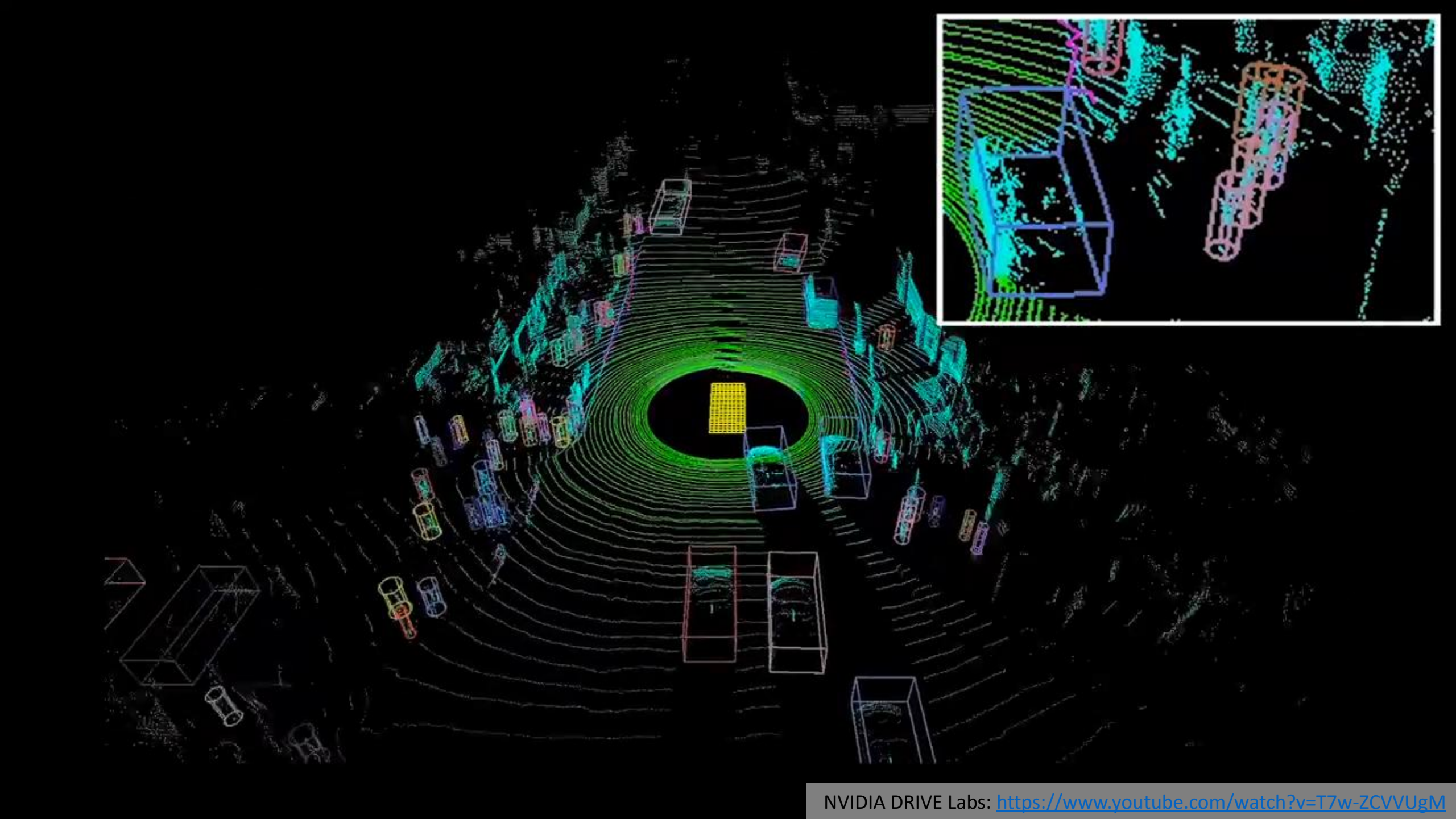
2D SLAM using PRLiDAR: https://www.youtube.com/watch?v=iVndhBqpp-0

Common Exteroceptive Sensors

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



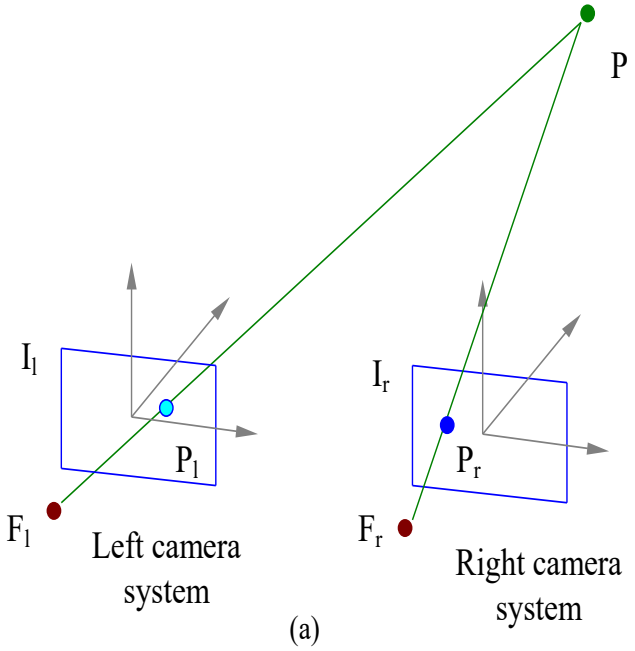


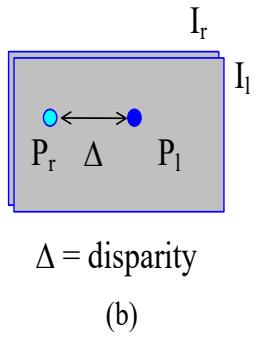


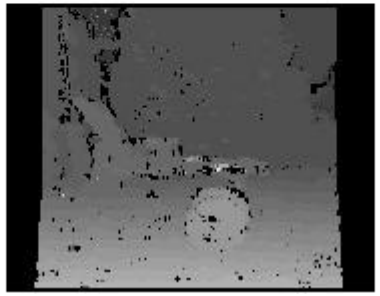
NVIDIA DRIVE Labs: https://www.youtube.com/watch?v=T7w-ZCVVUgM

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.

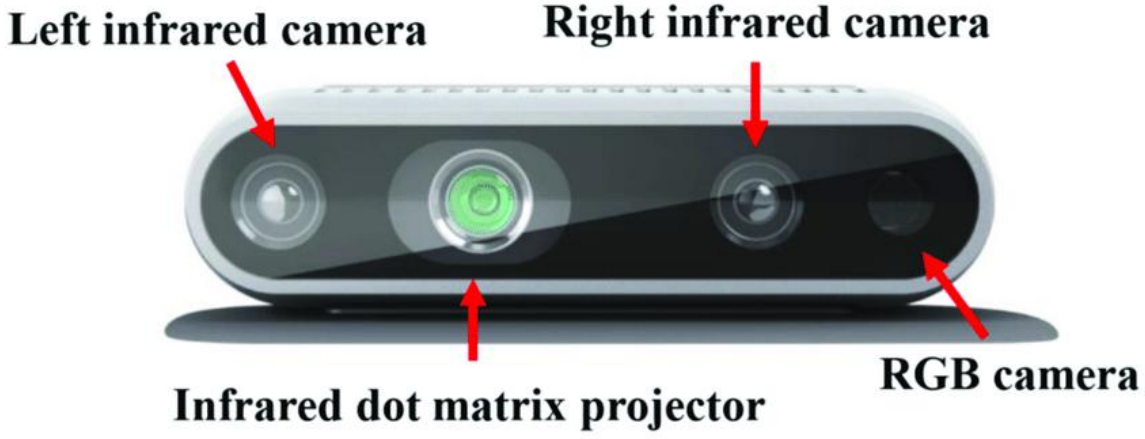




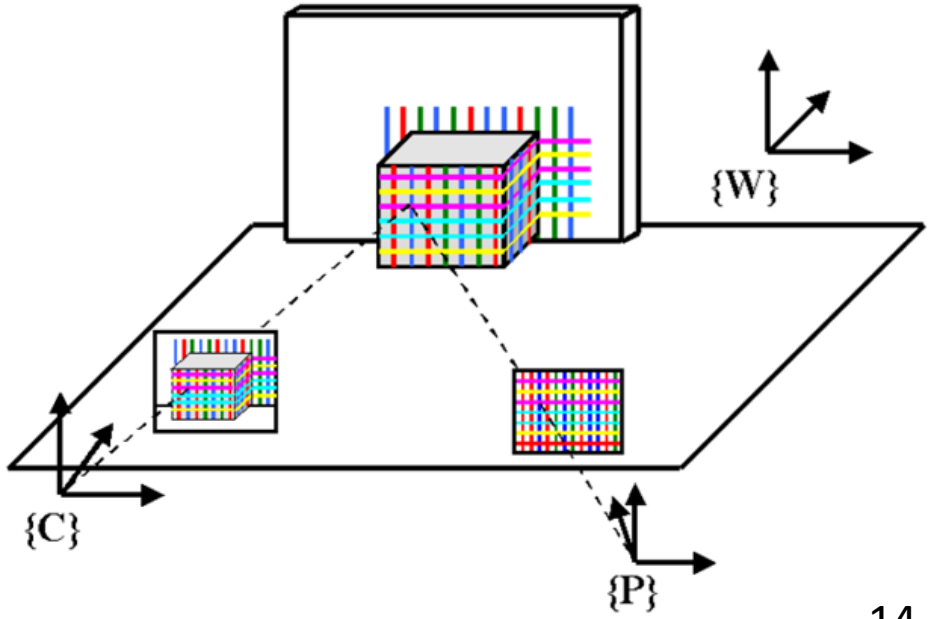


Common Exteroceptive Sensors

- 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.

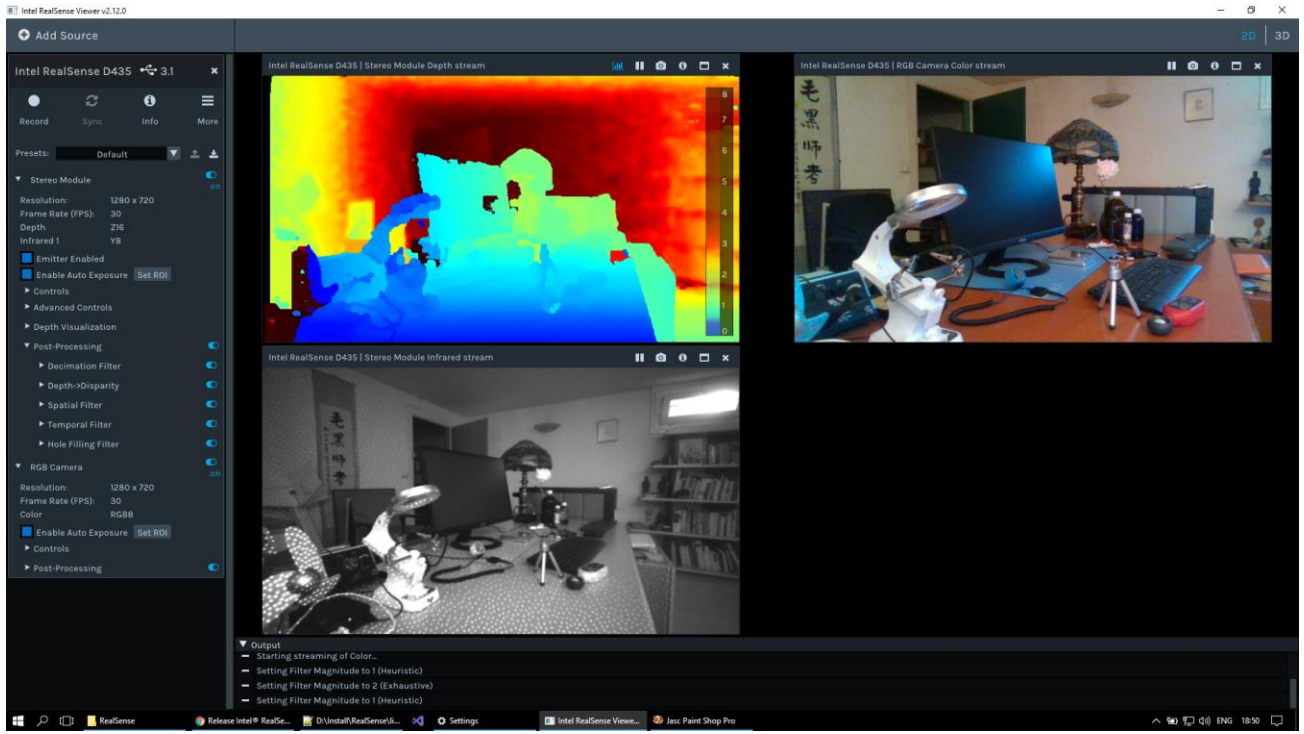


Intel RealSense D435

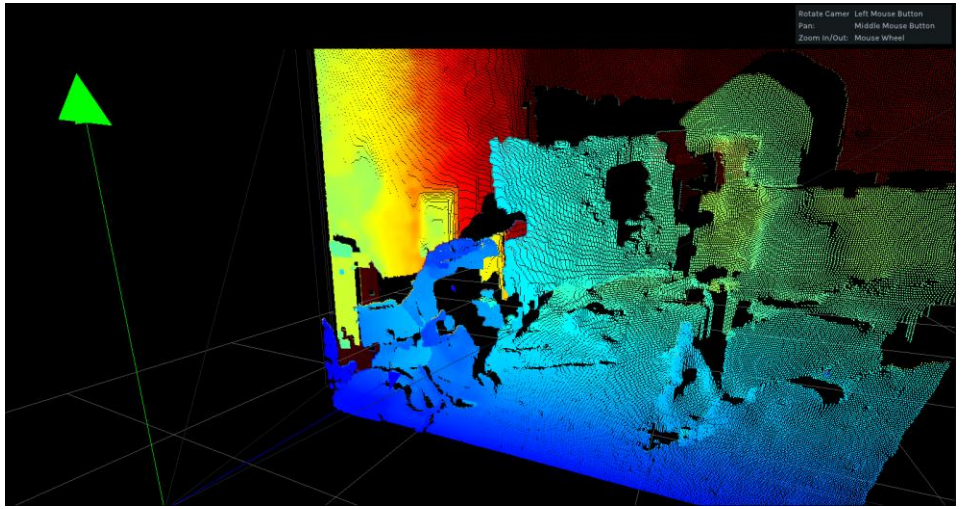


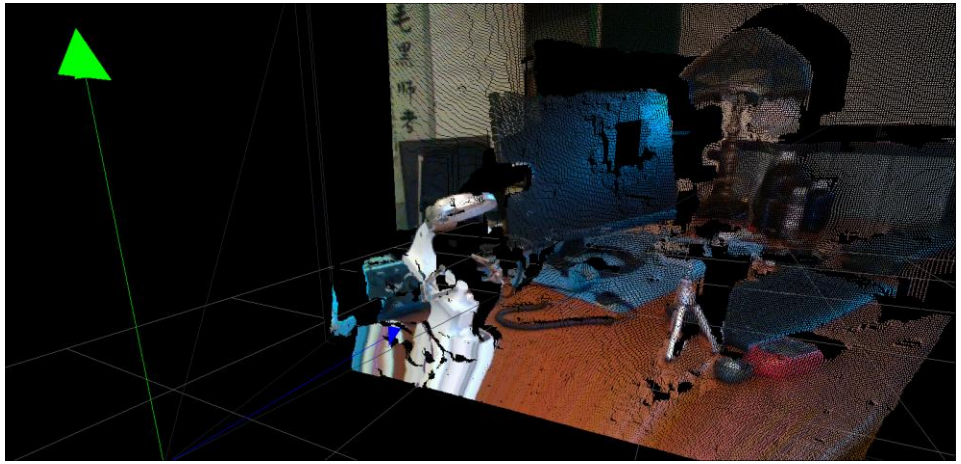
Common Exteroceptive Sensors

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



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

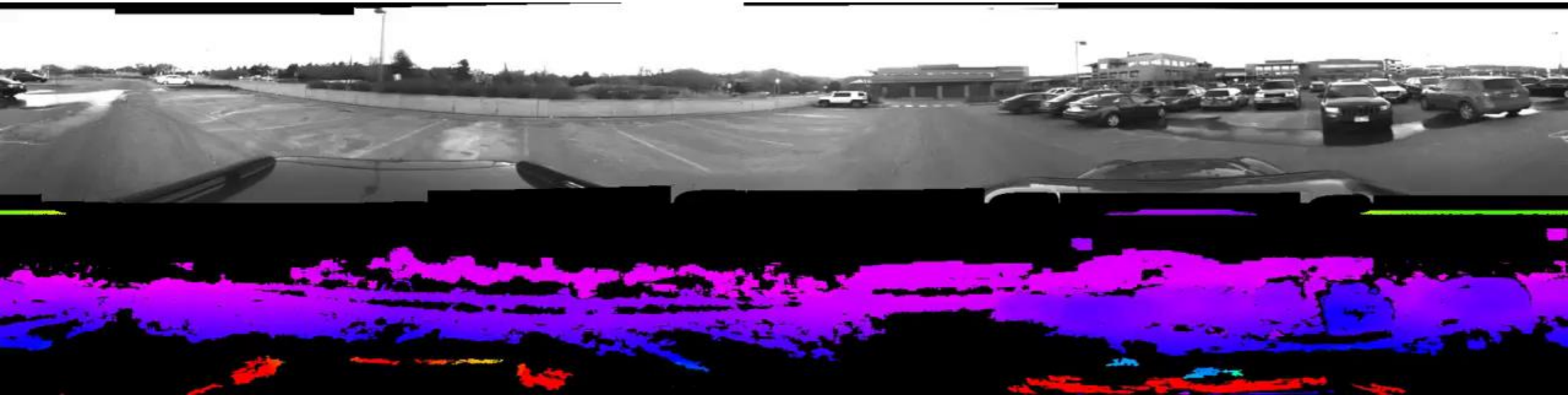




http://www.youtube.com/watch?v=9Y4RQVpp-BY

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								
Commercial								
Consumer								

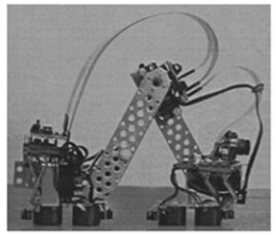
Yole Developpment Report, “Sensors for drones and robots: market opportunities and technology revolution,” 2016

Actuating: Mobile Robots


Delta Extreme


ACM-III


ACM-R3

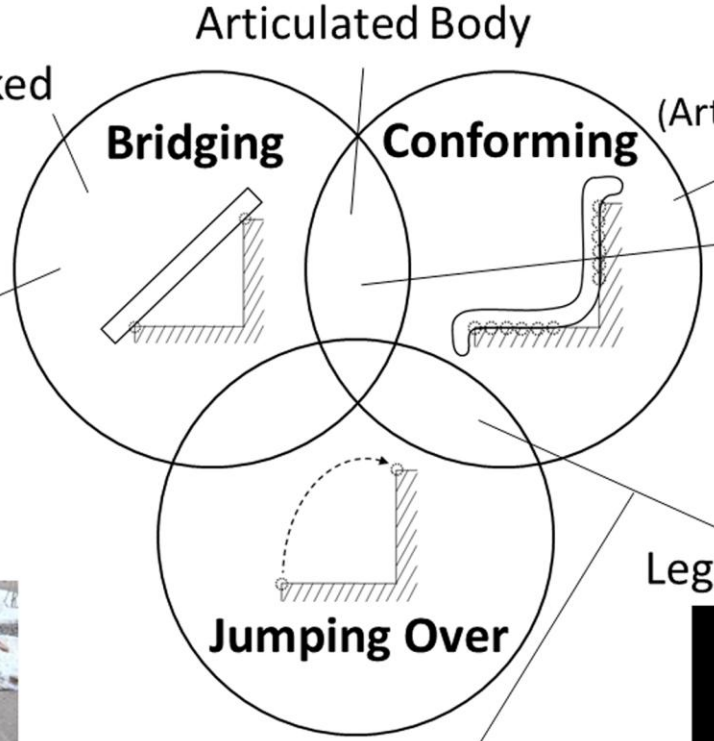

Inch Worm


RobuRoc


Soryu 4


Slug Crawler


Talon




Segway RMP440


Atlas J8 XTR


Tri-Star Wheel


PackBot


Curiosity


Asimo

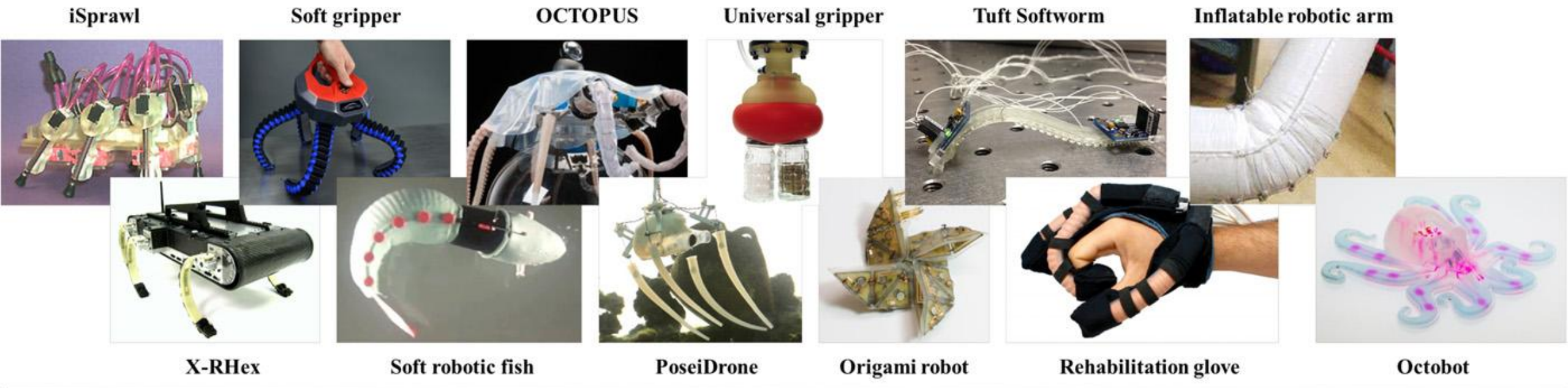

Genghis


Big Dog


RHex

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.

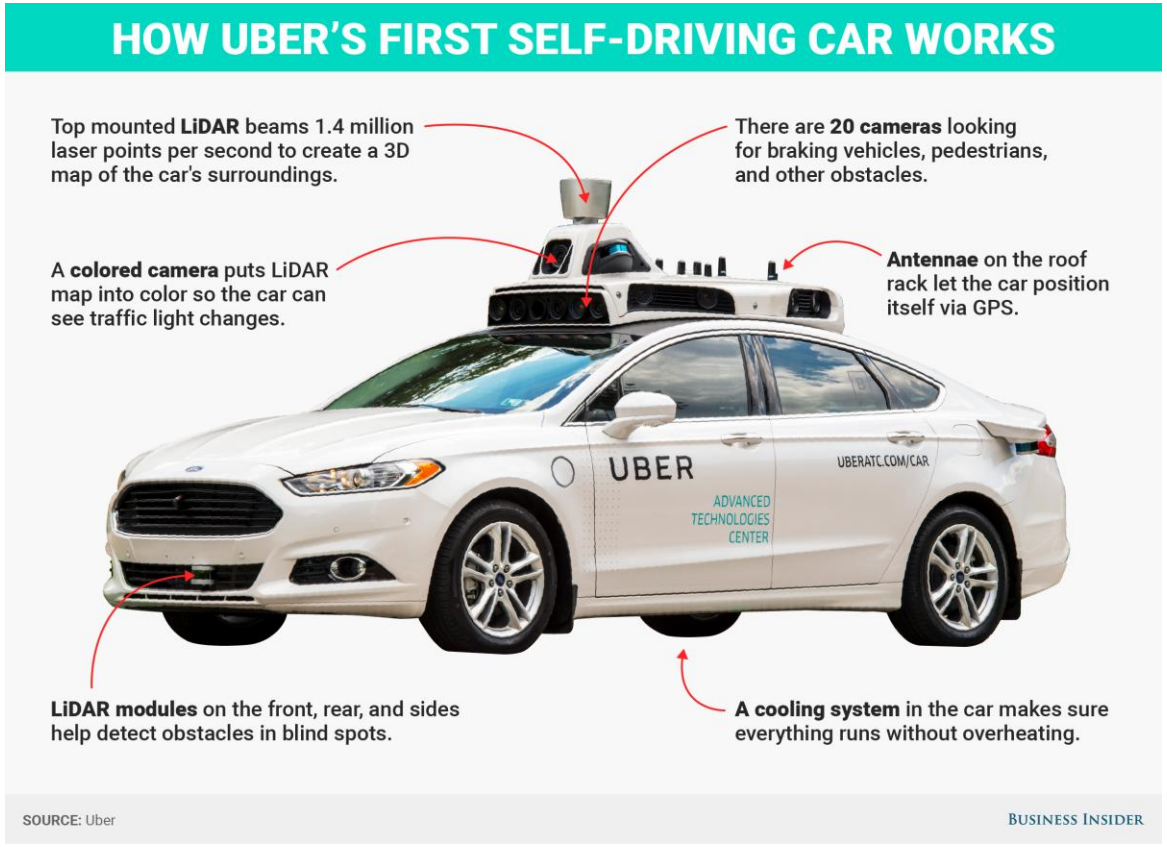
Actuating: Soft Robots

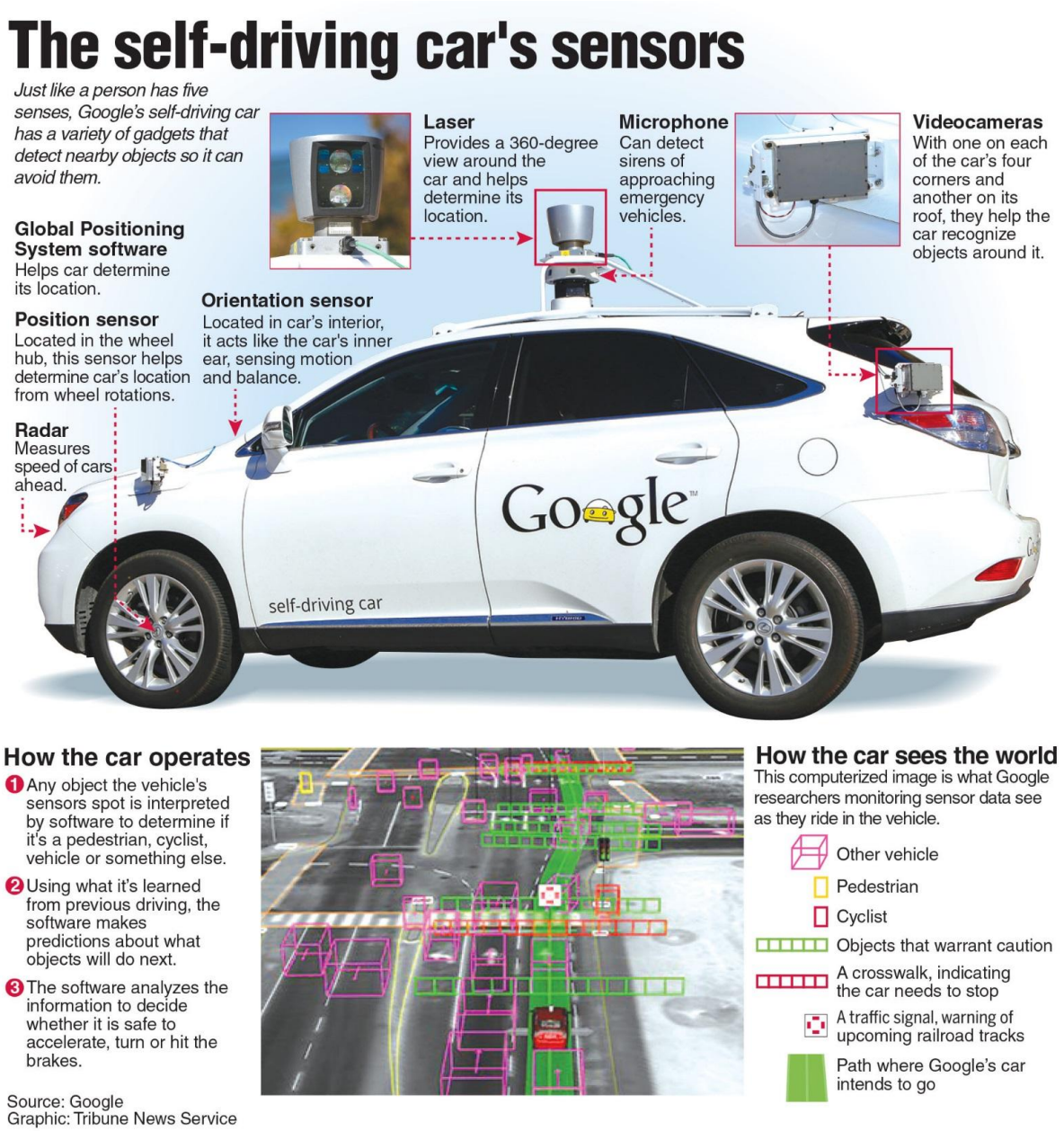


Cecilia Laschi, Barbara Mazzolai, and Matteo Cianchetti. "Soft robotics: Technologies and systems pushing the boundaries of robot abilities." Science robotics 1, no. 1. 2016.

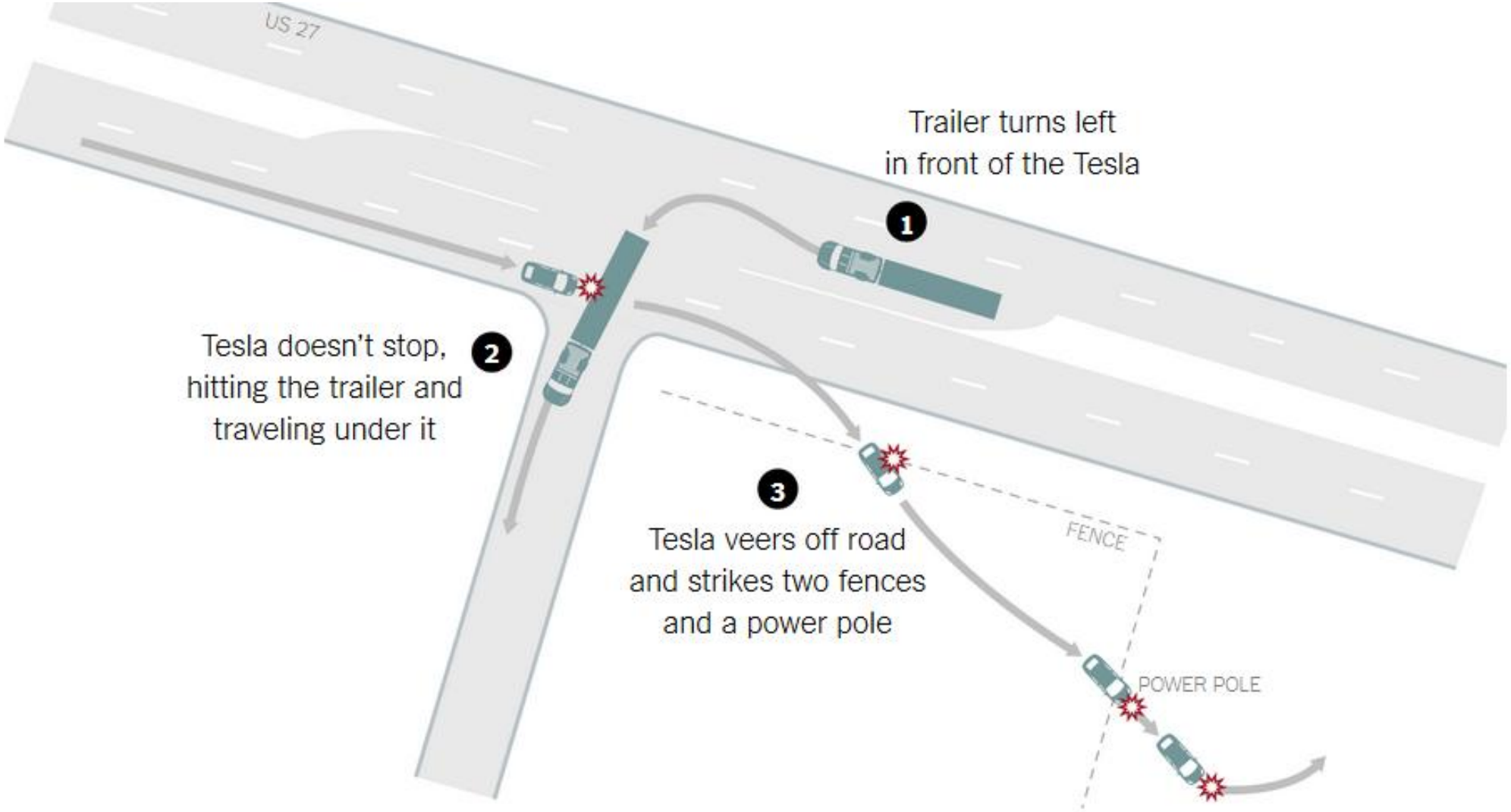
Real-World Robots

- Autonomous driving

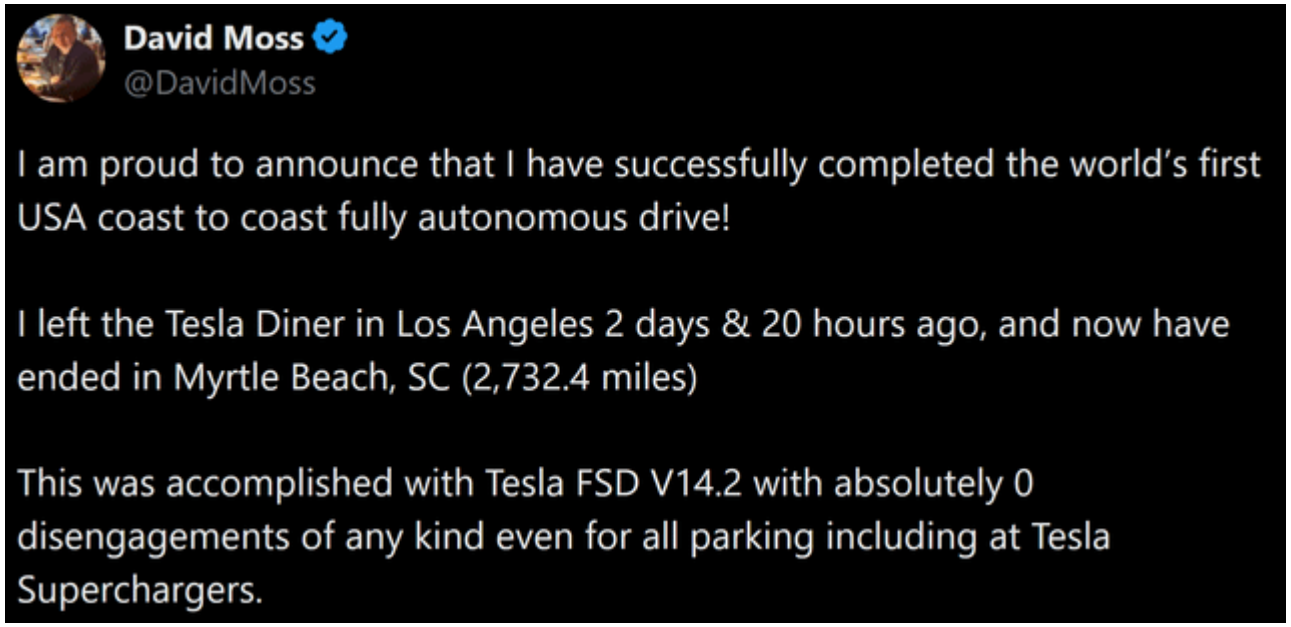




- On May 7, 2016, a Tesla Model S crashed in northern Florida into a truck that was turning left in front of it.



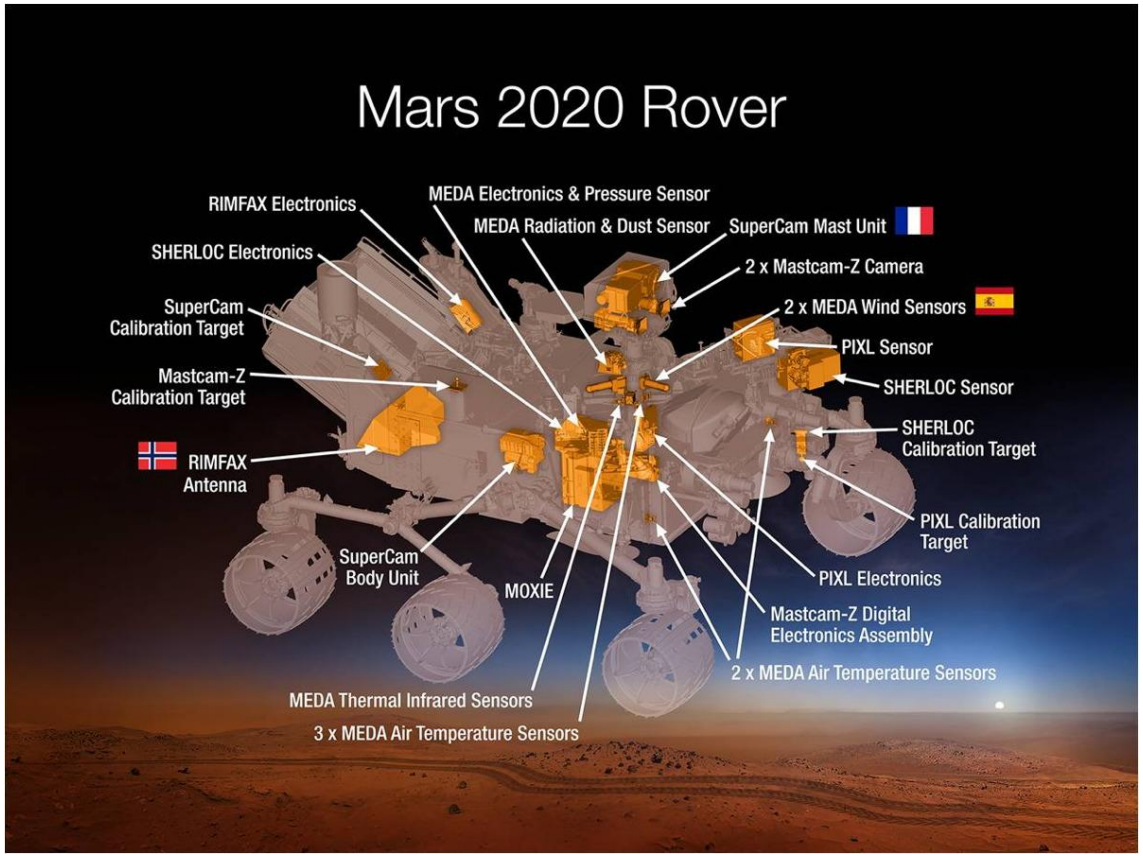
- In December 2025, Tesla FSD successfully completes full coast-to-coast drive with zero interventions

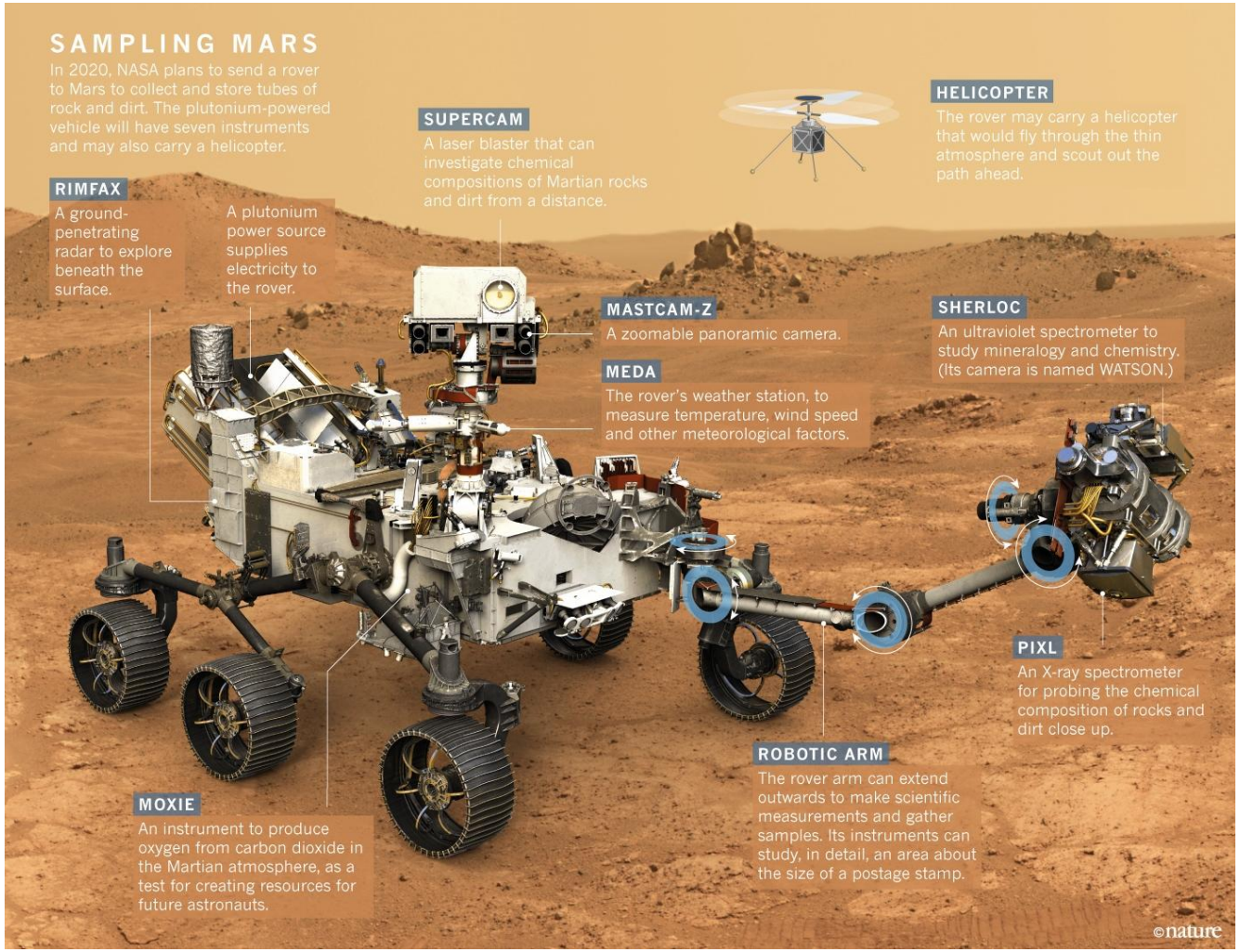


- **Zero-Intervention Milestone:** David Moss completed a ~2,732-mile journey in a Model 3 without touching the steering wheel or pedals.
- **Trip Details:** The trip took 2 days and 20 hours (68 hours total) from Los Angeles to Myrtle Beach, SC.
- **Technology & Route:** The car used FSD V14.2.2.3, 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?

https://www.youtube.com/watch?v=f8iZUnR0RkQ

Real-World Robots

- Security Robots

BBC Home News Sport Reel Worklife Travel Future

NEWS

Home | War in Ukraine | Coronavirus | Climate | Video | World | US & Canada | UK | Business | More

Tech

Tech

Robot 'drowns' in fountain mishap

18 July 2017

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.

CNN tech business culture gadgets future startups search

300-pound mall robot runs over toddler

by Matt McFarland @mattmcfarland

July 14, 2016: 3:58 PM ET

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

CNN Money Stream