CSCE274 Robotic Applications and Design
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Robot Components
Sensors

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Sensors

- Sensors are devices that can sense and measure physical properties of the environment

Sensors

- Sensors provide partial information about the world

- Sensors are noisy

- Sensors cannot be modeled completely as finding the inverse is an ill-posed problem, namely the solution is not uniquely defined

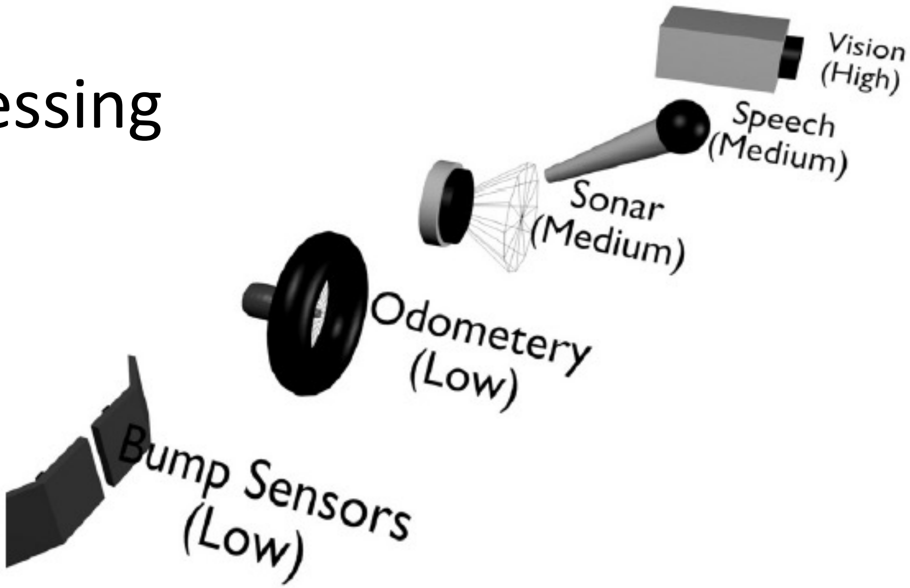
Classification

- According to the operation mode:
  - Active: emit energy in the environment
  - Passive: receive energy from the environment

- According to what kind of information is able to detect:
  - Proprioceptive: monitor the state of the robot
  - Exteroceptive: monitor the environment

Level of processing

- Raw data processed at different levels, depending on the sensor
  - Low: electronics
  - Medium: signal processing
  - High: computation



Source: [Mataric, 2007, MIT Press]

Sensor fusion

- Sensor fusion is the process of combining data from multiple sensors

- Complex process because:
  - Every sensor has some noise and inaccuracy
  - Each sensor provides different types of information

Sensor characteristics

- Sensitivity: change of output wrt change of input
- Linearity: constancy of output wrt input
- Measurement/Dynamic range: difference between min and max measurable values
- Response time: time required for a change in input to cause a change in the output
- Accuracy: difference between the measured and actual value
- Repeatability: difference between repeated measurements
- Resolution: smallest observable increment
- Power consumption
- Size and weight

Acceleration sensors

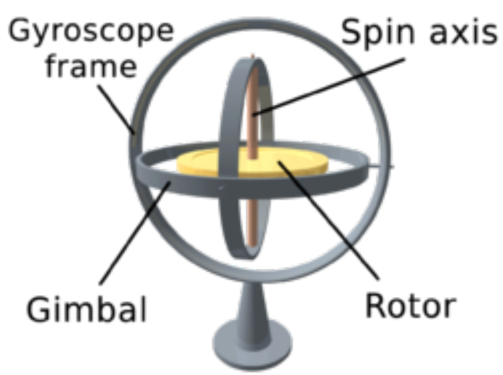
- Measures acceleration in a single direction
  - Measure the displacement of a mass on a spring, then use Newton's second law:

$$a = -\frac{k}{m}x$$

Source: mbed.org

Gyroscopes

- Measures angular velocity
  - By having a spinning gyroscope and trying to rotate its spin axis, the gyroscope will try to rotate about an axis at right angles to the force axis



Source: Wikipedia.org

Source: robotshop.com

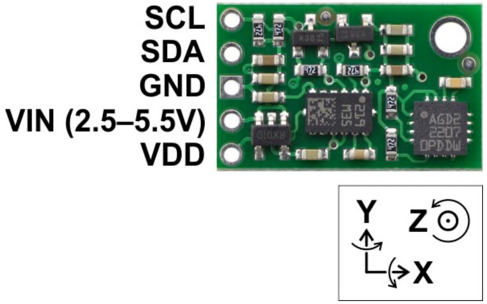
Compass

- Compass measures orientation w.r.t. Earth's magnetic field
- Note that data could be affected by
  - Design of the robot
  - Unexpected variations in magnetic field

Source: dfrobot.com

IMUs

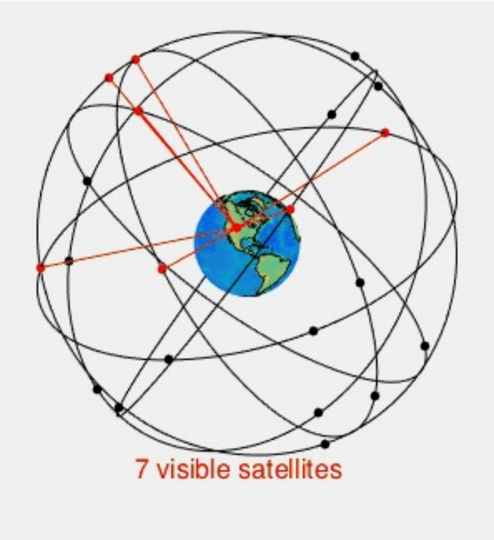
- Inertial Measurement Units (IMUs) combine 3 accelerometers with 3 gyroscopes, and possibly compass



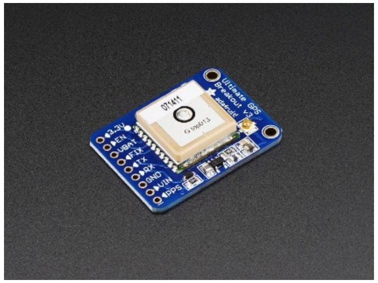
Source: pololu.com

GPS

- GPS provides the position on Earth by using a constellation of between 24 and 32 Medium Earth Orbit satellites



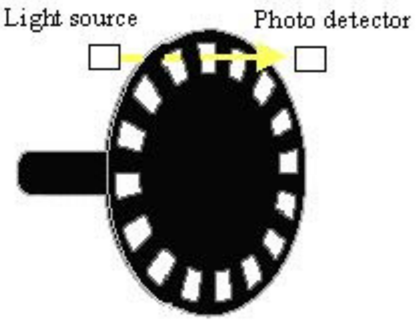
Source: Wikipedia.org



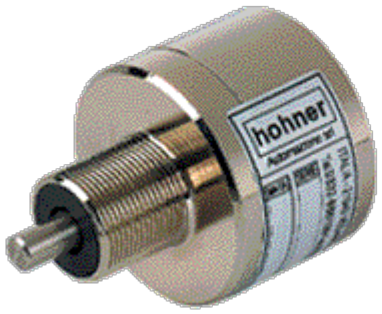
Source: adafruit.com

Encoders

- Encoders measure the amount of rotation in a joint or wheel



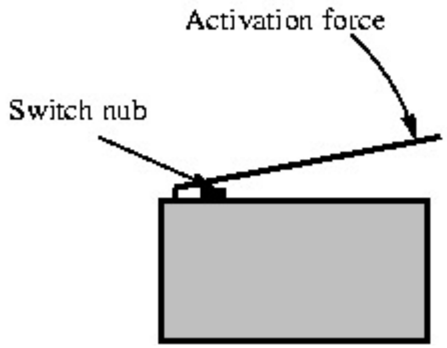
Source: robotix.in



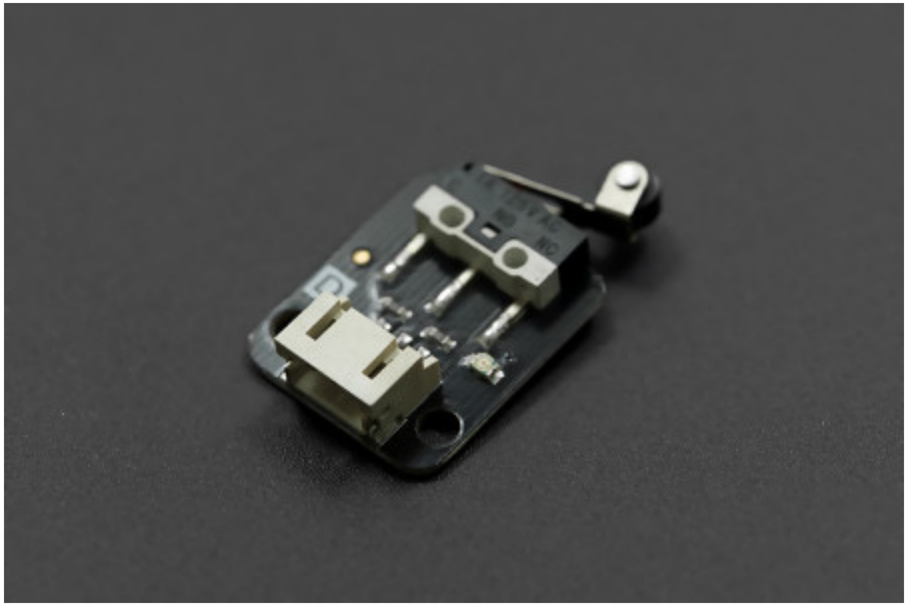
Source: hohner.com

Tactile sensor

- Sensor that reports if in contact with an object



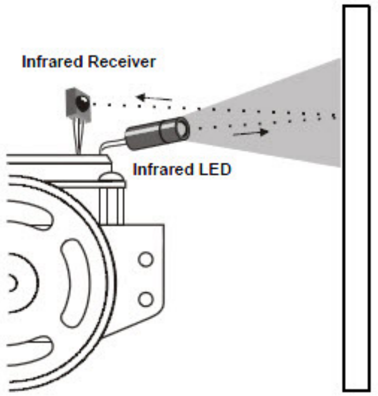
Source: clear.rice.edu/elec201/



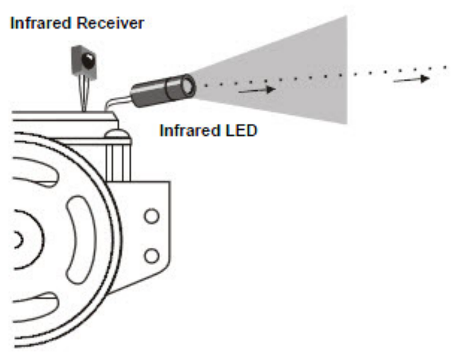
Source: dfrobot.com

Infrared sensors

- Sensor that measures distance from objects by transmitting an IR pulse and measures the intensity of the signal reflected back
  - Note that it strongly depends on the reflective properties of the obstacle surface



Infrared reflected, obstacle detected.



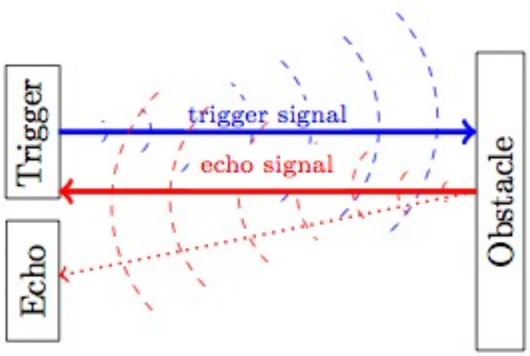
Infrared not reflected, no obstacle detected.

Source: parallax.com

Source: tinkerforge.com

Sonar sensors

- Sensor that measures distance from objects by transmitting sound waves and measures the time-of-flight
  - Note that there are a number of problems and uncertainties associated to the readings



Source: robotics.jcu.io

Source: parallax.com

Laser sensors

- Sensor that measures distance from objects by transmitting a short pulse of laser light and measuring the time-of-flight

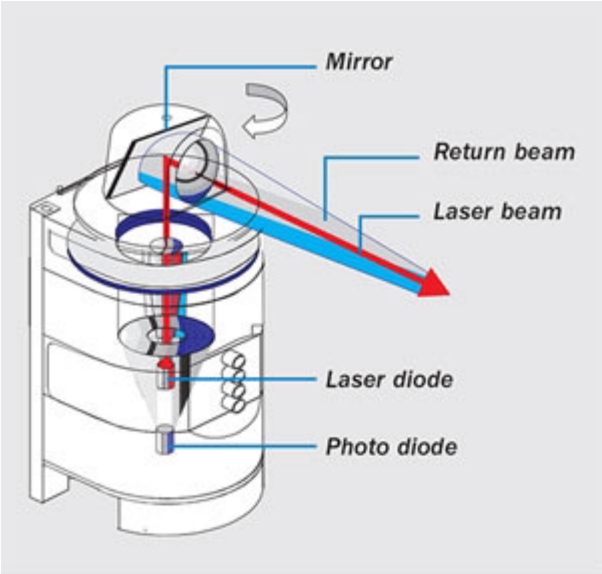


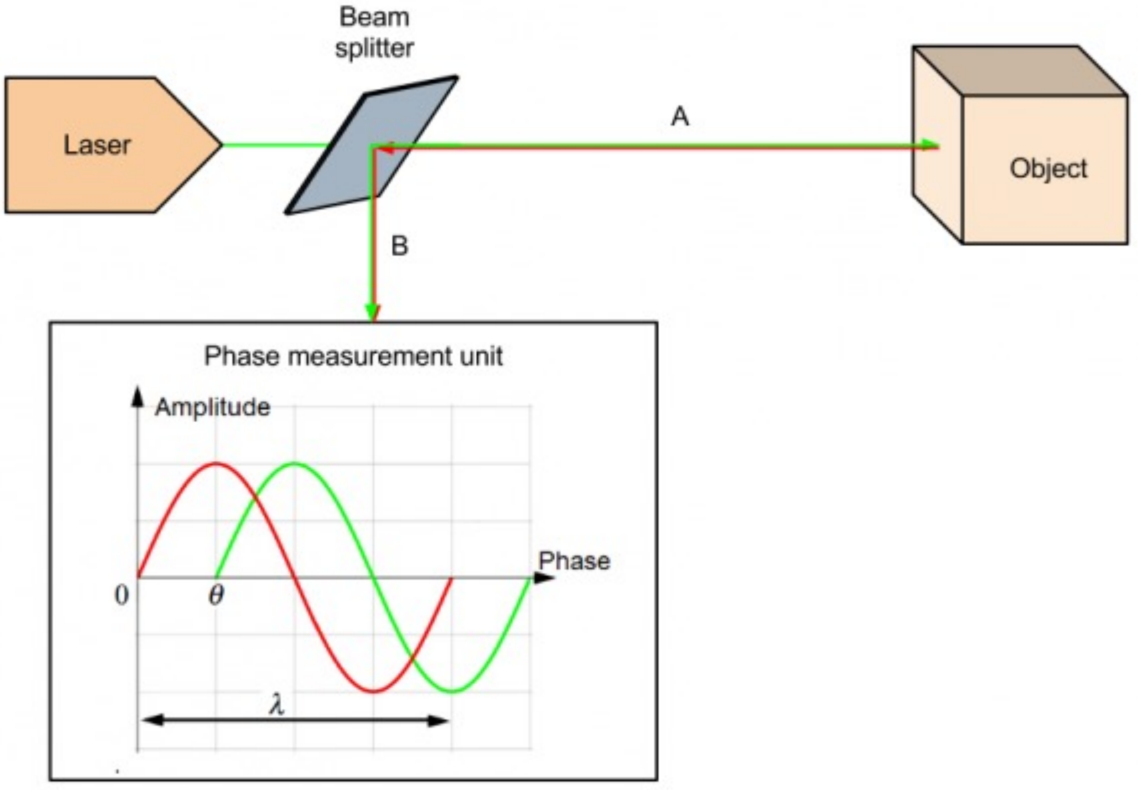
Illustration of LIDAR sensor demonstrating the time of flight principle. *(Courtesy of SICK, Inc.)*

Source: robotics.org

Source: hokuyo-aut.jp

Laser sensors

- As light is faster, phase shift is used



Source: roboticlab.eu

Laser sensors

- A higher resolution in the FOV of the sensor is obtained by a rotating mirror

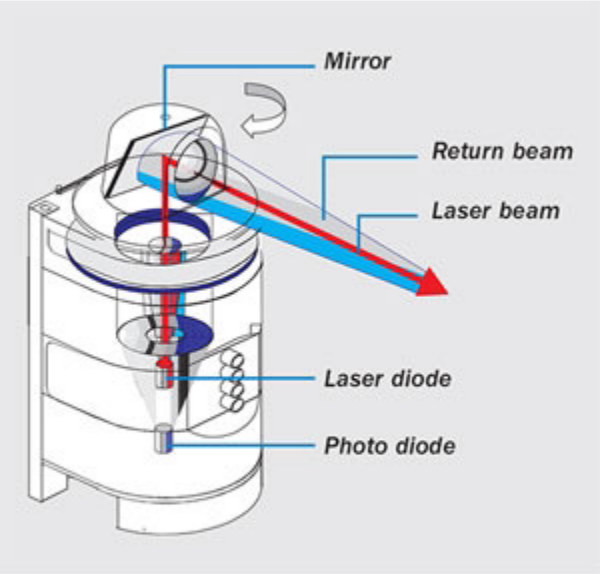
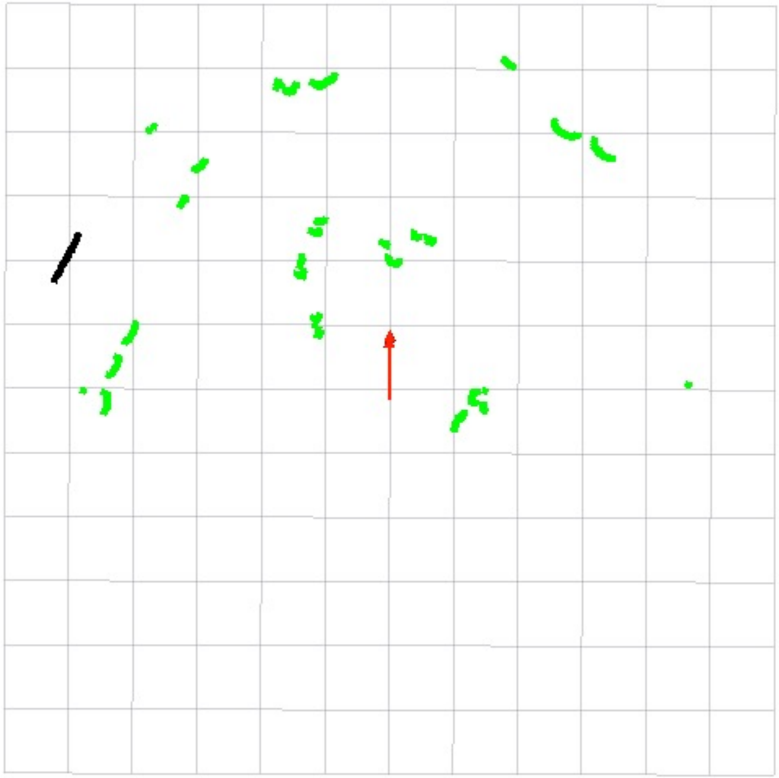


Illustration of LIDAR sensor demonstrating the time of flight principle. *(Courtesy of SICK, Inc.)*

Source: robotics.org

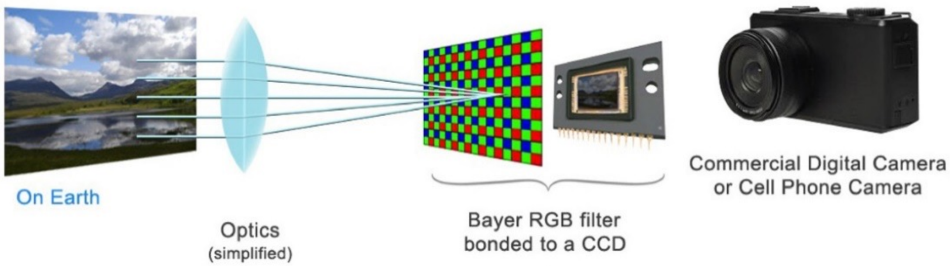
Laser sensors

- Many laser sensors are *planar* sensors

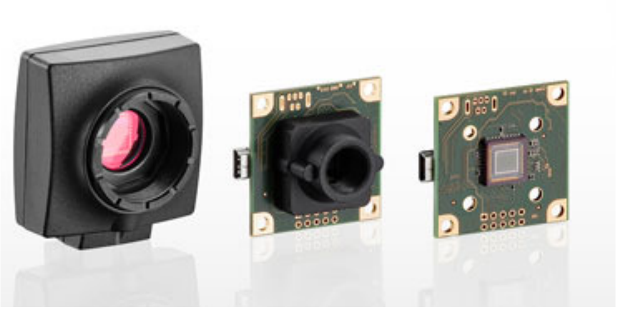


Cameras

- Passive sensor that capture lights from the world



Source: jpl.nasa.gov



Source: ids-imaging.com

Cameras

- Images are data heavy

From GoPro HERO3+ at Barbados 2015 Field Trials

$$\overset{1920}{}$$

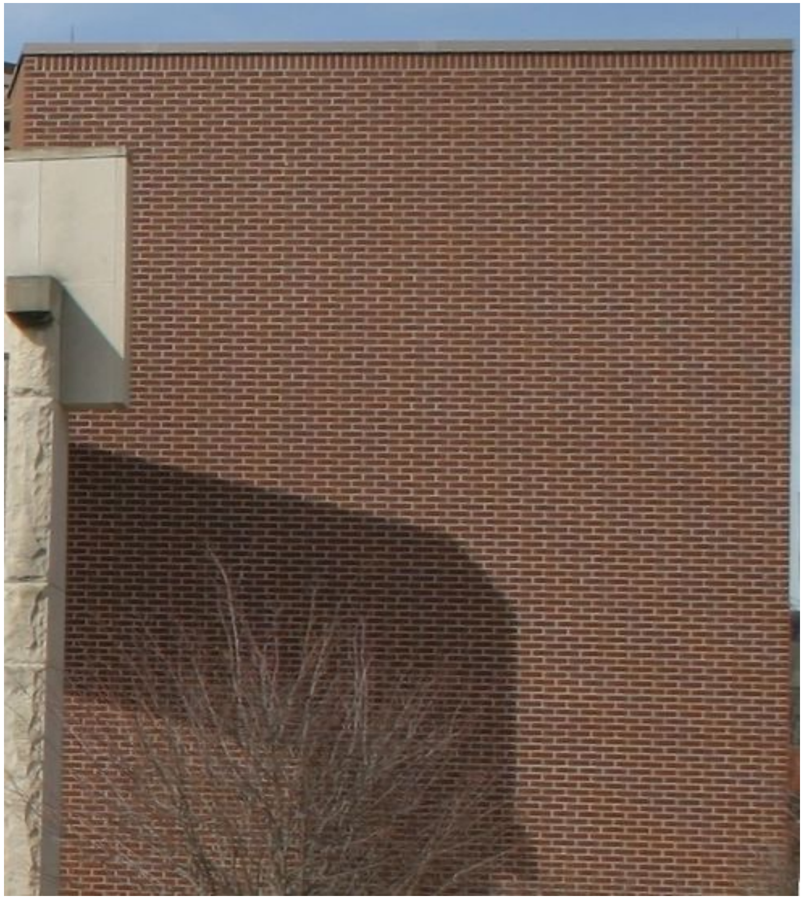
$$1080\ \begin{bmatrix} 43 & 43 & 42 & 40 & 39 & \cdots & 29 & 29 & 31 & 33 \\ 42 & 41 & 40 & 39 & 38 & \cdots & 31 & 32 & 35 & 37 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \cdots & \vdots & \vdots & \vdots & \vdots \\ 54 & 57 & 60 & 62 & 66 & \cdots & 42 & 43 & 56 & 46 \end{bmatrix} \quad \text{R}$$

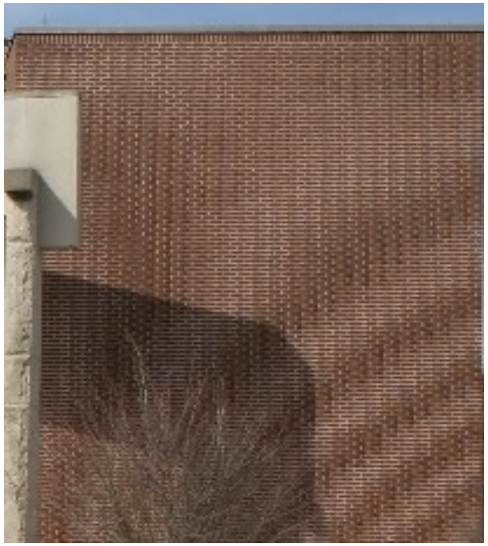
$$1080\ \begin{bmatrix} 129 & 129 & 129 & 129 & 128 & \cdots & 149 & 149 & 151 & 153 \\ 128 & 128 & 127 & 128 & 127 & \cdots & 151 & 152 & 155 & 157 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \cdots & \vdots & \vdots & \vdots & \vdots \\ 146 & 146 & 148 & 148 & 148 & \cdots & 149 & 150 & 151 & 152 \end{bmatrix} \quad \text{G}$$

$$1080\ \begin{bmatrix} 146 & 146 & 146 & 145 & 146 & \cdots & 166 & 166 & 168 & 170 \\ 145 & 145 & 144 & 144 & 145 & \cdots & 168 & 169 & 172 & 174 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \cdots & \vdots & \vdots & \vdots & \vdots \\ 159 & 160 & 160 & 161 & 162 & \cdots & 165 & 166 & 165 & 166 \end{bmatrix} \quad \text{B}$$

Cameras

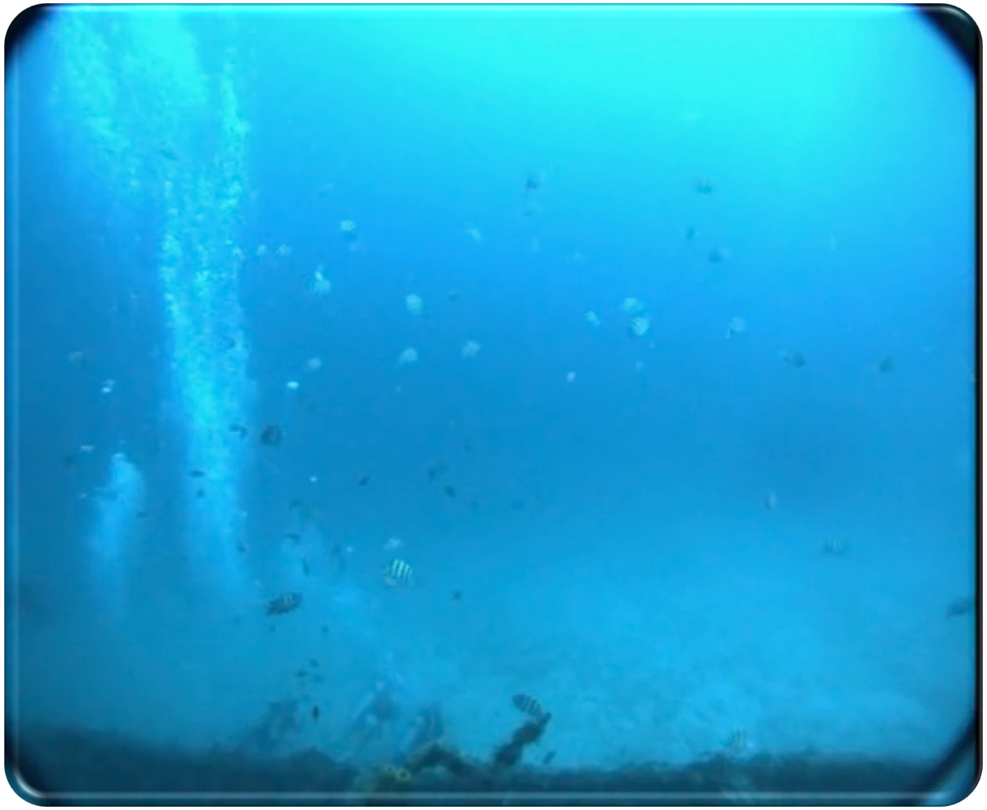
- Aliasing





Cameras

- Challenging scenarios



Cameras

- 3d structure in 2d

Cameras

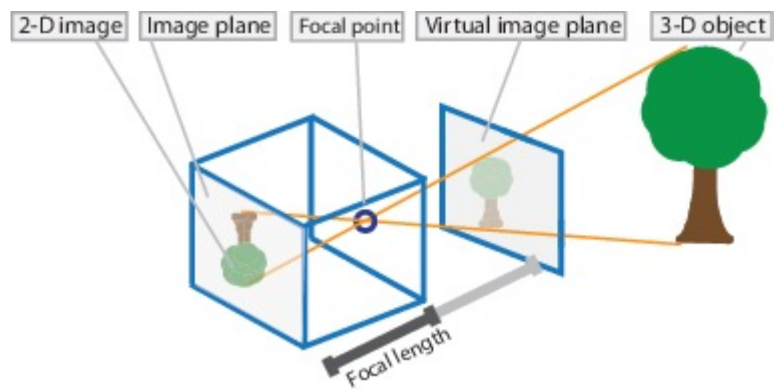
- 3d structure in 2d

Cameras

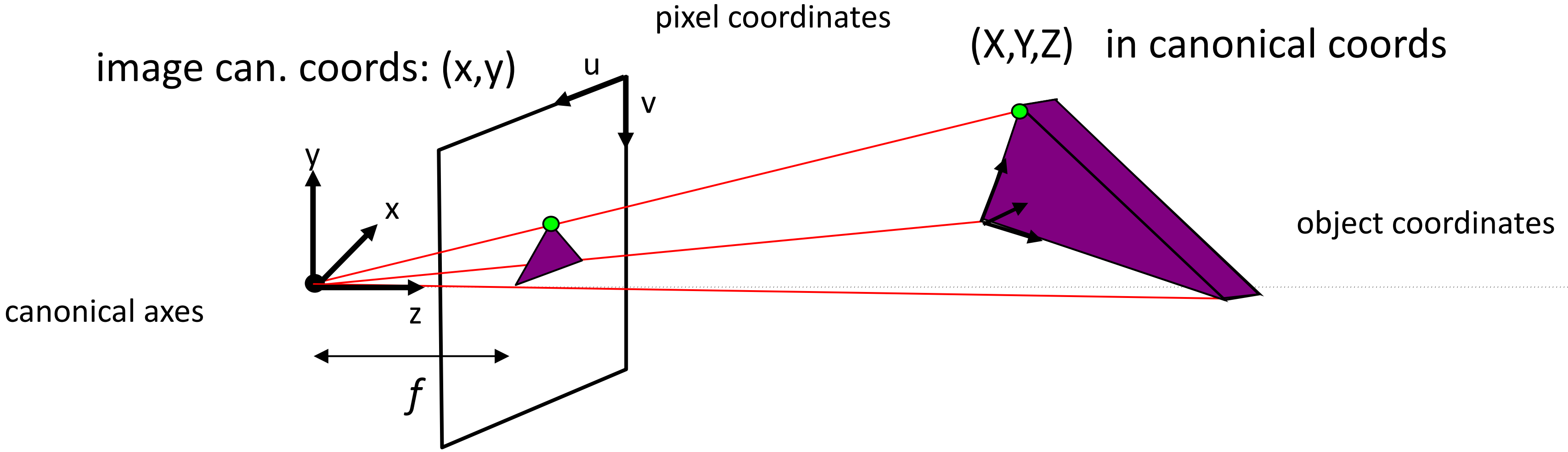
- 3d structure in 2d

Pinhole camera model

- Pinhole camera model describes the *relationship* between the coordinates of 3D points of objects in the world and its projection onto the image plane of an ideal pinhole camera

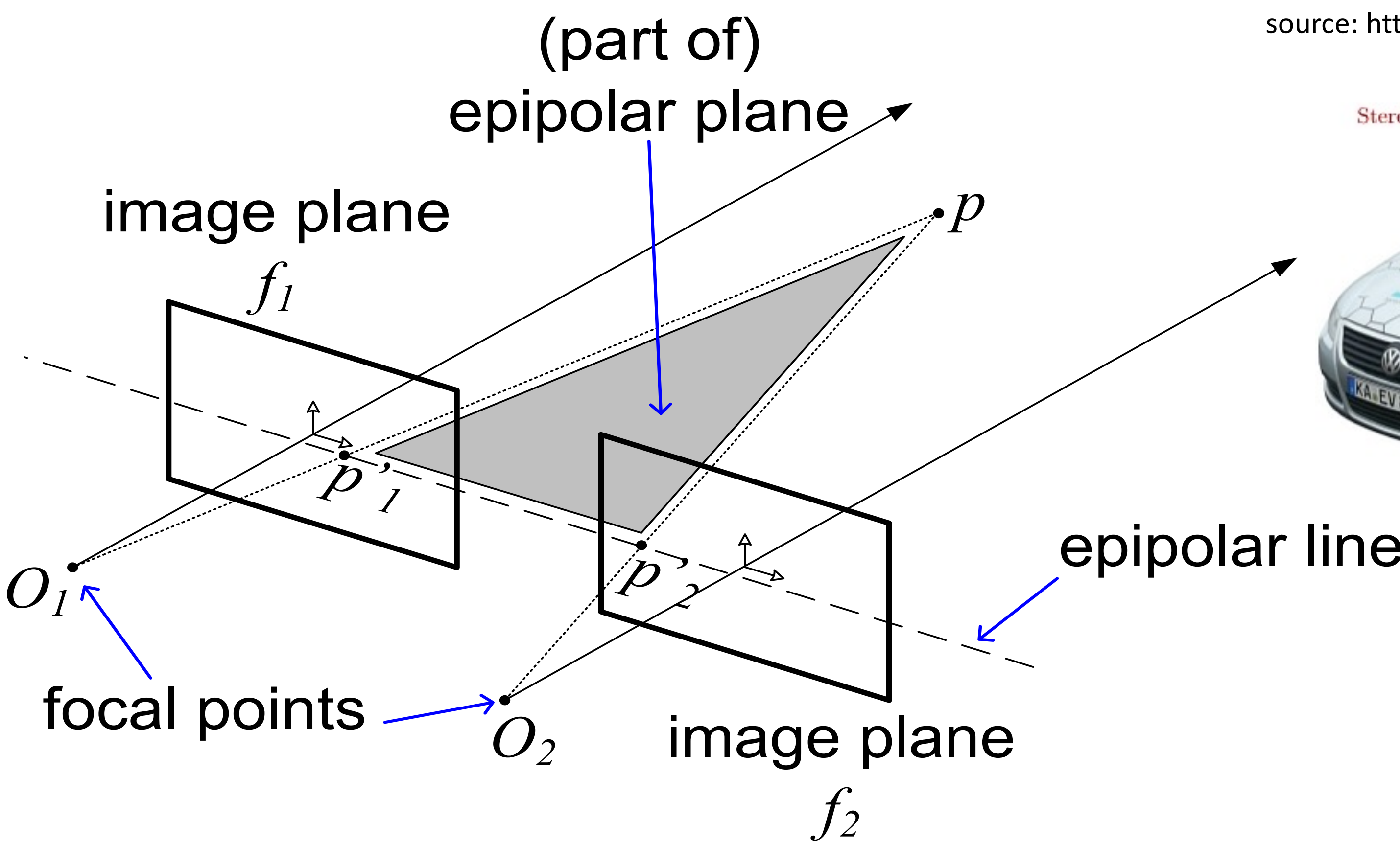


Source: mathworks.com



Stereo vision

- Stereo vision to recover depth information

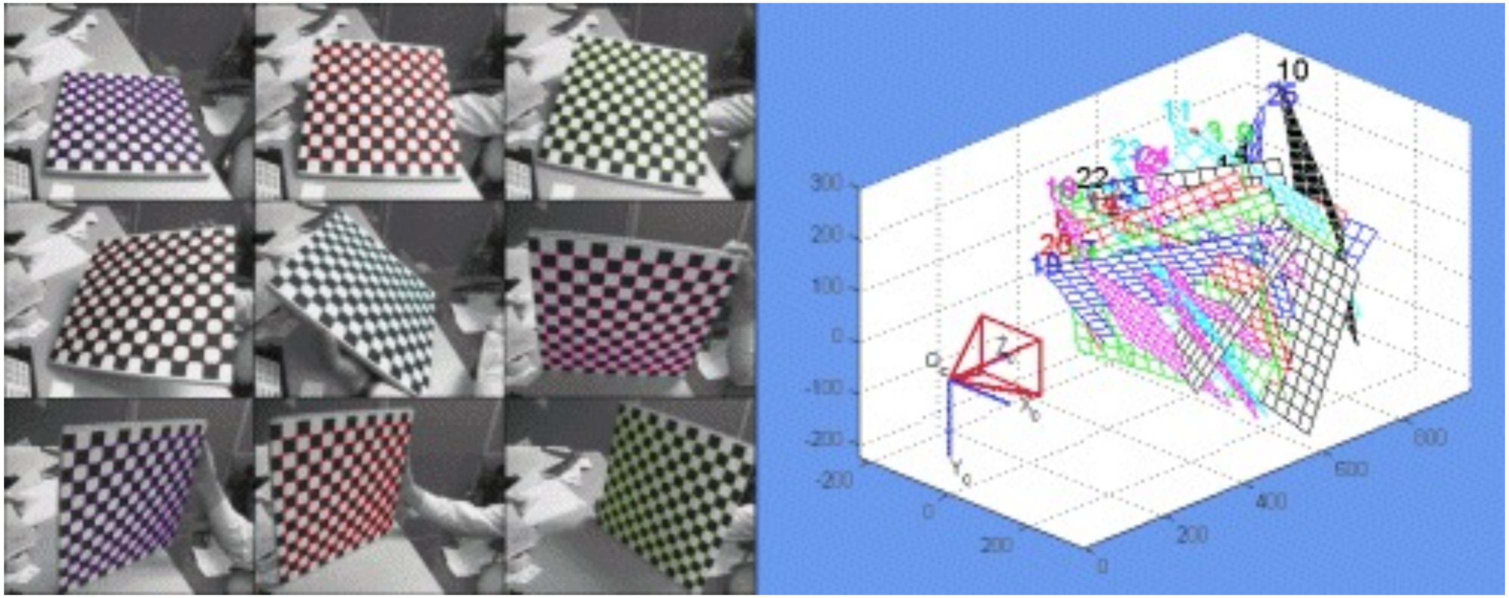


source: http://www.cvlibs.net/datasets/kitti

Camera calibration

- Camera calibration is estimating the parameters of lens and image sensor of a camera

source: vision.caltech.edu/bouguetj



Camera calibration

- These parameters can be used to correct for lens distortion, measure size of an object, or determine the location of the camera

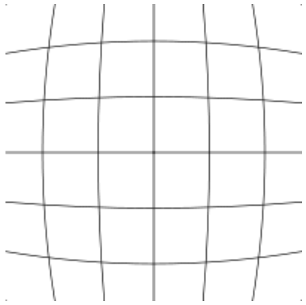
Unrectified

Rectified

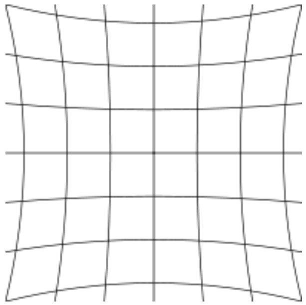
From Parrot ARDrone 2.0 front camera

LENS

- Pros:
  - Can put sensor much closer to aperture than pinhole
  - Can adjust light independent of focus (mostly)
  - Relatively easy to make at variety of focal lengths
- Cons:
  - Focal length usually fixed
  - Lens distorts image
  - Imperfections in lens distort image further



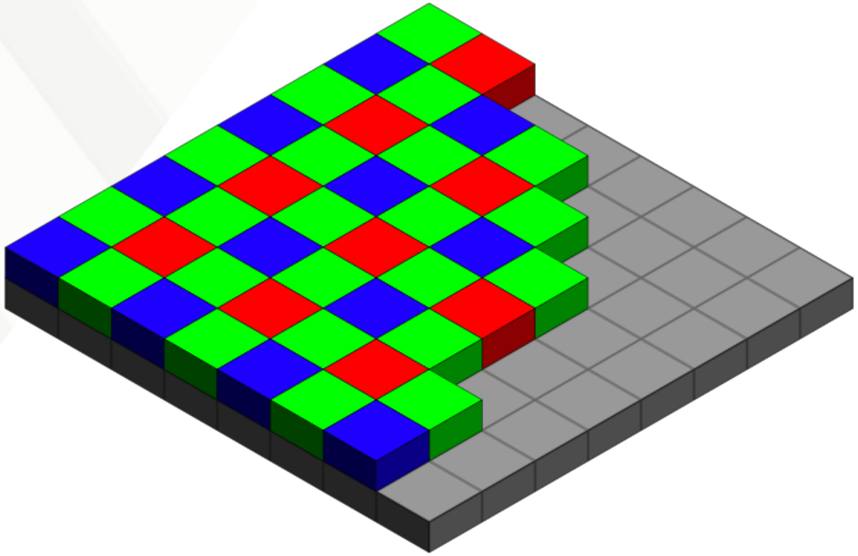
Barrel Distortion

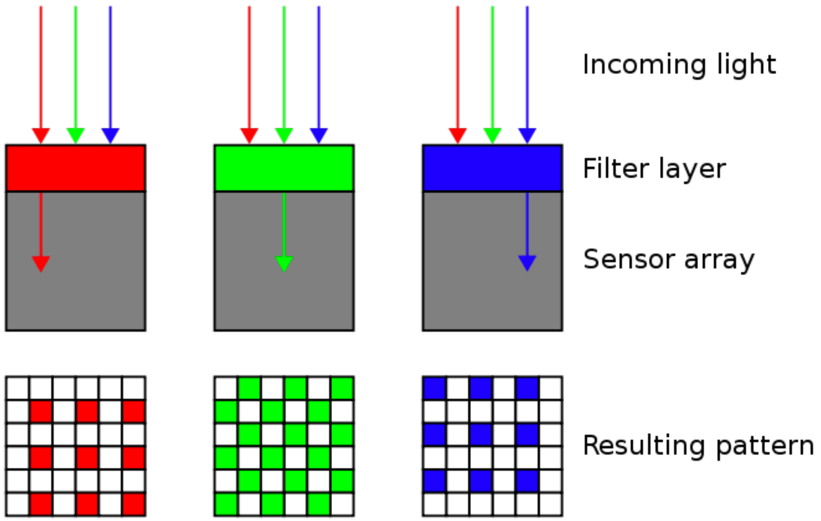


Pincushion Distortion

https://en.wikipedia.org/wiki/Distortion_(optics)

BAYER FILTER





https://en.wikipedia.org/wiki/Bayer_filter

What does a robot need?

doesn't need a full interpretation of available images

"In the middle of Assembly street, big truck coming my way, license plate number, driver has a beard, sky has clouds, leaves on trees are changing color..."

does need information about what to do...

"Get out of the way!!"

reactive

- avoiding obstacles (or predators)
- pursuing objects
- localizing itself
- Mapping
- finding targets
- reasoning about the world ...

deliberative

environmental interactions

Key problems

- Recognition:
  - What is that thing in the picture?
  - What are all the things in the image?
- Scene interpretation
  - Describe the image?
- Scene “reconstruction”:
  - What is the 3-dimensional layout of the scene?
  - What are the physical parameters that gave rise to the image?
  - What is a description of the scene?

Computer vision algorithms

- Tools necessary to solve the key problems
  - Image processing
  - Geometric computer vision
  - Semantic computer vision

OpenCV

python™

MATLAB

Java™

And many more…

REPRESENTING IMAGES

- OpenCV works really well with ROS
- Still, an OpenCV image is not quite the same as a ROS sensors_msg/Image
- Fortunately, there is an easy conversion!
  - CvBridge Class
  - imgmsg_to_cv function
  - cv_to_imgmsg function

For sending images on topics as sensor_msgs/Image

```
$ catkin_create_package <package_name> sensor_msgs cv_bridge rospy [other dependencies]
```

To convert between ROS and OpenCV image formats

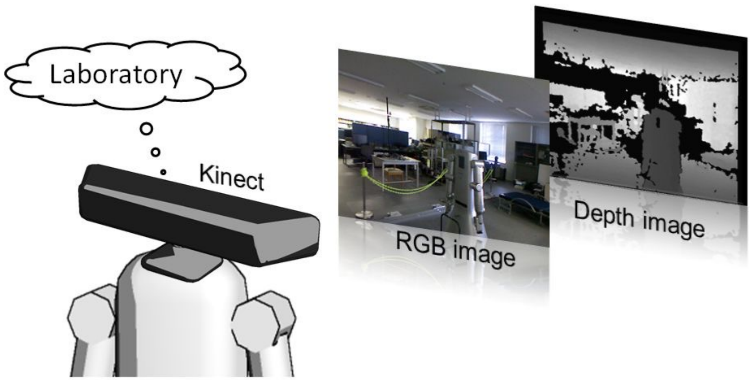
```python
#!/usr/bin/env python

import rospy
import cv2
from sensor_msgs.msg import Image
from cv_bridge import CvBridge

class ImageFlipper:
	def __init__(self):
		rospy.Subscriber("image", Image, self.flipper_cb)
		self.pub = rospy.Publisher("flipped", Image, 
		queue_size=10)
		# Instantiate the converter class once by using a class 
		member
		self.bridge = CvBridge()
	def flipper_cb(self, msg):
		# convert to a ROS image using the bridge
		cv_img = self.bridge.imgmsg_to_cv2(msg, "bgr8")
		# flip along the horizontal axis using an OpenCV function
		cv_flipped = cv2.flip(cv_img, 0)
		# convert new image to ROS to send
		ros_flipped = self.bridge.cv2_to_imgmsg(cv_flipped, 
		"bgr8")
		# publish flipped image
		self.pub.publish(ros_flipped)

if __name__=="__main__":
	# initialize our node and create a publisher as normal
	rospy.init_node("image_flipper", anonymous=True)
	img_flip = ImageFlipper()
	rospy.spin()
```

OPENCV PYTHON NOTES

- An OpenCV image is really just a 2D or 3D NumPy Array
- To access a pixel value, use array indexing:
  pixel = image[i,j,k]
  where
  - i is the row (vertical) number
  - j is the column (horizontal) number,
  - k is the color channel: 0=Blue,1= Green, 2=Red (if present)
- To create a new image that is a subset of the image use array slices:
  cropped_image = image[start_y:end_y, start_x:end_x]

RGBd Cameras

- Sensor that has a camera and IR sensor to enrich images with depth information



Source: robotics.ait.kyushu-u.ac.jp

Source: Microsoft.com

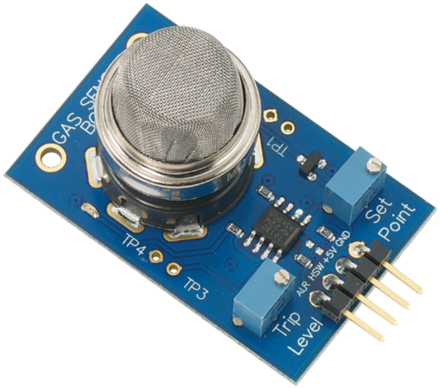
Many other sensors

- Many other sensors can be found for measuring different physical quantities

Depth/Pressure sensor

Source: bluerobotics.com

Gas sensor



Source: parallax.com

Sonde that includes sensor for measuring different water quantities, including water temperature, chlorophyll, pH level

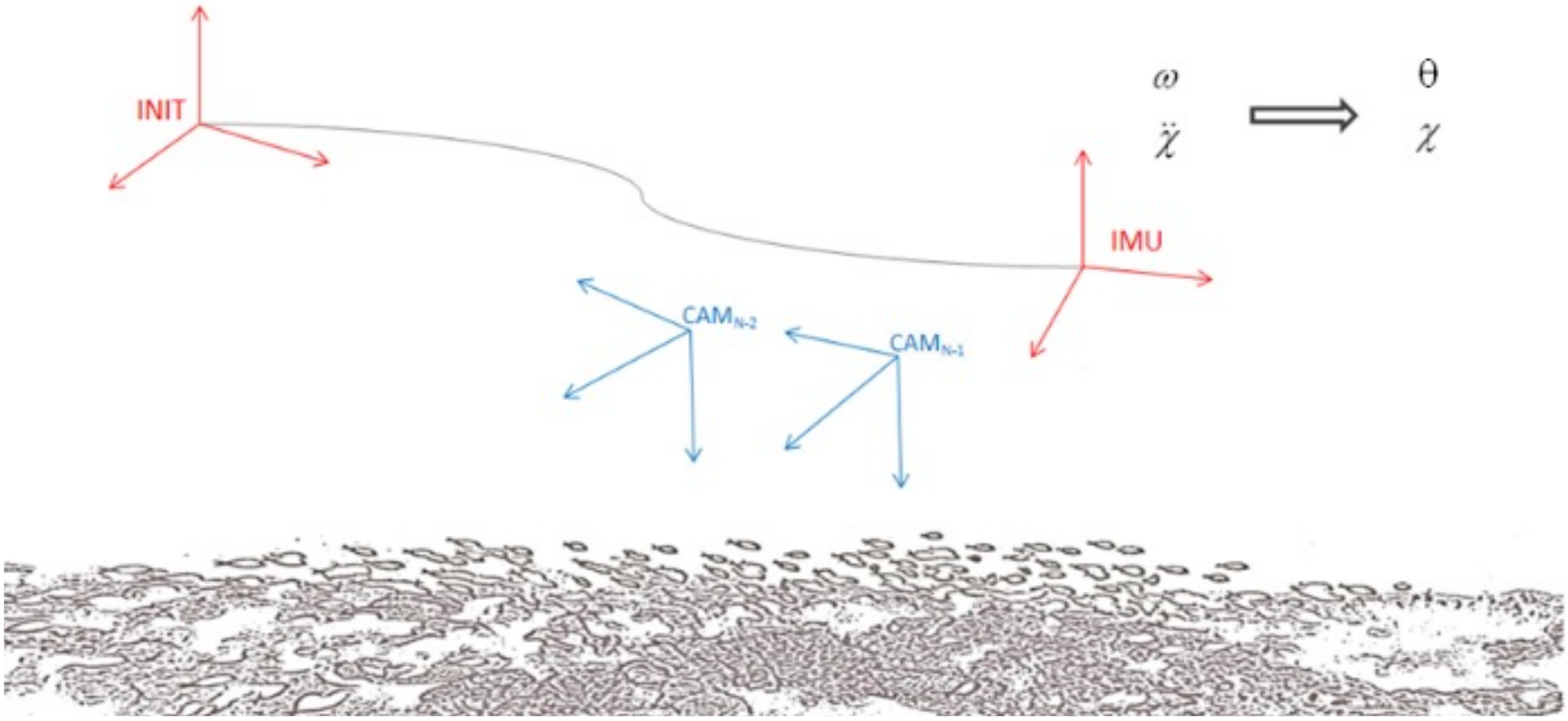
Source: ysi.com

State Estimation

- The use of sensor data allows to estimate the state of the robot and the world

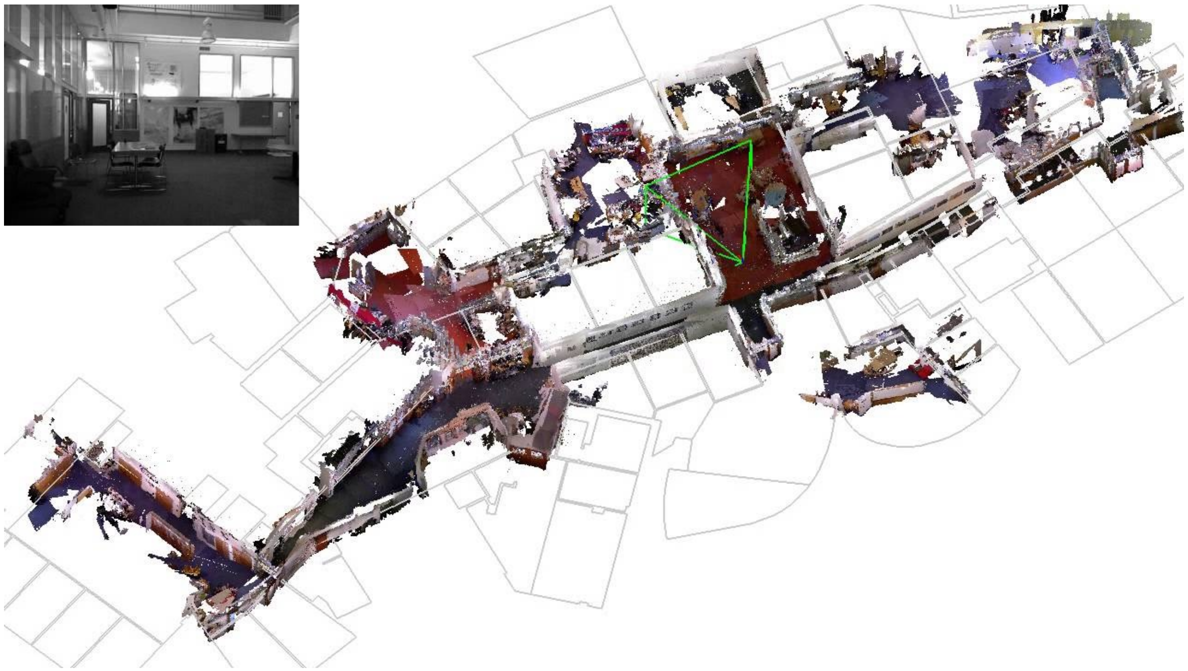
Localization

- Where am I?



Mapping

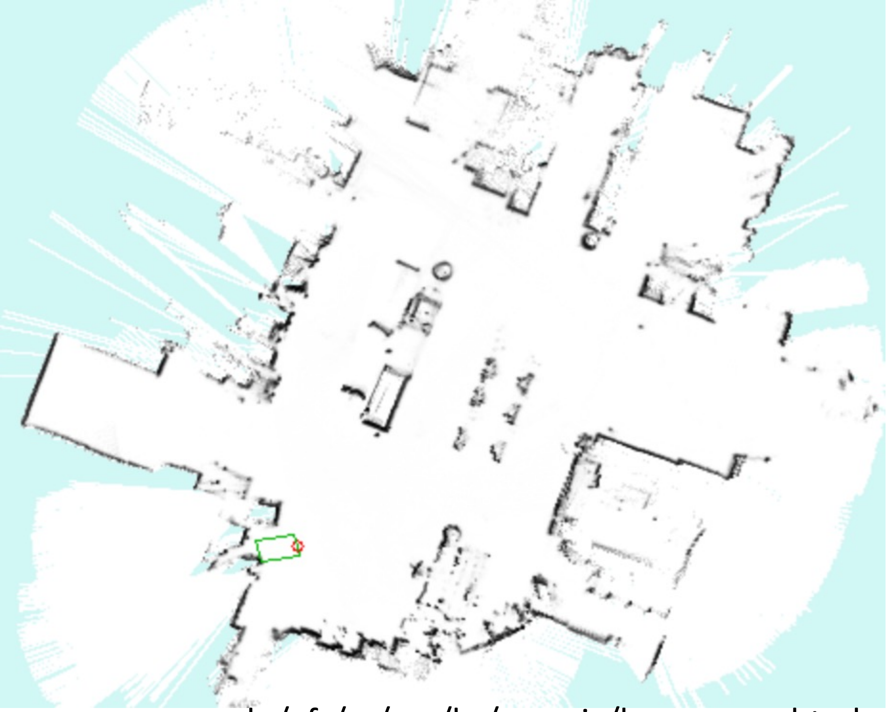
- What the world looks like



Source: http://people.csail.mit.edu/hordurj/

Simultaneous Localization and Mapping

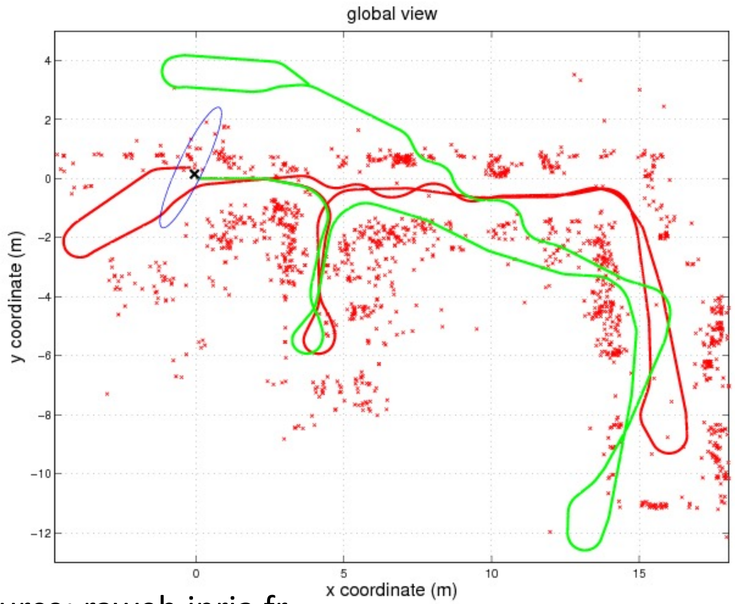
- Localization and Mapping together form the problem of SLAM



Source: cs.cmu.edu/afs/cs/usr/br/mosaic/homepage.html

State estimation process

- Fusing sensor data
- Update the state of the robot
- Adjust it according to observations



Source: raweb.inria.fr