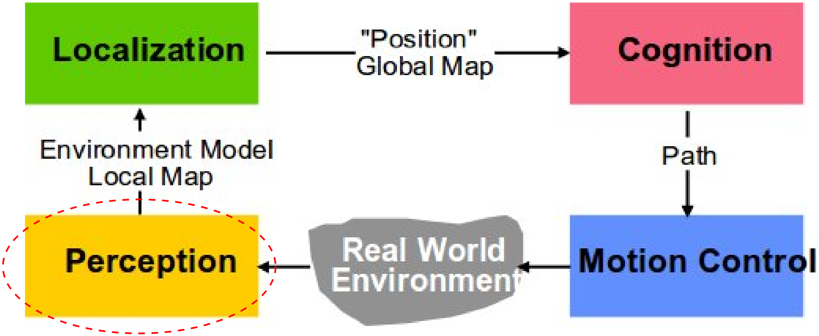
Robotics and Autonomous Systems

Lecture 7: Perception

Terry Payne

Department of Computer Science
University of Liverpool

Today



- We'll finish talking about perception.

Classification of sensors

- Proprioceptive sensors

- Exteroceptive sensors

- Passive sensors
- Active sensors

Classification of sensors

- Proprioceptive sensors
  - Measure values internally to the system (robot)
    (motor speed, wheel load, heading of the robot, battery status).
- Exteroceptive sensors
  - Information from the robots environment
    (distances to objects, intensity of the ambient light, unique features).
- Passive sensors
  - Energy coming from the environment.
- Active sensors
  - Emit their own energy and measure the reaction.
  - Better performance, but some influence on environment.

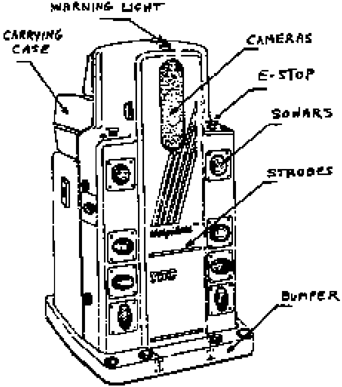
Classification of sensors

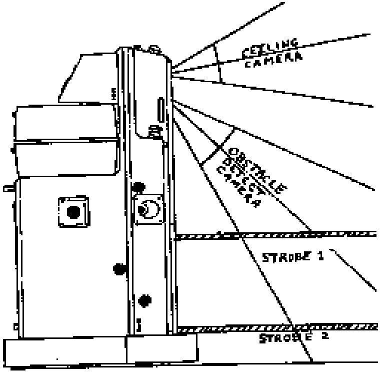
- Proprioceptive sensors
  - Measure values internally to the system (robot),
    (motor speed, wheel load, heading of the robot, battery status).
- Exteroceptive sensors
  - Information from the robots environment
    (distances to objects, intensity of the ambient light, unique features).
- Passive sensors
  - Energy coming from the environment.
- Active sensors
  - Emit their own energy and measure the reaction.
  - Better performance, but some influence on environment.

Classification of sensors

- Proprioceptive sensors
  - Measure values internally to the system (robot), (motor speed, wheel load, heading of the robot, battery status)
- Exteroceptive sensors
  - Information from the robots environment (distances to objects, intensity of the ambient light, unique features.)
- Passive sensors
  - Energy coming from the environment.
- Active sensors
  - Emit their own energy and measure the reaction
  - Better performance, but some influence on envrionment

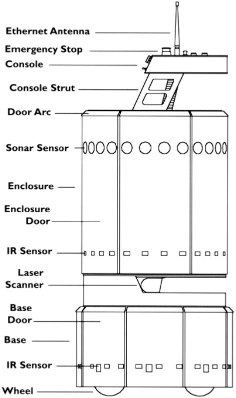
Helpmate





- Note that the robot has a number of different sensors.

B14 and B21


Ethernet Antenna
Emergency Stop
Console
Console Strut
Door Arc
Sonar Sensor
Enclosure
Enclosure Door
IR Sensor
Laser Scanner
Base Door
Base
IR Sensor
Wheel


RWI

Xavier

- Built at CMU.

Sensors include bump panels, a Denning sonar ring, a Nomadics laser light striper, and twin cameras mounted on a Directed Perception pan/tilt head for stereo vision.

- Also includes a 4-wheel synchrodrive.

BibaBot

- Omnidirectional and pan/tilt camera.
- Sonar
- Wheel encoders
- Laser range finder
- Bumpers

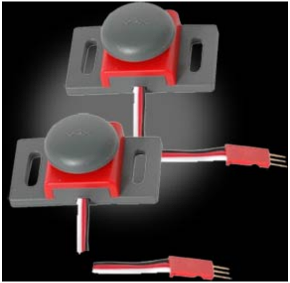
- BlueBotics SA, Switzerland

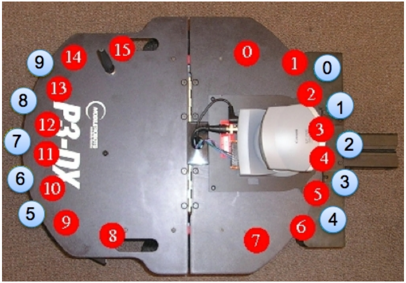
Sensor characteristics

- Range
  - The upper limit that a sensor can measure.
- Linearity
  - Variation of output signal as function of the input signal.
  - Less important when signal is post-processed.
- Bandwidth or Frequency
  - The speed with which a sensor can provide readings
  - Usually an upper limit. Depends on sensor and the sample rate.
  - Lower limit is also possible, e.g. acceleration sensor.
- Resolution
  - Minimum difference between two values. Usually the lower limit of dynamic range.
  - For digital sensors it is usually the A/D resolution. (e.g. 5V / 255 (8 bit))

Bumpers

- You should be a bit familiar with the bumper on our NXT robot by now.
    - Each bumper says when it has hit something.
- Bumpers are just contact switches — indicate when they are pressed.





- While our NXT robot has just two bumpers, a robot can have many.

Range sensors

- Large range distance measurement → called range sensors.
- Range information is the key element for localization and environment modeling.
- Ultrasonic sensors, infra-red sensors and laser range sensors make use of propagation speed of sound or electromagnetic waves respectively.
- The distance traveled by a sound or electromagnetic wave is given by

$$d = c.t$$

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

Ultrasound (sonar) sensor

- Transmit a packet of (ultrasonic) pressure waves
- Distance d of the echoing object can be calculated based on the propagation speed of sound c and the time of flight t.

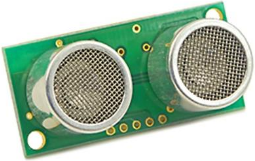
$$d = \frac{c.t}{2}$$

- The speed of sound c (340 m/s) in air is given by:

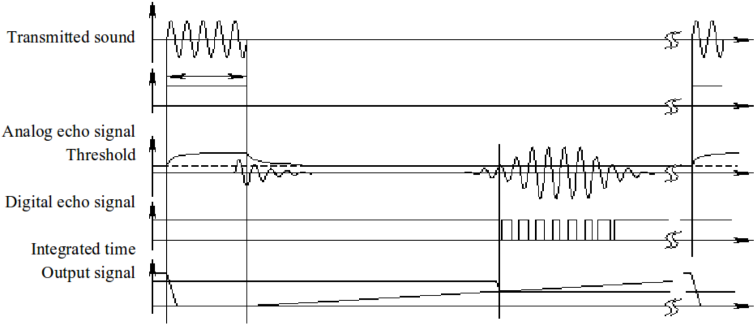
$$c = \sqrt{\gamma.R.T}$$

where:

  - γ : ratio of specific heats
  - R: gas constant
  - T: temperature in degree Kelvin

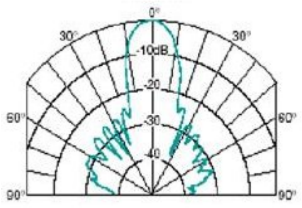


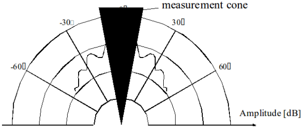
Sonar timing



What gets measured

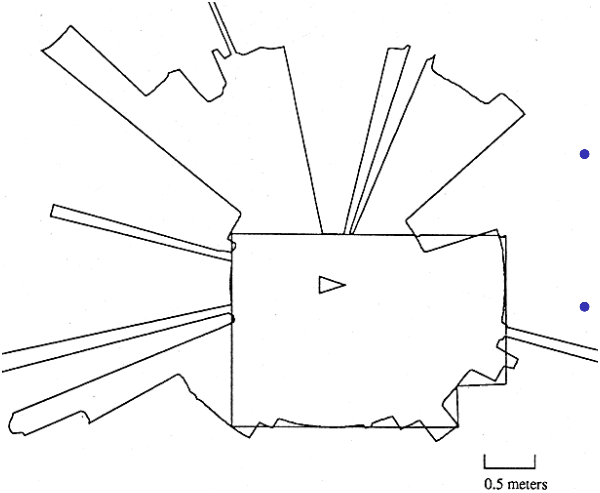
- Sound beam propagates in a cone.
- Opening angles around 20 to 40 degrees
- Detects regions of constant depth on segments of an arc





- Piezo electric transducer generates frequency: 40 – 180 kHz

Typical sonar scan



- Specular reflection from non-perpendicular surfaces.
- Absorption from soft surfaces.

- Note that in places the result is far from accurate.

- To use the sonar you first need to link the right library:

  ```
  import lejos.nxt.UltrasonicSensor;
  ```

- Then you need to create an instance of the sensor:

  ```
  UltrasonicSensor us = new
  UltrasonicSensor(SensorPort.S1);
  ```

  (make sure you use the right port for your robot).

- Then you can read the distance of the nearest object in front of the robot:

  ```
  us.getRange();
  ```

- You will likely want to use the sonar in your first assignment, so get familiar with it.

Laser range finder

- A laser range-finder uses light rather than sound.

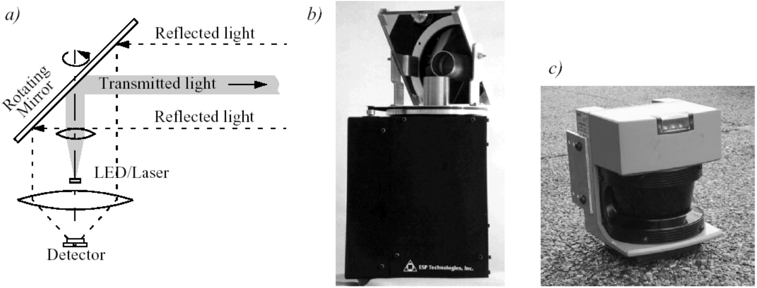
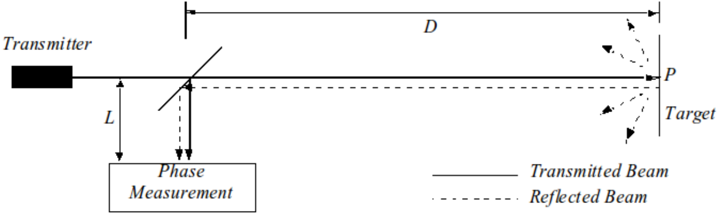


Figure 4.11
(a) Schematic drawing of laser range sensor with rotating mirror; (b) Scanning range sensor from EPS Technologies Inc.; (c) Industrial 180 degree laser range sensor from Sick Inc., Germany

- The rotating mirror allows the laser to take many measurements.

Laser range finder

- For any wave, speed is related to frequency and wavelength by: $c = f.\lambda$

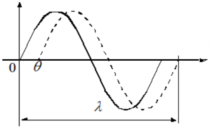


- The total distance covered by the light is:

$$distance = L + 2D = L + \frac{\theta}{2\pi}\lambda$$

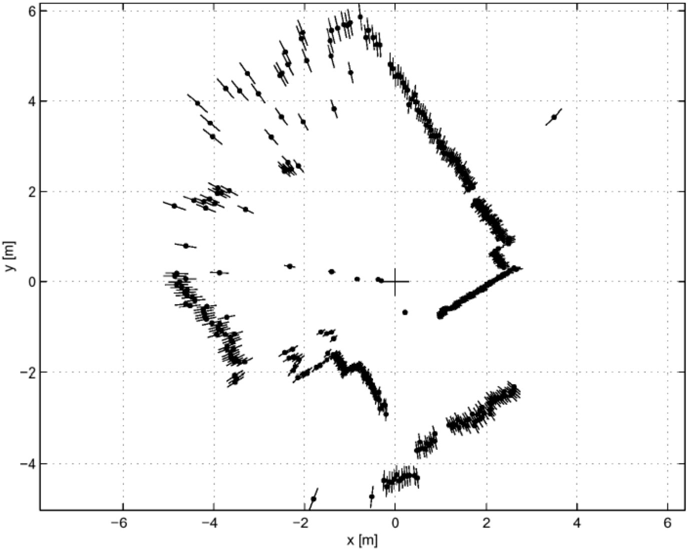
- The distance of the target is then:

$$D = \frac{\lambda}{4\pi}\theta$$



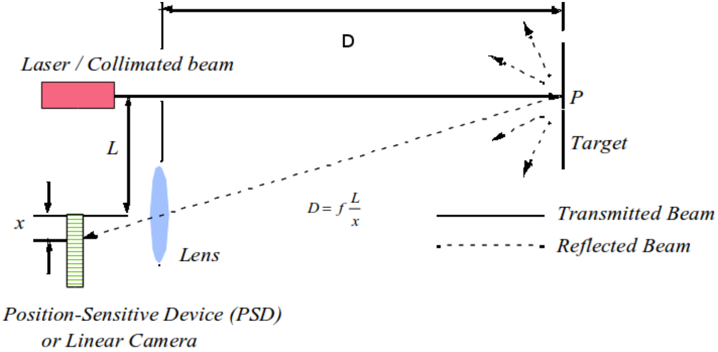
where θ is the phase shift.

Typical laser scan



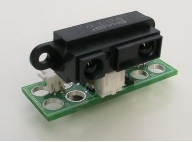
- Length of bars is an estimate of the error.

IR distance sensor



- Distance is inversely proportional to x

$$D = f\frac{L}{x}$$



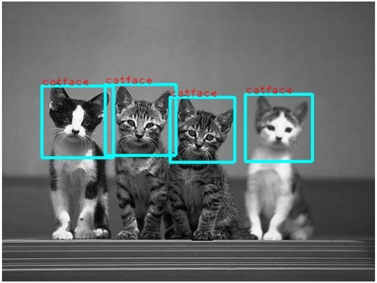
State of the art

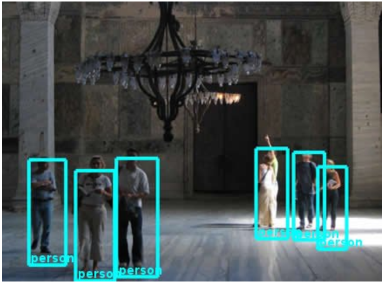
- Hokuyu manufacture a cheap laser scanner.

- The Kinect has made accurate range-finder data much cheaper to acquire.

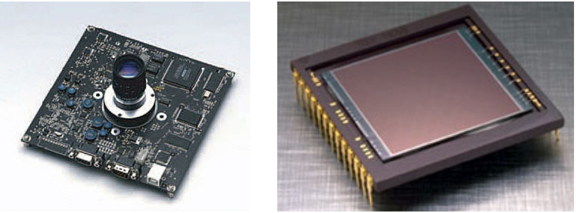
Vision

- Vision is the sense that humans rely upon most.
- It provides the means to gather lots of data very quickly.
- Attractive for use on robots which are often data-poor.
- However, presents a new challenge
    - How can we extract data from an image
    - Or from a sequence of images.

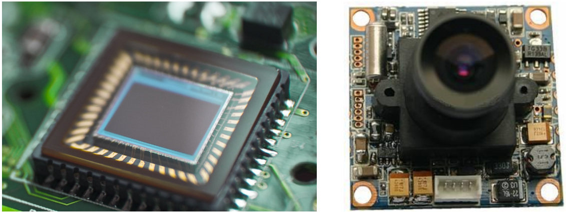




Cameras



- Today, with cheap CMOS cameras, the hardware cost of adding a camera to a robot is negligible.



Vision

- Although vision seems to be easy for humans, it is hard for machines.

  (as always, remember how long it takes us to learn to “see”).
- Reasons include:
  - variable illumination,
  - uncontrolled illumination,
  - shadows,
  - irregular objects,
  - occulsion of objects,
  - noisy sensors,
  - . . .
- Typically these problems are worse outside.

Vision

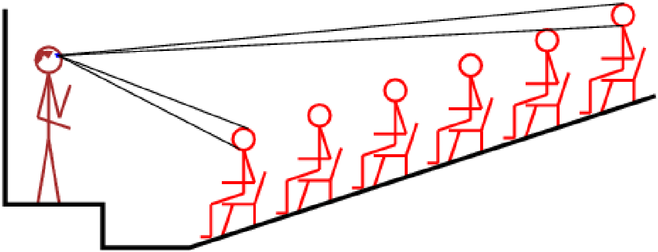
- The lens produces a perspective projection of the scene.
- The 3-d scene becomes a 2-d image:

  $$I(x, y, t)$$

  x and y are the co-ordinates of the array, t is time.
- The image is just an array.
- Well, typically 3 arrays — each with one entry per pixel in the image.
  - Why?
- These must be processed to extract the information that we need.

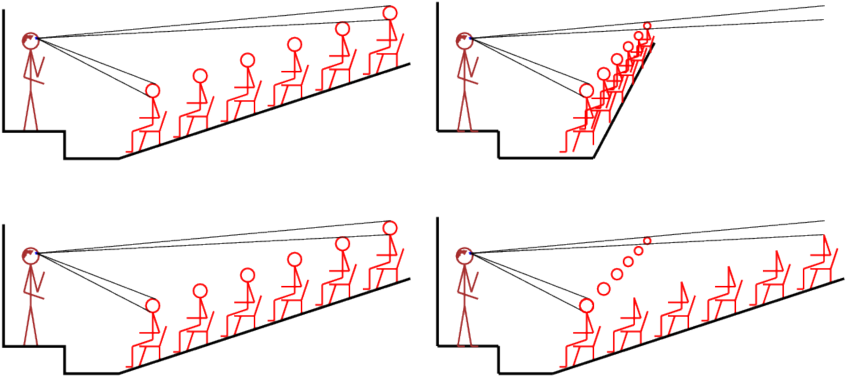
Problems in processing

- The projection from 3D to 2D introduces massive ambiguity.



- What the camera sees in one view can be generated by many different scenes.

Problems in processing



Vision techniques

- We will look briefly at a couple of basic computer vision techniques.
- These don’t come close to solving the general vision problem.
    - Nobody has come close to solving that.
- However, they give us some ways to extract data that can help our robots in some domains.
- Where we know what to expect, we can look for it.

Color segmentation

- An image is a two dimensional array of pixels.
- Each pixel is a set of three values:

  $$\langle red, green, blue \rangle$$

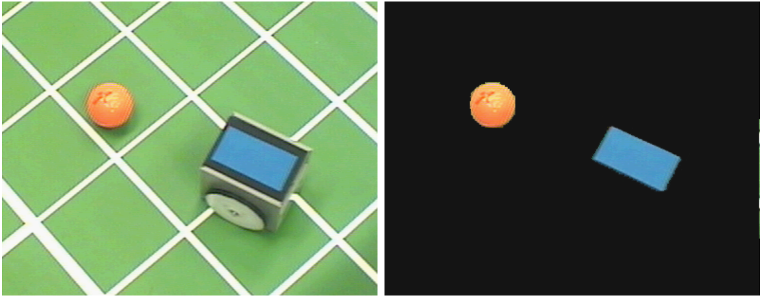
  typically with a value between 0 and 255 (8 bit).
- (Well, most computer vision uses something other than RGB, but the principle is the same.)
- Define a color you want to recognise as a box in RGB space:

  $$\begin{aligned} red &\in [30, 100] \\ blue &\in [70, 120] \\ green &\in [150, 230] \end{aligned}$$

- Label each pixel 1 if it falls in the box, 0 if it falls outside the box.

Color segmentation

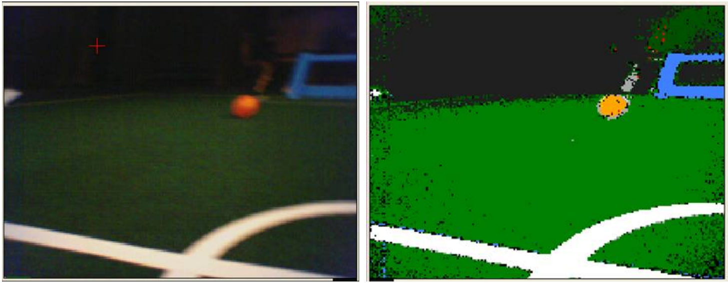
- Result is a set of “blobs” which, if you calibrated correctly, identify objects of interest.



- Example: segmentation in robot soccer.

Color segmentation

- Result is a set of “blobs” which, if you calibrated correctly, identify objects of interest.

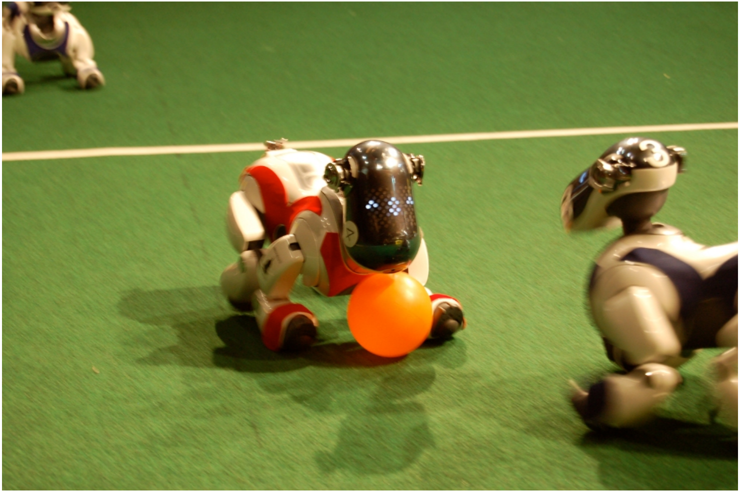


- Example: segmentation in robot soccer.

What you can do with a segmented image

- Object identification:
  - “I see an orange blob” means “I see the ball”.
- Object tracking:
  - Keep the orange blob in the center of the frame.
- Limited navigation:
  - Walk towards the orange blob.
  - When you get to the orange blob, kick it towards the blue blob.
- Localization.
  - Measure angles of blue and yellow blobs to me.
  - If I know the location of the blobs, I can tell where I am.

Works well enough for some applications



Edge detection

- We often want to identify edges.
- We can then use the edges to identify shapes that we are looking for in an image.
- What we do has a mathematical interpretation in terms of convolution, but there's also a simple way to think about this.
- Edges are all about changes in color (in a color image) or intensity (in a black and white image).
- So identifying pixels that are on an edge is relatively easy.
  - We look for sudden changes in R, G and B in a color image or the single value in a b/w image.

Edge detection

- Gives us something like:

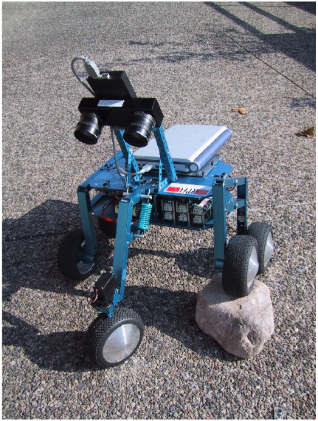
Edge detection

- Often edge detection gives us many mini-edges that need to be merged or removed:

Edge detection

- Pre-processing the image can also help.
- For example, noise can be removed by smoothing the image.
    - Averaging across the pixel values.
- For example we might replace the value of every pixel by the average of the values of the 8 pixels around it.
- The larger the area we average over, the more robust the results are against noise.
- Of course, all this processing is expensive, and slows down the speed of reaction of the robot.

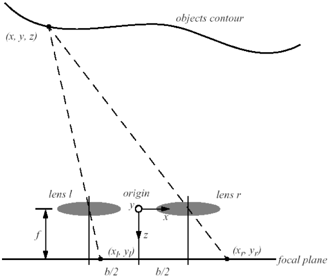
Stereo vision



- Two cameras, spaced as widely as possible.
- Can get depth information if we can identify the common point(s) in two images.

Stereo vision

$$\begin{aligned} x &= b\left(\frac{x_l + x_r}{2(x_l - x_r)}\right) \\ y &= b\left(\frac{y_l + y_r}{2(x_l - x_r)}\right) \\ z &= b\left(\frac{f}{x_l - x_r}\right) \end{aligned}$$

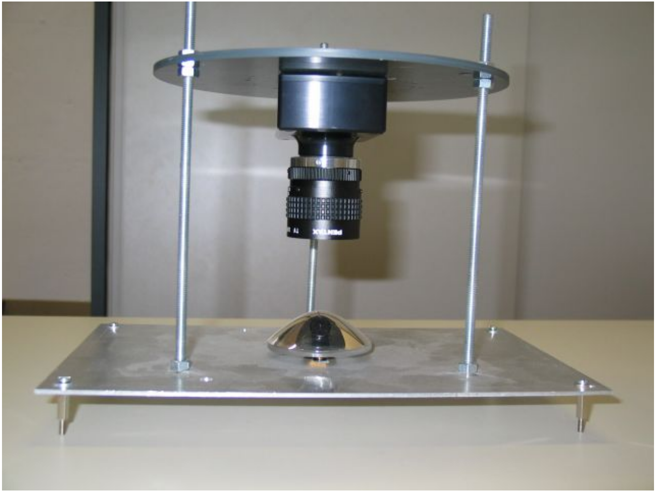


- The accuracy of the depth estimate increases with increasing baseline *b*.

Using stereo vision

- Also equipped with several other sensors.

The current frontier

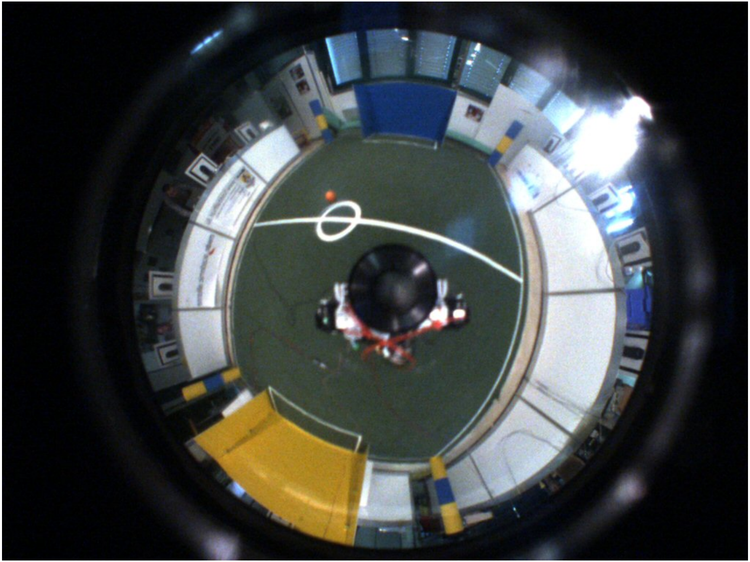


- Omnidirectional cameras allow robots to see all around them.
    - Usually mounted with the lens above the camera.

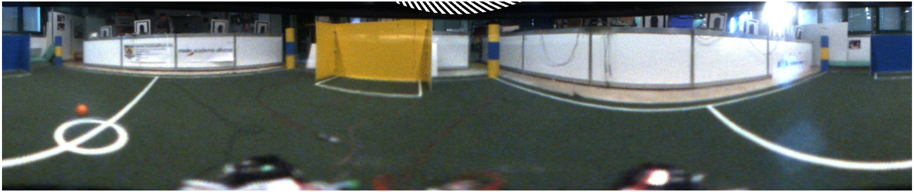
The current frontier

- Presents new challenges in machine vision.

The current frontier



The current frontier



Summary

- This lecture finished our look at sensors and perception.
- We spent most of our time looking at:
  - Range sensors
  - Cameras and image data.
- These are probably the most widely used sensors in robotics today.