Introduction to Vision and Perception Sensors and Devices

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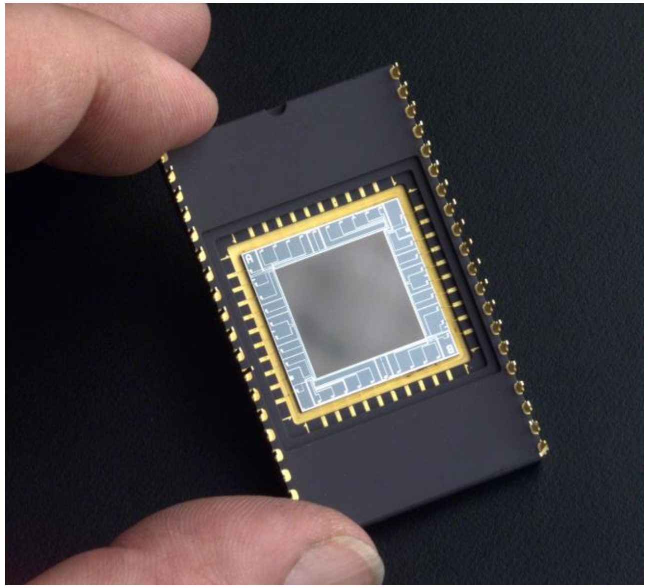
Sensors

- Sensors are physical devices that provides information about the world. This process is called Sensing or Perception.
- Examples:
  - Accelerometer
  - Gyroscope
  - Camera
  - Temperature and Humidity Sensor
  - Ultrasonic Sensor
  - IR Sensor
  - LiDAR Sensor

Types of Digital Imaging Sensors



CCD Sensor

CMOS Sensor

Charge-coupled Device (CCD)

- First developed in 1969 by Willard Boyle and George E. Smith at AT&T Bell Labs in USA
- A charge-coupled device or CCD is a highly-sensitive photon detector which can detect light between the wavelength of 400nm to 1000nm.
- The chip is an array of light sensitive small areas called *pixels.* (*There could be several millions of pixels in a single chip*)

Charge-coupled Device (CCD): How it works??

1. **Charge Collection**

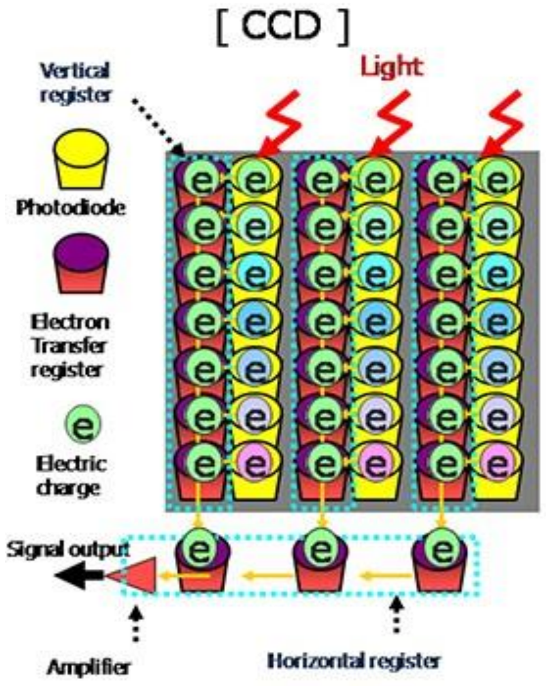
   When photons strike the pixels, they will release a number of electrons (*proportional to the intensity of the scene at the pixel*) which are then captured by electric fields and retained at the pixel.

2. **Readout**

   - Each row of pixels or CCD Columns are then shifted using vertical conveyor belts(*Implemented using shift registers*) to the final row (**Readout Register**)
   - In the read-out register, the electrodes are arranged in such a way that the charge can be transferred horizontally along the readout register.
   - At the time of read-out, the collected charge is transferred one at a time to **an output amplifier** which converts the charge to voltage.

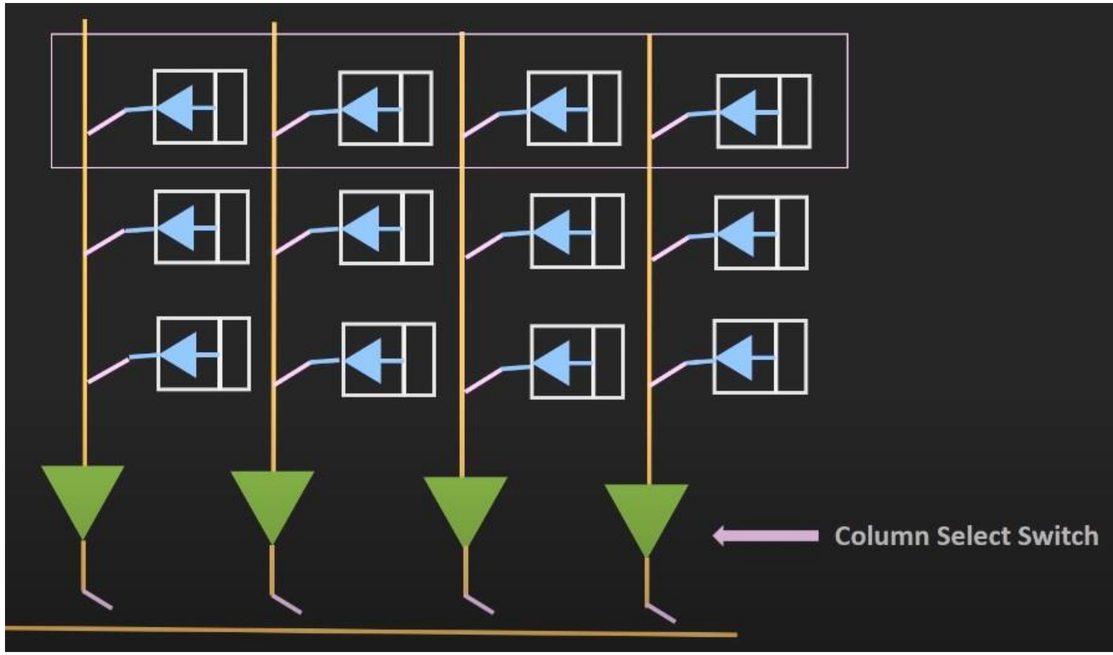
3. **Image Construction**

   Finally, using an ADC (Analog to Digital Converter) and other electronic devices in the camera, the voltage is converted to digital form. This process continuously runs until all pixels' charge have been amplified and output.



Working Principle of CMOS Sensors

- CMOS sensors are built with fabrication tech similar to ICs.
- Hence, amplifiers, converters can be integrated into the circuit.
- Compared to CCD, the charge to voltage conversion and the amplification is performed *inside* the pixels. So the processing speed of the CMOS sensors are *higher* than CCD.
- The pixels are finally read row by row using pixel select switches



https://www.youtube.com/watch?v=FKJFIzDfUNE&ab_channel=ALLABOUTELECTRONICS

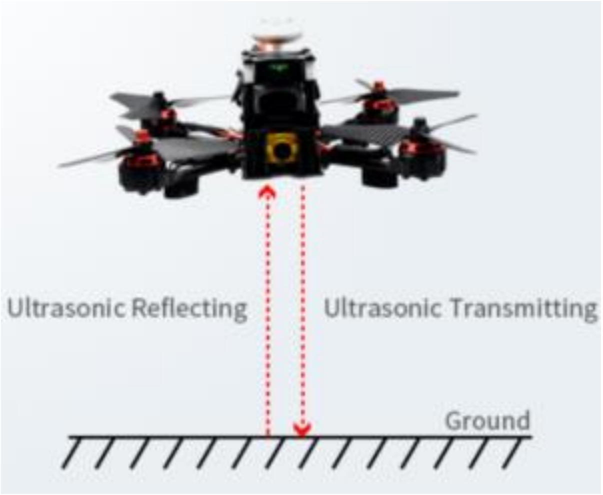
Comparison of CCD and CMOS Sensors

	CCD	CMOS
Circuit Complexity	Complex	Compact
Power Supply	High	Low
Processing Speed	Low	High
Photon Sensitivity	High	Low

Ultrasonic Sensor

- Converts electrical energy into acoustic wave, which is an ultrasonic wave travelling at above 18kHz frequency.
  - HC-SR04 operates at 40kHz
- a microcontroller is used for communication with an ultrasonic sensor.
- Applications
  - Measure wind speed and direction
  - Navigation of UAV
  - Measure tank depth

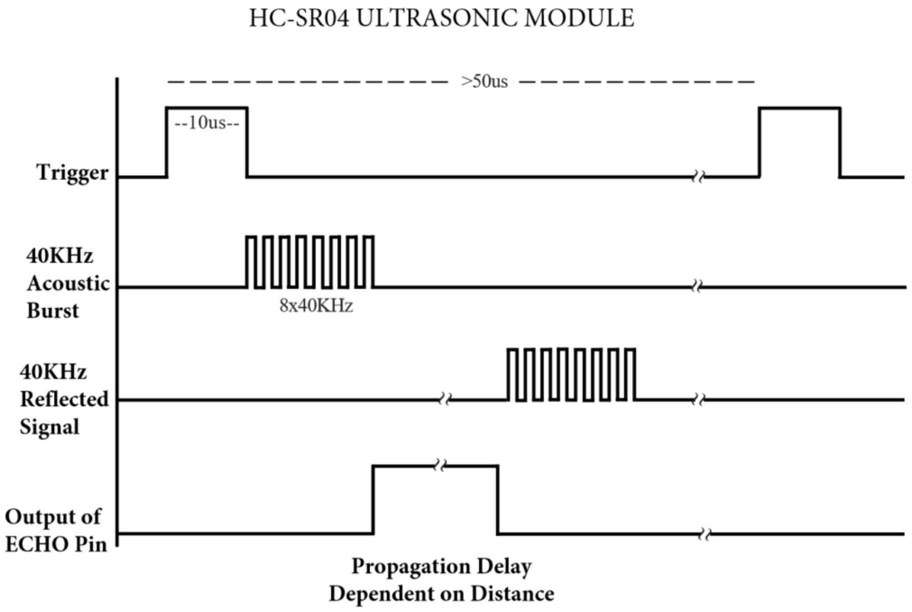
HC-SR04 Ultrasonic Sensor
(*Source: Digikey*)



Ultrasonic sensor measuring height during drone's flight.
(*Source: RadioLink*)

Ultrasonic Sensor: How It Works??

1. a microcontroller is used for communication with an ultrasonic sensor.
2. To begin measuring the distance, the microcontroller sends a trigger signal to the ultrasonic sensor. The duty cycle of this trigger signal is 10µS for the HC-SR04 ultrasonic sensor.
3. When triggered, the ultrasonic sensor generates eight acoustic (ultrasonic) wave bursts and initiates a time counter.
4. As soon as the reflected (echo) signal is received, the timer stops. The output of the ultrasonic sensor is a high pulse with the same duration as the time difference between transmitted ultrasonic bursts and the received echo signal.



Ultrasonic Sensor: How It Works??

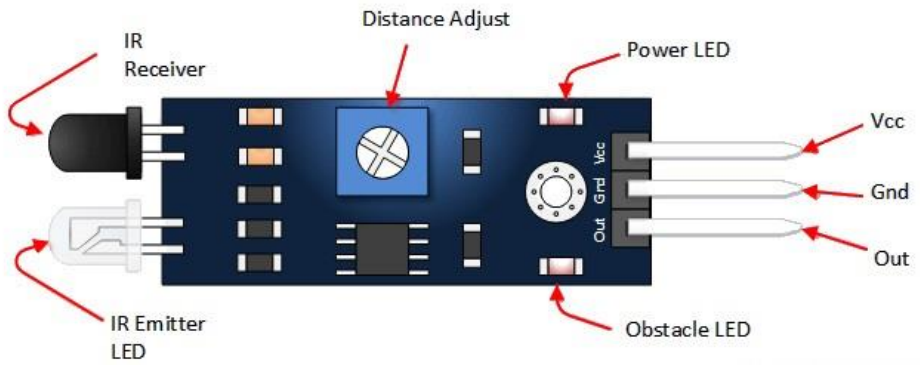
1. Distance (cm) = $\frac{echo\ pulse\ width\ (\mu S)}{58}$

2. Distance (inch) = $\frac{echo\ pulse\ width\ (\mu S)}{148}$

3. Distance = $\frac{time\ taken\ * speed\ of\ sound}{2}$

Infrared Sensors

- An electronic device that can detect and measure infrared (IR) radiation in the environment
- Anything that emits heat (everything that has a temperature above around five degrees Kelvin) gives off infrared radiation
- Applications
  - TV Remote
  - Motion Sensing
  - Proximity Sensing
  - Gas and Flame Detection and Monitoring



Infrared Sensors: Types

- Passive IR Sensor (PIR)
  - Does not have any IR sources but can detect energy emitted from the obstacles or objects in the field of view
  - Two types: Thermal and Quantum
    - Thermal IR sensor use IR energy as the source of heat and are not dependent on wavelength. Examples include thermocouples, bolometers etc.
    - Quantum IR sensors, on the other hand, have higher detection capability and its photosensitivity is wavelength dependent.

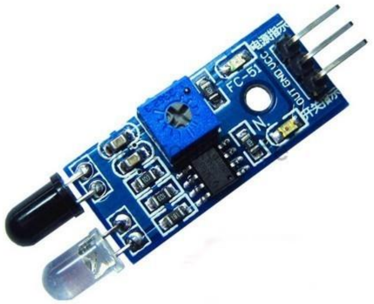
HC-SR501 PIR Motion Sensor Module

Infrared Sensors: Types

- Active IR Sensor
  - They can emit IR energy using infrared LED or infrared laser diode and receive the reflected energy using an infrared detector e.g. photodiode, phototransistors

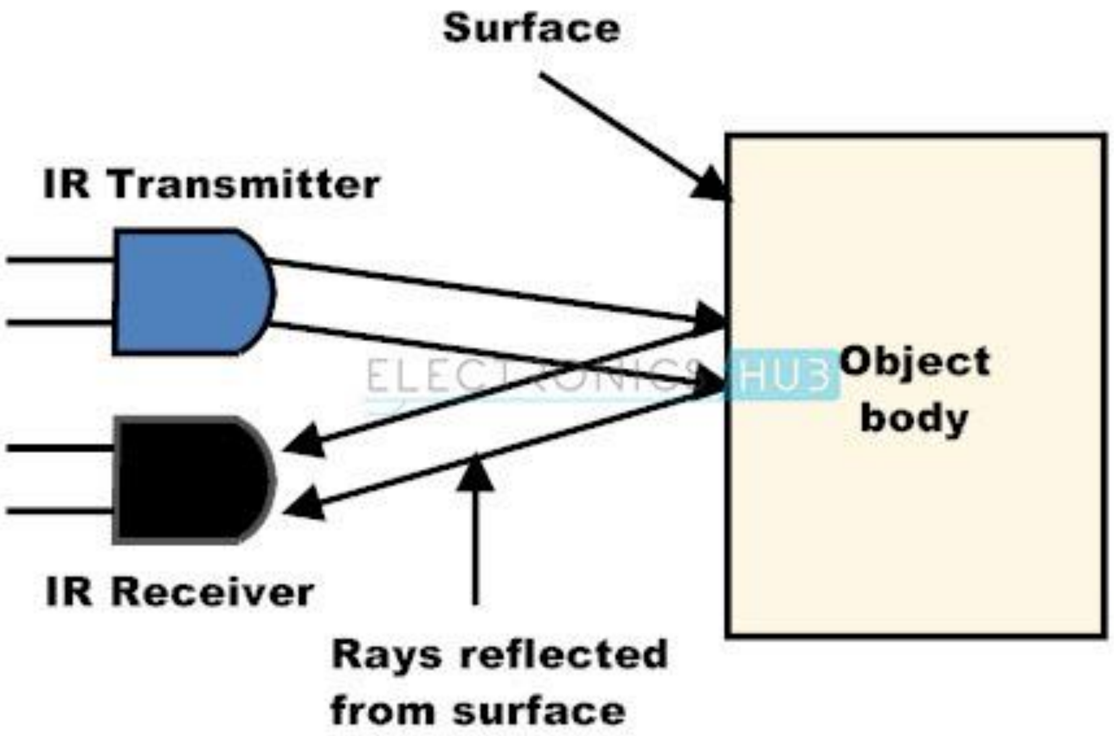
IR Emitter LED

IR Receiver



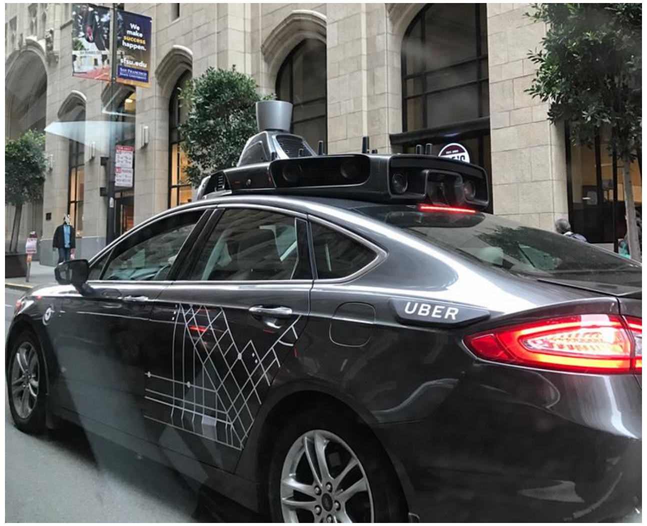
Module

Infrared Sensors: How Active Sensing Works



LiDAR

- Stands for Light Detection And Ranging
- Similar to Radar and Sonar
- Uses laser instead of radio wave or sound wave
- Applications include:
  - High Resolution Mapping
  - Laser Guidance Systems
  - Control and Navigation of Robots and Autonomous Cars



Components of a LiDAR Scanner

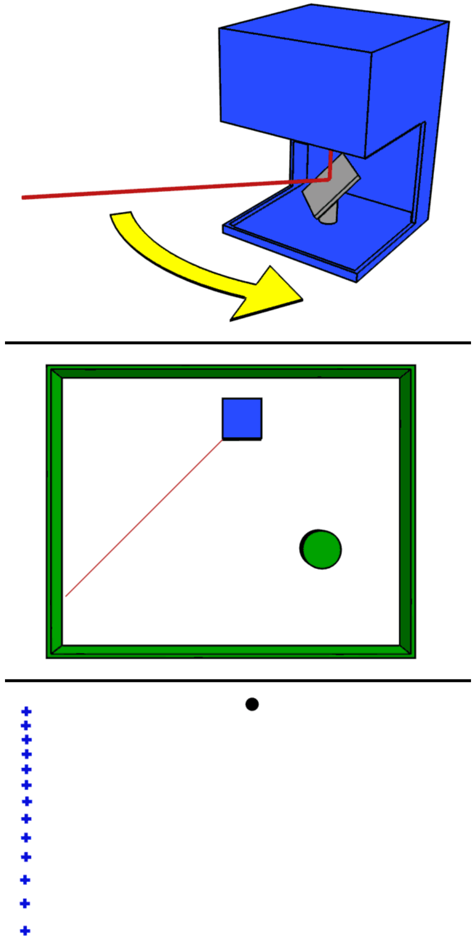
- Laser
  - 600-1000 nm Lasers are the most prevalent for non-scientific usage such as agricultural mapping
  - One common alternative, 1550 nm lasers
    - eye-safe at relatively high power levels
    - wavelength is not strongly absorbed by the eye,
    - However, detector technology is less advanced
    - and so used at longer ranges with lower accuracies.
  - Laser can be emitted using a phased antenna array

Components of a LiDAR Scanner

- **Scanners and Optics**
  - Different scanners and mirrors are used for changing detection resolution or range.
  - Beam splitters can be used for capturing the return signal
- **Photodetector and receiver electronics**
  - Solid State Photodetectors
  - Photomultipliers (They convert photon into electrical signal)
- **Position and navigation systems**
  - GPS or IMU (Inertial Measurement Unit)
  - Used to determine the position and orientation of sensors especially when the LiDAR unit is on airplane or satellite
- **Sensors** for signal detection and sending. They can be built using hybrid CCD/CMOS fabrication technology.

Basic Working Principles

- Each time the laser is pulsed:
  - Laser generates an optical pulse(*Up to 200,000+ pulses/second*)
  - After reflecting off an object, the pulse returns to the receiver sensor
  - High-speed counter measures the time of flight from the start pulse to the return pulse
  - Time measurement is converted to a distance
  - An onboard computer records each laser's reflection point, translating this rapidly updating "point cloud" into an animated 3D representation of its surroundings.



Point Cloud Identification

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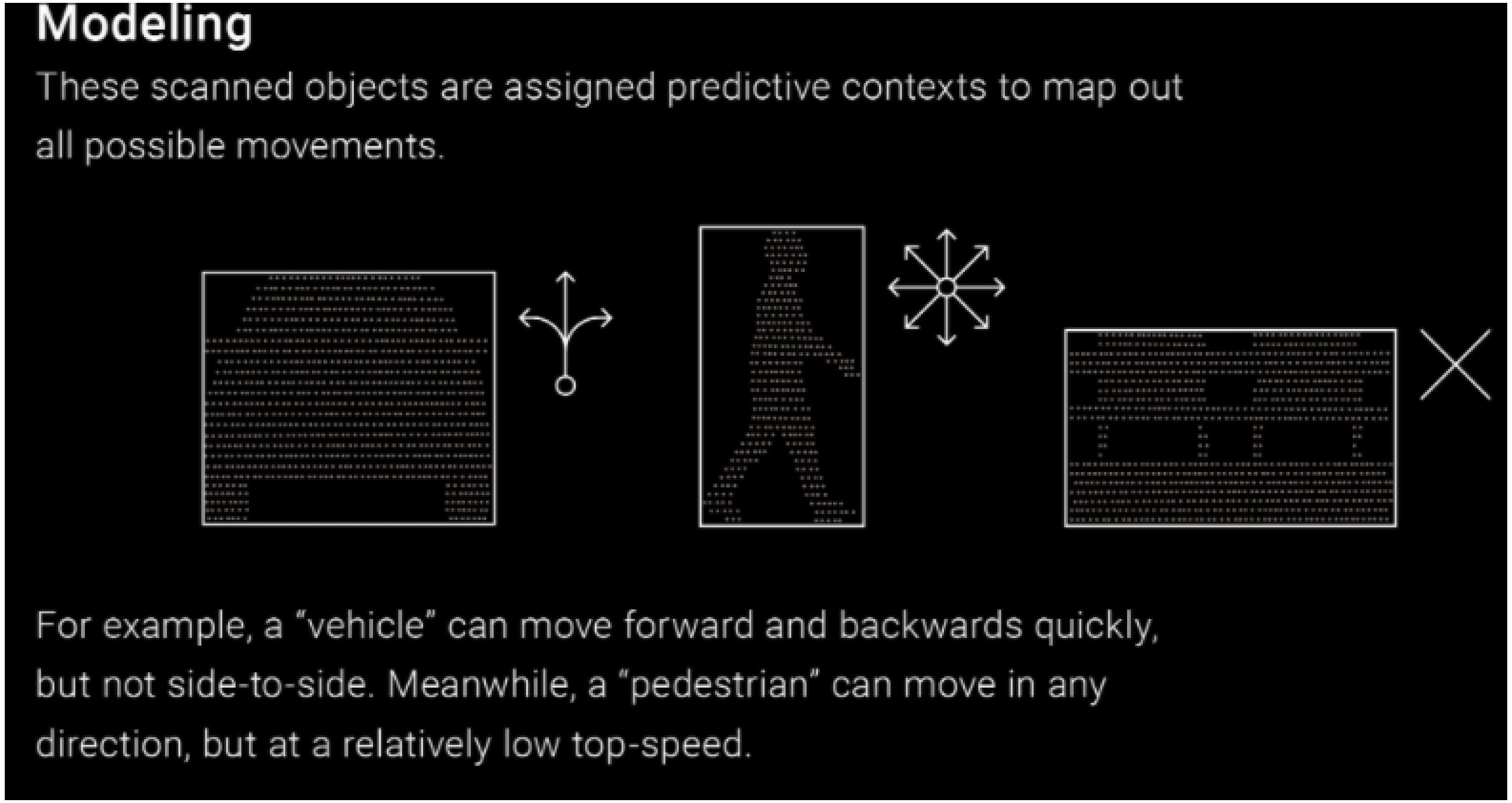

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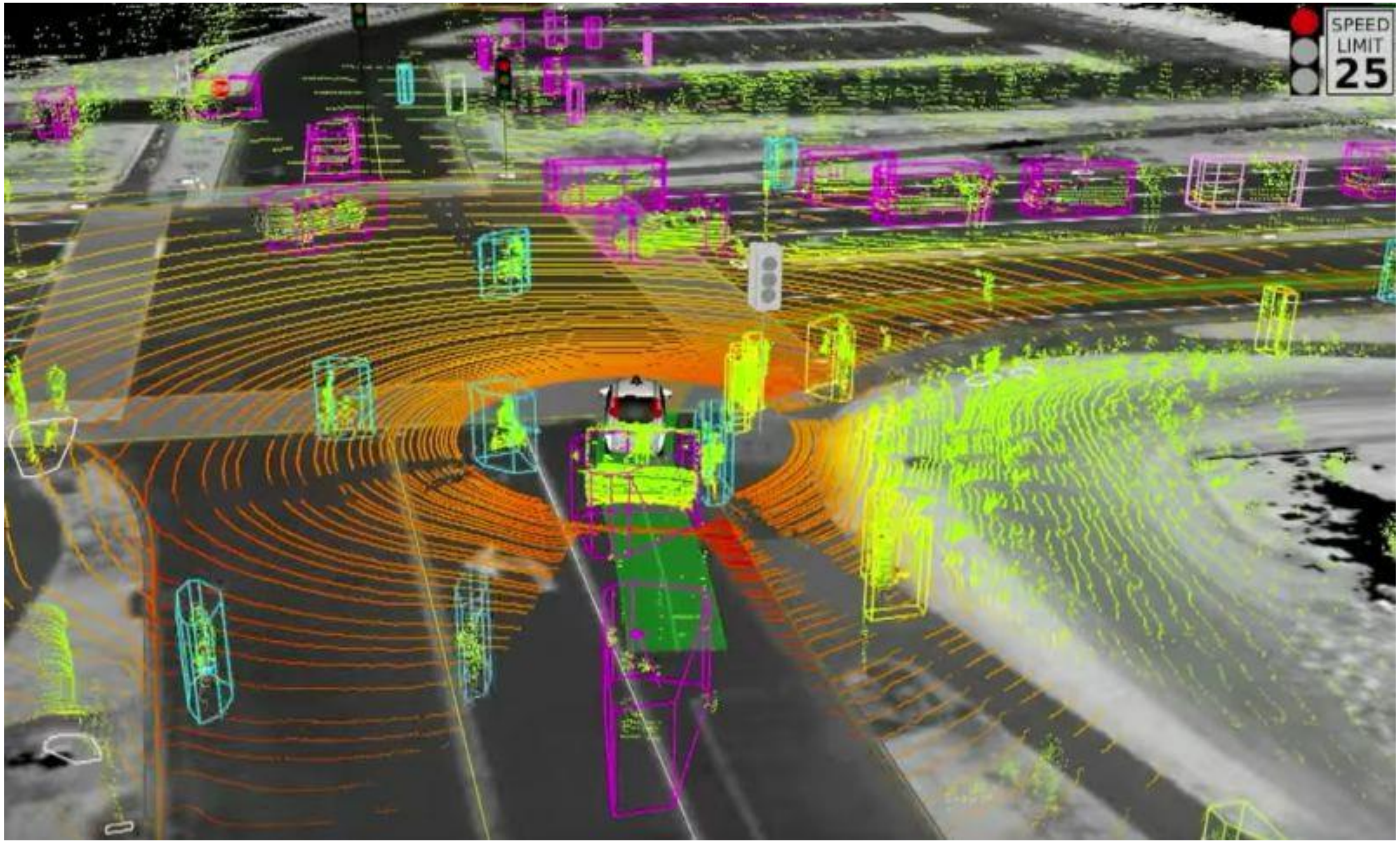
Autonomous Navigation using Lidar



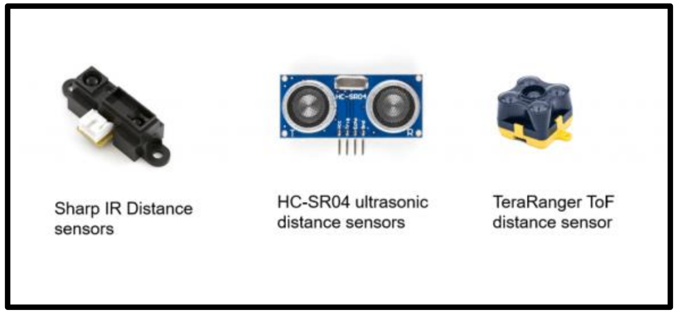
- To see LiDAR in action
  - https://www.youtube.com/watch?v=JC94Y063x58&ab_channel=GeospatialWorld
  - https://www.youtube.com/watch?v=EYbhNSUnIdU&ab_channel=NEONScience

Choosing The Proximity and Range Sensors

- Depends on applications!!
- Proximity Sensors
  - 1-D range finders
    - Distance is measured from observer to object in a straight line. Used in obstacle detection and avoidance
    - IR sensors, Ultrasonic sensors etc.
  - 2-D range finders
    - Mainly includes laser scanners that can scan 2D plane and calculate the range measurement
    - 2D static laser scanners can scan in limited angles
    - 2D rotational laser scanners can scan in 360 degrees
    - Used in object detection and avoidance, navigation

Choosing The Proximity and Range Sensors

- 3-D Static Range Finders and RGB-D cameras
  - Have to be mounted on robots
  - RGB-D cameras use IR projection and reflection to calculate 3d range
  - Can give 3D range within a specific angle



1-D

2-D

3-D

Courtesy: https://robocademy.com/2020/04/10/how-to-choose-a-sensor-for-your-robot/

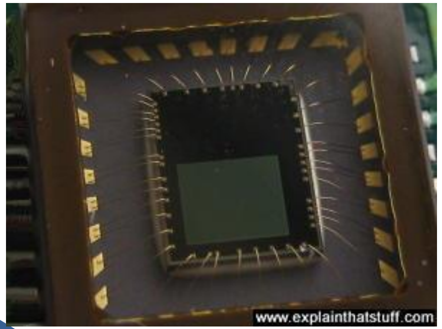
Introduction to Imaging Devices

Digital Imaging Devices

How Digital Cameras Work

1. This is the insides of a webcam. We can see that a lens is planted directly onto an electronic chip

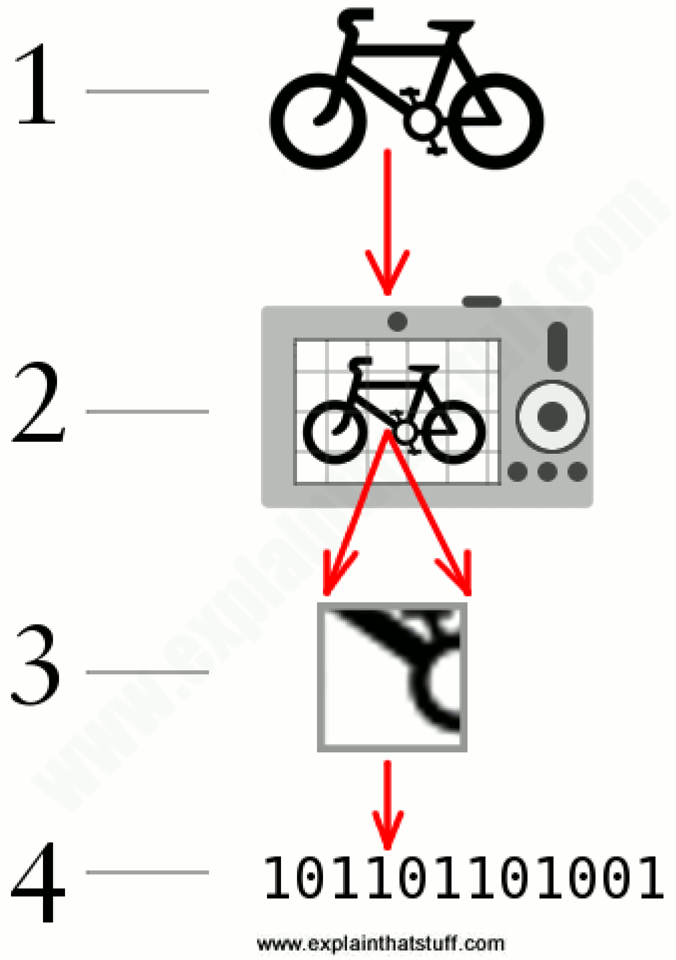
2. This is the image sensor (CCD or CMOS).You should observe that the chip has a dark green part in the middle which is the light sensitive part. The outer parts are connections with the main



3. Closeup look at the sensor

How Digital Cameras Work (Contd)

- Step 1: Light enters the camera through the aperture
- Step 2: The image sensor splits the image into a number of pixels (could be millions, depends on the size of the sensor)
- Step 3: The sensor, after measuring the brightness and the color of the image, then stores the color and brightness info in the memory card as binary numbers.



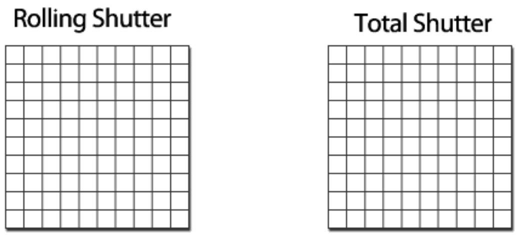
Choosing The Right Camera Module

- Look at the camera interfacing available for your development board
  - MIPI CSI – 2 (MIPI Camera Serial Interface 2)
    - Default camera interface in RPi and NJN. Has high performance, cost-effective and easy-to-use
    - On the RPi, the MIPI CSI-2 interface takes the form of two physical connectors: 15-pin connector on standard Raspberry Pi models and a 22-pin connector on Pi zero and the Jetson Nano uses a 15-pin connector
  - USB Camera
    - Typically driver free (USB Video Class Cameras or UVC Cameras)
    - Mostly used type is webcam. They can be plug and play
    - Other UVC cameras available for embedded uses. Arducam offers several UVC board cameras as an implement for our current embedded MIPI camera modules. These cameras have more case-specific features like Wide Dynamic Range (WDR), low light enhancement and so on

https://www.arducam.com/choose-camera-modules-raspberry-pi-jetson-nano-guide/

Choosing The Right Camera Module

- Monochrome or Color Sensor
  - Color Sensor with Rolling Shutter
    - Color sensors are image sensors with color filters
    - Color sensors typically implement Rolling shutter. This is a method of capturing image where the image sensor is gradually exposed from top to bottom
    - Cheaper to build and easy to add more pixels
    - Cannot capture scenes with fast moving objects properly. Causes distortion in these cases.
  - Monochrome Sensor with Global Shutter
    - a global shutter camera exposes all pixels at the same time. The shutter opens and closes in a short period. Therefore, it can take better pictures of fast-moving objects without blurring the details.
  - **For taking videos in higher frame rates and fast-moving objects, global shutter monochrome cameras can be good option. For capturing detailed still photos, high-resolution rolling shutter color cameras are better.**
- Have to choose between manual focus or autofocus camera.



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Choosing The Right Camera Module

- KNOW YOUR APPLICATIONS AND REQUIREMENTS
- NEED TO CAPTURE CRISP DETAILED IMAGES?
- OR MOVING IMAGES?
- HOW FAR IS THE OBJECT?? HOW LARGE IS THE AREA OF SHOOTING?
- LIGTING CONDITION??

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ANY QUESTIONS?