CMPE 185 Autonomous Mobile Robots

Different Sensors

Dr. Wencen Wu
Computer Engineering Department
San Jose State University

Sensors

- Sensor Characteristics
- Sensor Uncertainty
- Different Sensors

Camera

- The images obtained from cameras are very useful for recognizing the environment around the robot
  - Object recognition, facial recognition
  - Depth information obtained from the difference between two images using two cameras (stereo camera)
  - Mono camera visual SLAM
  - Color recognition

Camera

- Cheap
- Highest resolution
- Detect color and fonts
- Huge data → deep learning
- Bad at depth estimation
- Not good in extreme weather

Range Sensors

- Measure relative distance (range) between sensor and objects in environment
- Range information is the key element for localization and environment modeling
- Most range sensors are active sensors
- Range sensor make use of propagation speed of sound or electromagnetic waves respectively

Range Sensors

- Common types of range sensors
  - Sonar (ultrasonic sensor, SOund Navigation Ranging)
  - Radar (RAdio Detection And Ranging)
  - Lidar (Light Detection And Ranging , Laser range finder)
  - Infrared (IR)
  - Etc.

Range Sensors

- Distance traveled by a wave is given by

$$d = ct$$

  - *d*: distance traveled (usually round-trip)
  - *c* = speed of wave propagation
  - *t* = time of flight

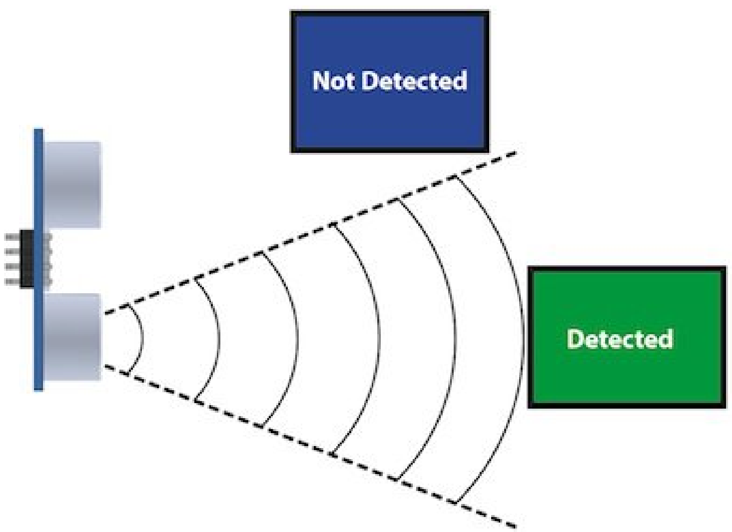
- For sound, *v = 0.3 m/ms*
- For electromagnetic signals, *v = 0.3 m/ns* (one million times faster than sound)
- If distance = 3m:
  - $t_{ultrasonic}$= 10ms
  - t_{laser} = 10 ns
  - t_{laser} is difficult to measure, laser range sensors are expensive and difficult

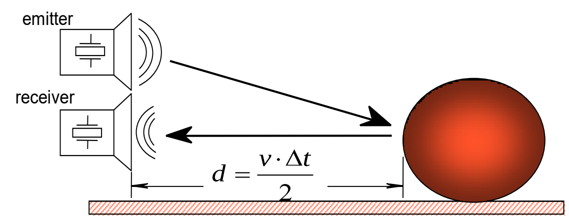
Range Sensors

- Quality of range sensors depend on:
  - Inaccuracies in the time of fight measurement (laser range sensors)
  - Opening angle of transmitted beam (especially ultrasonic range sensors)
  - Interaction with the target (surface, specular reflections)
  - Variation of propagation speed (sound)
  - Speed of mobile robot and target (if not at stand still)

Range Sensors -- Sonar (Ultrasonic Sensor)

- Range between 12cm up to 5m
- Resolution of ~2cm
- Relative error 2%
- Sound beam propagates in a cone (approx.)
  - opening angles around 20 to 40 degrees





<http://www.robot-electronics.co.uk/
shop/Ultrasonic_Rangers1999.htm>

Range Sensors -- Sonar (Ultrasonic Sensor)

- Main characteristics
  - Precision influenced by angle to object
  - Useful in ranges from several cm to several meters
  - Typically relatively inexpensive

- Applications
  - Distance measurement (also for transparent surfaces)
  - Collision detection

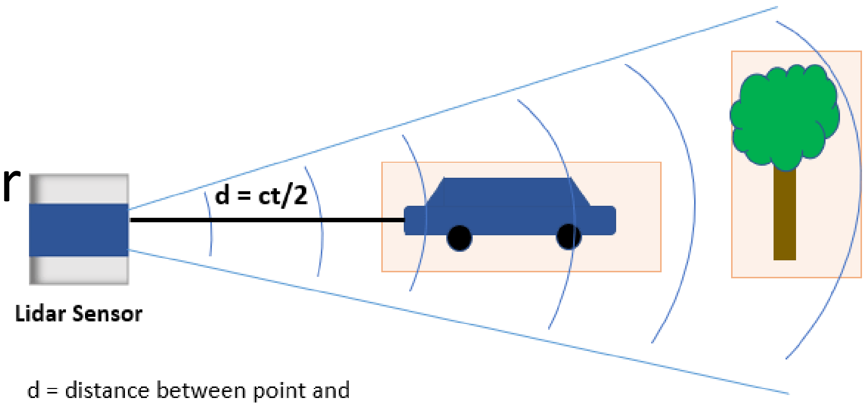
Range Sensor: Infrared (IR)

- Active proximity sensor
- Emit near-infrared energy and measure amount of IR light returned
- Range: inches to several feet, depending on light frequency and receiver sensitivity
- Typical IR: constructed from LEDs, which have a range of 3-5 inches
- Challenges:
  - Light can be "washed out" by bright ambient lighting
  - Light can be absorbed by dark materials

Range Sensors – LiDAR

Lidar (Light Detection And Ranging , Laser range finder)

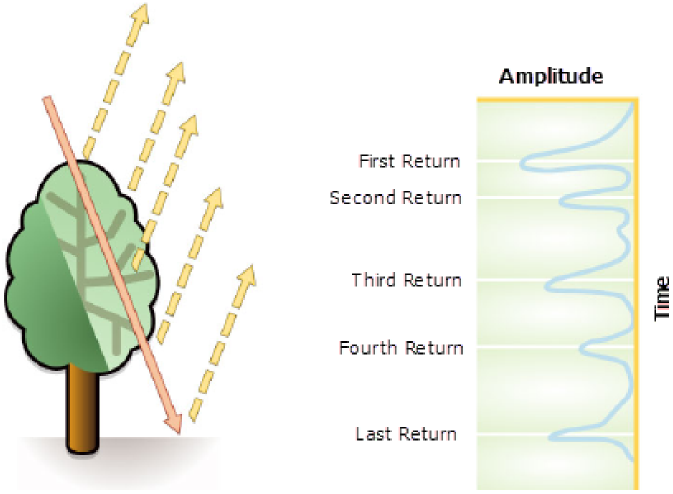
- Lidar sensors provide 3D structural information about an environment
- Advanced driving assistance systems (ADAS), robots, and unmanned aerial vehicles (UAVs) employ Lidar sensors for accurate 3D perception, navigation, and mapping
- Lidar is an active remote sensing system that uses laser light to measure the distance of the sensor from objects in a scene
  - Emits laser pulses
  - Time-of-flight principle



d = distance between point and the sensor
c = speed of light
t = time of flight

Range Sensors – LiDAR

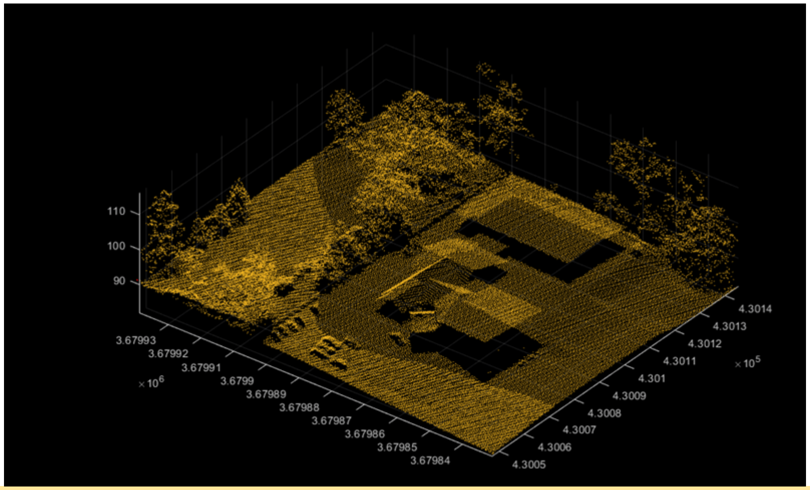
- Laser pulses emitted from a Lidar system reflect from objects both on and above the ground surface: vegetation, buildings, bridges, and so on
- One emitted, laser pulse can return to the Lidar sensor as one or many returns
- Any emitted laser pulse that encounters multiple reflection surfaces as it travels toward the ground is split into as many returns as there are reflective surfaces
- The first returned laser pulse is the most significant return and will be associated with the highest feature in the landscape like a treetop or the top of a building
- Multiple returns are capable of detecting the elevations of several objects within the laser footprint of an outgoing laser pulse



https://desktop.arcgis.com/en/arcmap/10.3/manage-data/las-dataset/what-is-lidar-data-.htm

Range Sensors – LiDAR

- A Lidar sensor stores the reflected laser pulses, or laser returns, as a collection of 3D points **– a point cloud**
- A Lidar sensor captures attributes to generate a 3D map of an environment
  - The location in xyz-coordinates
  - The intensity of the laser light
  - The surface normal at each point of a point cloud



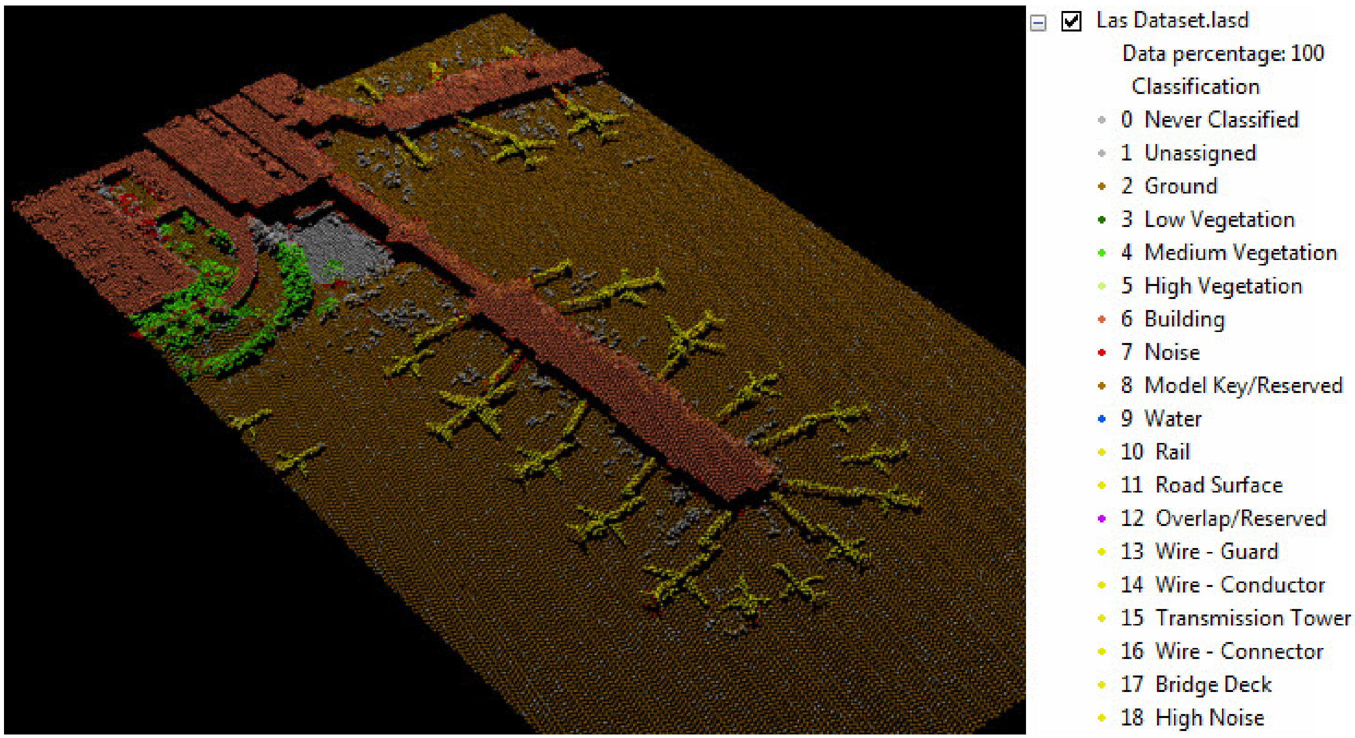
Lidar Point Attributes

Lidar attribute	Description
Intensity	The return strength of the laser pulse that generated the lidar point.
Return number	An emitted laser pulse can have up to five returns depending on the features it is reflected from and the capabilities of the laser scanner used to collect the data. The first return will be flagged as return number one, the second as return number two, and so on.
Number of returns	The number of returns is the total number of returns for a given pulse. For example, a laser data point may be return two (return number) within a total number of five returns.
Point classification	Every Lidar point that is post-processed can have a classification that defines the type of object that has reflected the laser pulse. Lidar points can be classified into a number of categories including bare earth or ground, top of canopy, and water. The different classes are defined using numeric integer codes in the **LAS files**.
Edge of flight line	The points will be symbolized based on a value of 0 or 1. Points flagged at the edge of the flight line will be given a value of 1, and all other points will be given a value of 0.
RGB	Lidar data can be attributed with RGB (red, green, and blue) bands. This attribution often comes from imagery collected at the same time as the Lidar survey.
GPS time	The GPS time stamp at which the laser point was emitted from the aircraft. The time is in GPS seconds of the week.
Scan angle	The scan angle is a value in degrees between -90 and +90. At 0 degrees, the laser pulse is directly below the aircraft at nadir. At -90 degrees, the laser pulse is to the left side of the aircraft, while at +90, the laser pulse is to the right side of the aircraft in the direction of flight. Most Lidar systems are currently less than ±30 degrees.
Scan direction	The scan direction is the direction the laser scanning mirror was traveling at the time of the output laser pulse. A value of 1 is a positive scan direction, and a value of 0 is a negative scan direction. A positive value indicates the scanner is moving from the left side to the right side of the in-track flight direction, and a negative value is the opposite.

A LAS file is an industry-standard binary format for storing airborne lidar data.

Lidar Point Classification

- Every Lidar point can have a classification assigned to it that defines the type of object that has reflected the laser pulse
- Classification codes were defined by the American Society for Photogrammetry and Remote Sensing (ASPRS) for LAS formats 1.1, 1.2, 1.3, and 1.4. ArcGIS supports all versions of LAS

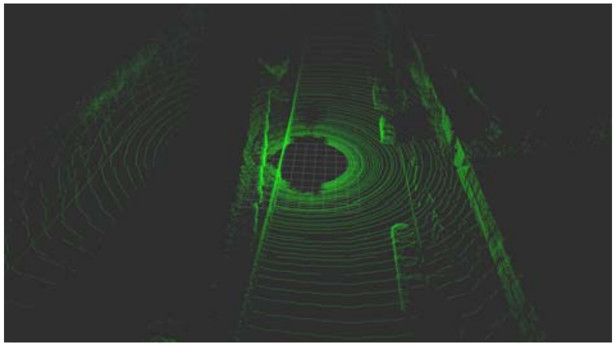


https://desktop.arcgis.com/en/arcmap/10.3/manage-data/las-dataset/lidar-point-classification.htm

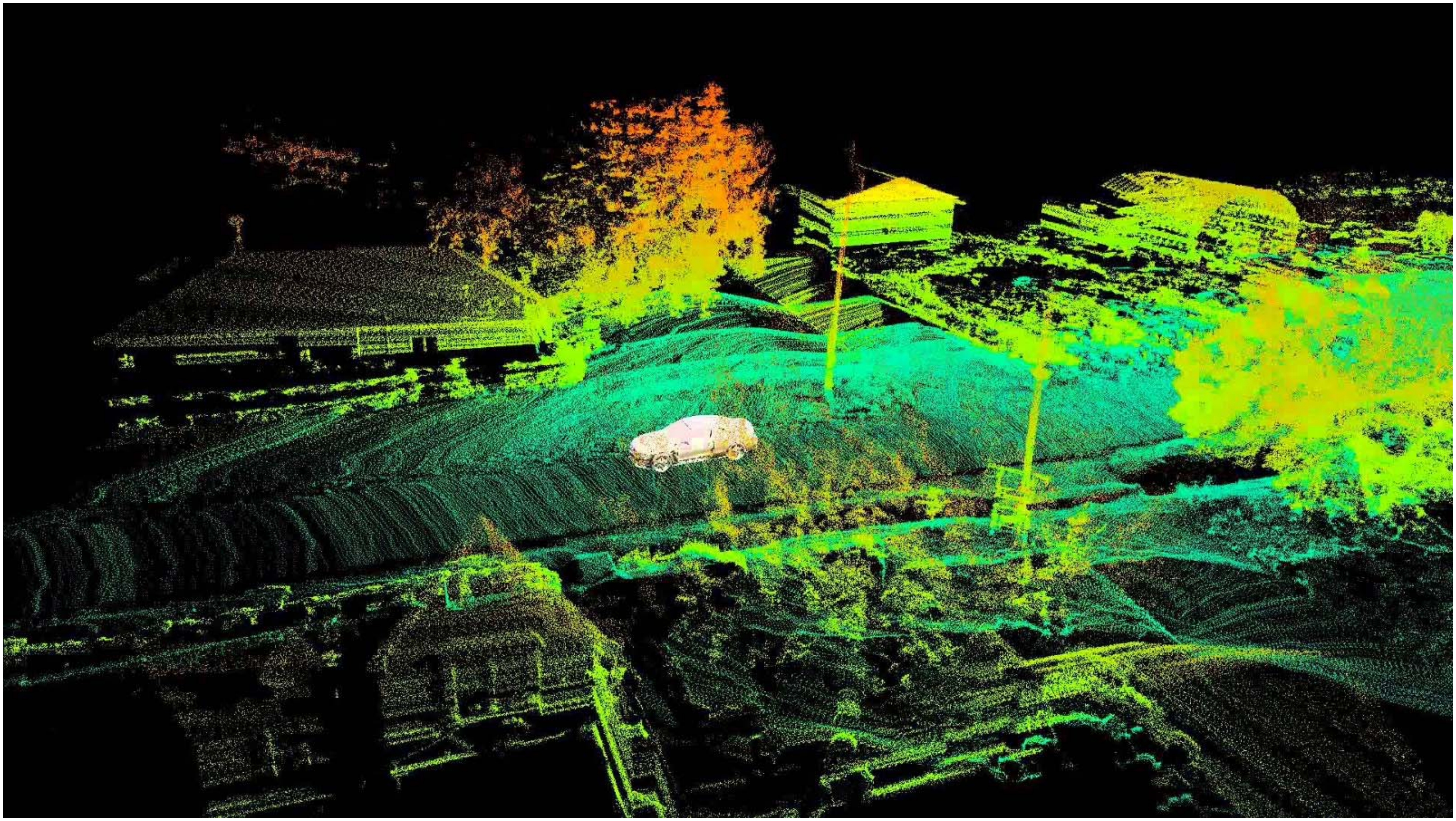
Range Sensors – LiDAR

Lidar (Light Detection And Ranging , Laser range finder)

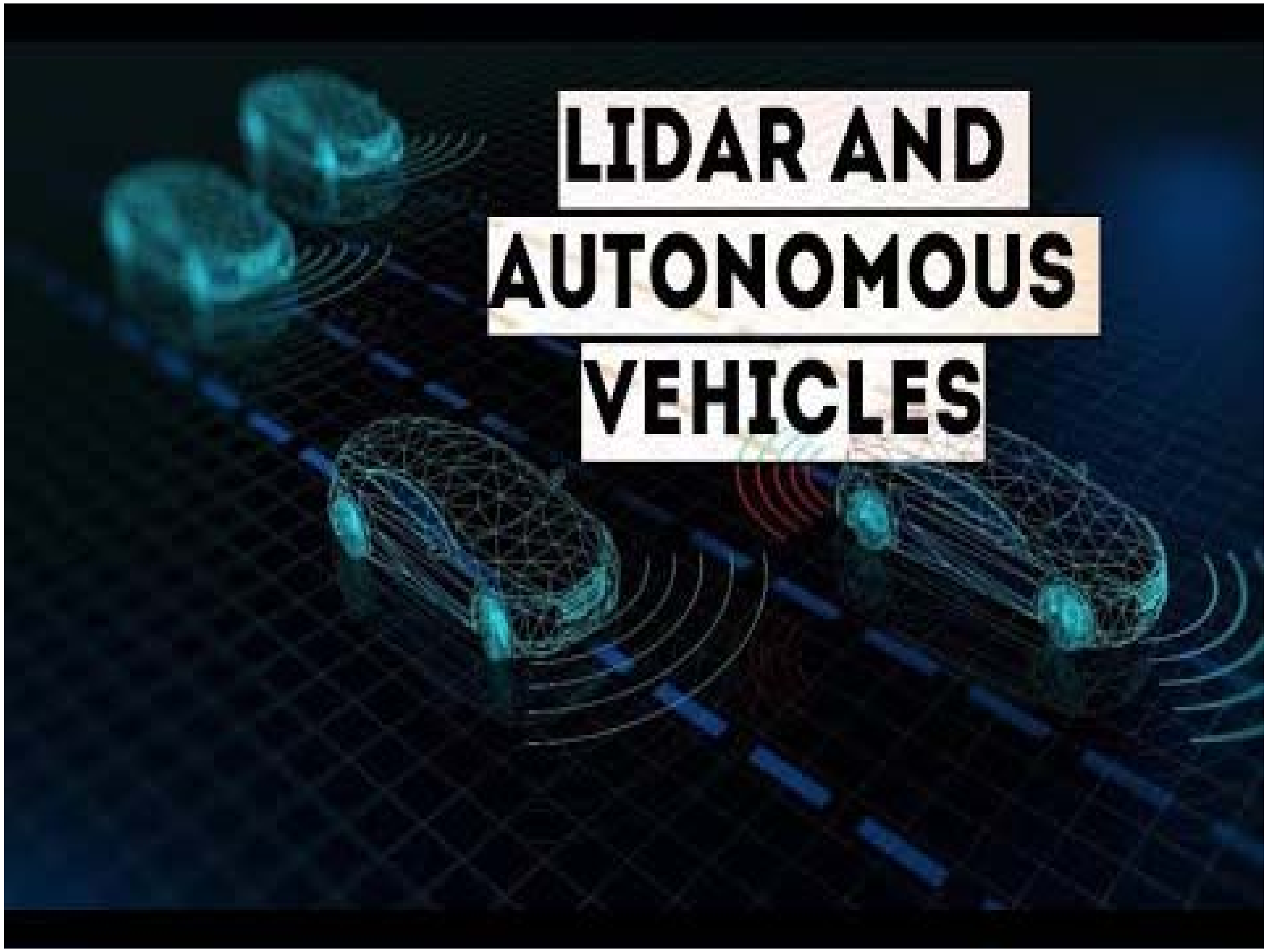
- The Velodyne HDL-64E uses 64 laser emitters.
  - turn-rate up to 15 Hz
  - The field of view is 360° in azimuth and 26.8° in elevation
  - Angular resolution is 0.09° and 0.4° respectively
  - Delivers over **1.3 million data points per second**
  - The distance accuracy is better than 2 cm and can measure **depth** up to 50 m
  - Expensive



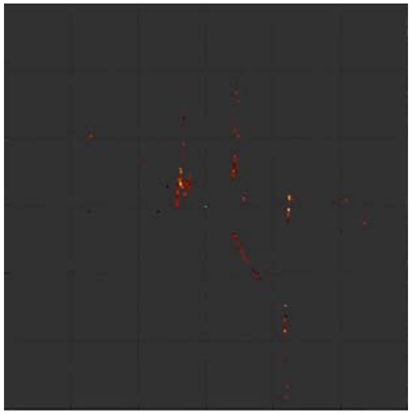
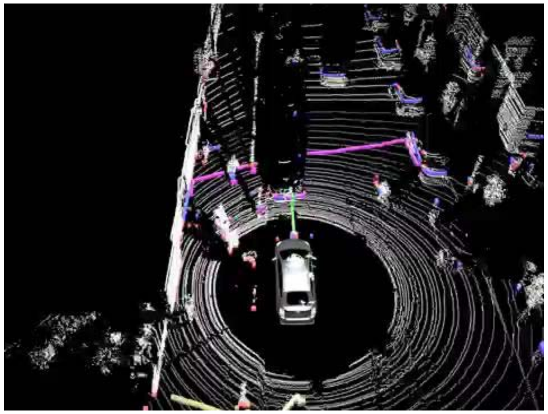
How does the world look like in the eyes of an Autonomous Vehicle



How is Lidar Used in Autonomous Vehicles?



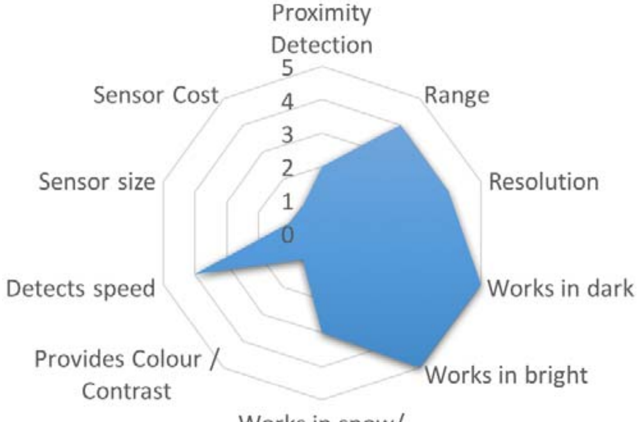
Range Sensors -- Radar v.s. LiDAR

  v.s  

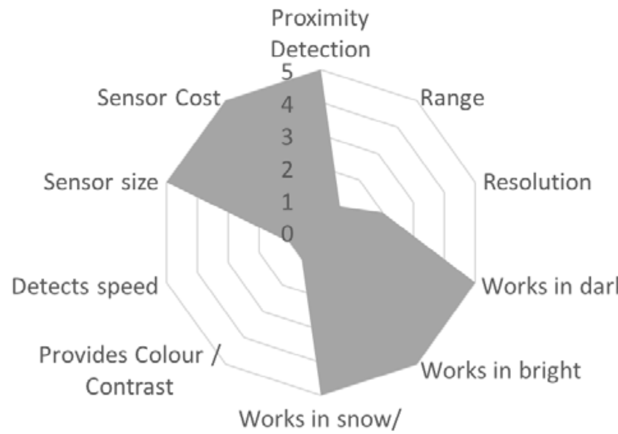
- Cheap
- Does well in extreme weather, i.e., rain, fog, snow
- Low resolution
- Most used automotive sensor for object detection and tracking

- Expensive
- Extremely accurate depth information
- Resolution much higher than radar
- 360 degrees of visibility
- Does poorly in rain, fog, snow…

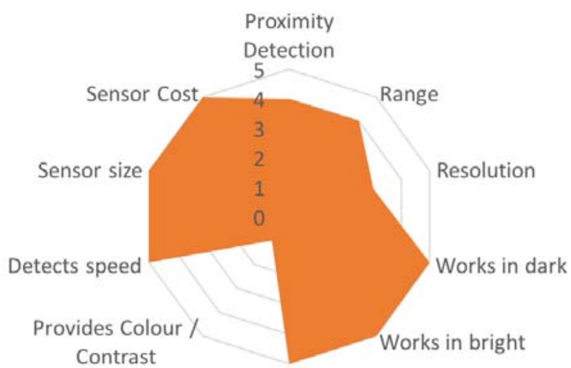
Sensor Comparisons



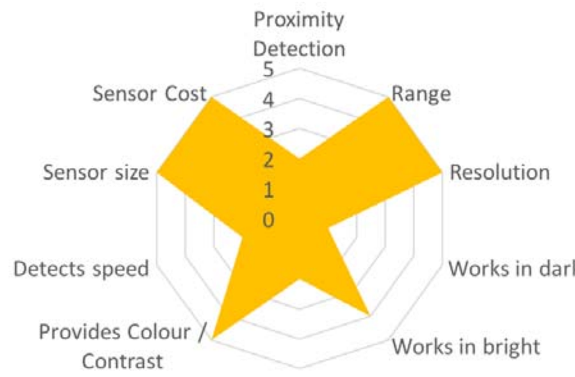
LiDAR



Ultrasonic



Radar



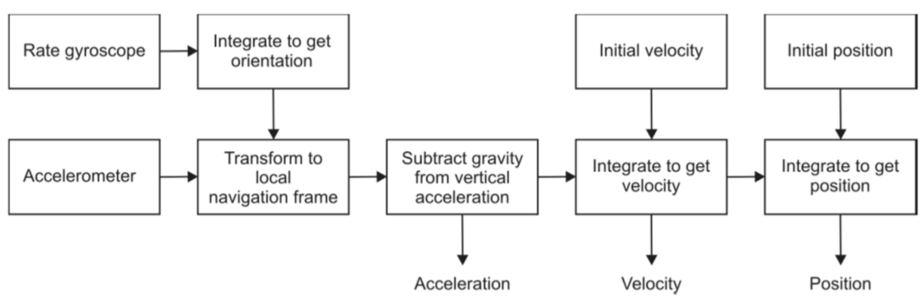
Camera

Matlab Lidar ToolBox

- **Lidar Toolbox:**
  - https://www.mathworks.com/help/lidar/
- What is Lidar data
  - https://desktop.arcgis.com/en/arcmap/10.3/manage-data/las-dataset/what-is-lidar-data-.htm
- Read, process, and write Lidar point cloud data
  - https://www.mathworks.com/help/lidar/ug/read-process-write-lidar-point-cloud-data.html
- Extract on-road and off-road points from point cloud
  - https://www.mathworks.com/help/lidar/ug/extract-onroad-offroad-points-from-pointcloud.html
- Extract ground points and non-ground points from Lidar data
  - https://www.mathworks.com/help/lidar/ug/extract-ground-points-and-non-ground-points-from-lidar-data.html

Inertial Measurement Unit (IMU)

- An Inertial Measurement Unit (IMU) is a combination of sensors that uses **gyroscopes**, **accelerometers** and sometimes **magnetometers** to estimate the linear and angular motion of a moving vehicle with respect to an inertial frame, and the earth's magnetic field.
- In order to estimate the motion, the gravity vector must be subtracted and the initial velocity has to be known
- After long periods of operation, drifts occurs: need external reference to cancel it



Global Positioning System (GPS)

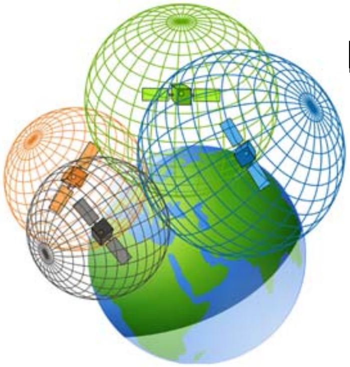
- Satellite-based sensing system
- GPS satellites broadcast their location and time
- Developed for military use
- Now accessible for commercial use (e.g., hiking, flying,…)
- There are 24 satellites orbiting the earth every 12 hours at height of 20+ km
- There are 4 satellites located in each of 6 planes inclined at 55 degrees to the equator

Garmin Image

Global Positioning System (GPS)

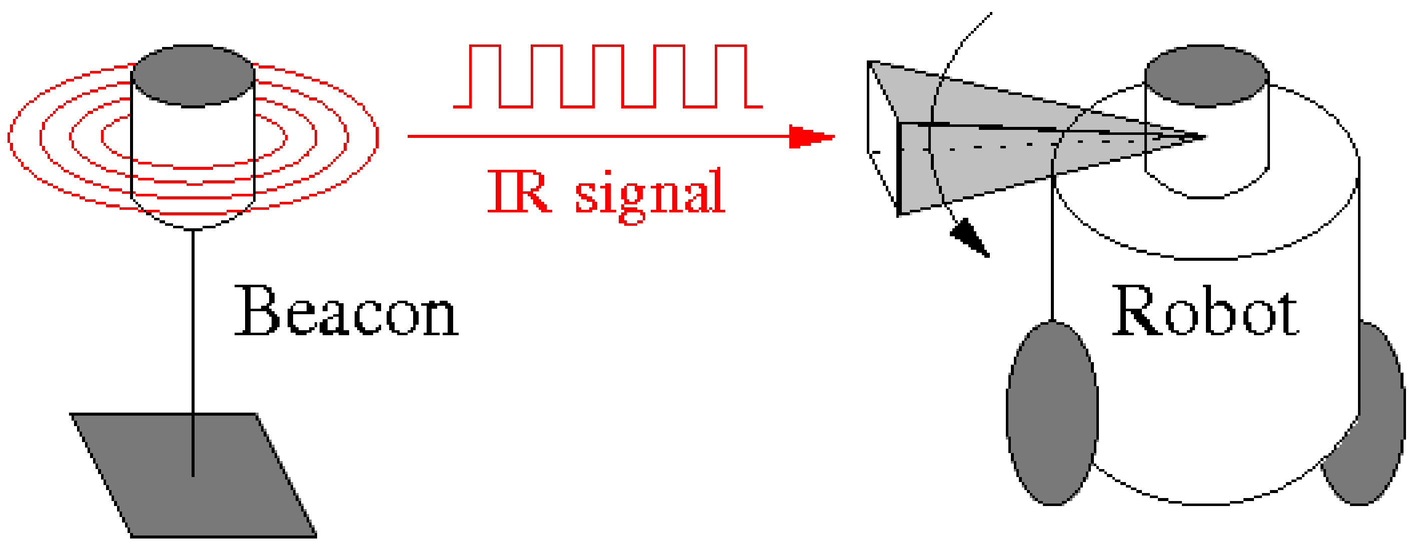
- Regular GPS, can get accuracy 10 – 15cm
- With a second receiver of known location, differential GPS (i.e.g, DGPS) can resolve down to 1 m.
- Carrier-phase can get resolution down to 1 cm.

- Robot GPS receiver:
  - Triangulates relative to signals from 4 satellites
  - Outputs position in terms of latitude, lon ıde, and change in time



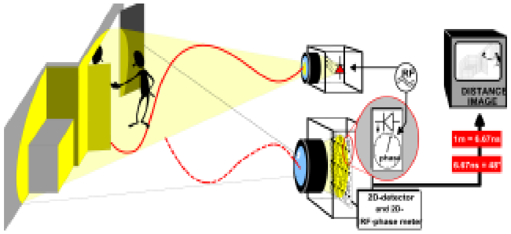
Ground-Based Beacon Systems

- Used for localization
- Used by humans (e.g., stars, lighthouses)
- Beacons can be active or passive
- Known location of beacons allows localization
- Problem is that they are not flexible



3D Time-of-Flight Camera

- A Time-of Flight camera (TOF camera) works similarly to a lidar with the advantage that the whole 3D scene is captured at the same time and that there are no moving parts.
- This device uses an infrared lighting source to determine the distance for each pixel of a Photonic Mixer Device (PMD) sensor.



Swiss Ranger 3000
(produced by MESA)

Other Types of Sensors

- Odor sensors
  - Detection of chemical compounds and their density in an area
  - A lot of applications, e.g., mine detection

- Touch sensors (tactile sensors)
  - Whiskers, bumpers etc.
  - mechanical contact leads to
    - closing/opening of a switch
    - change in resistance of some element
    - change in capacitance of some element
    - change in spring tension
    - Etc…

- Temperature sensor
- Light sensor
- …

- Thank you!