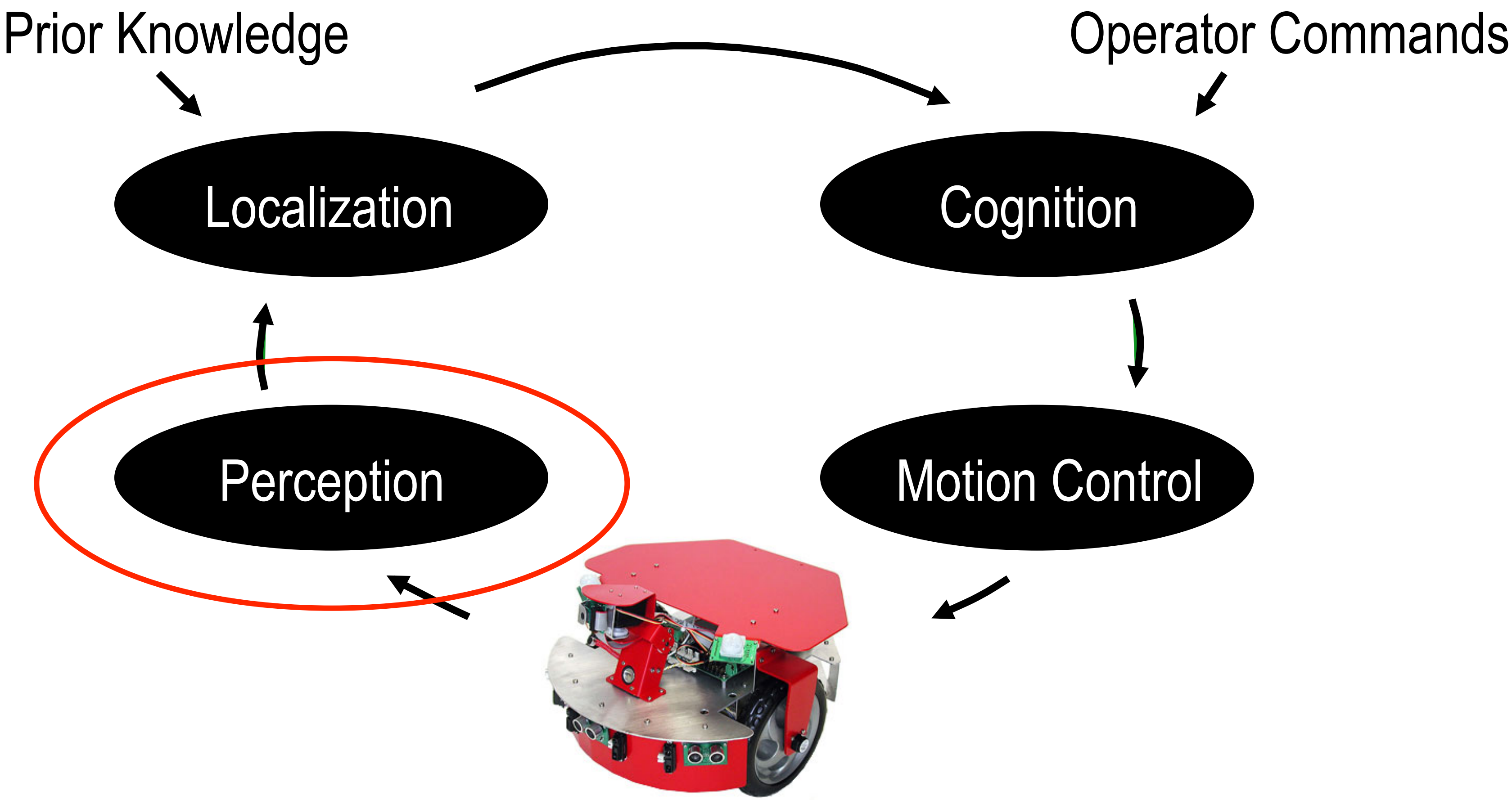
COS 495 - Lecture 8
Autonomous Robot Navigation

Instructor: Chris Clark

Semester: Fall 2011

Figures courtesy of Siegwart & Nourbakhsh

Control Structure



Sensors: Outline

Sensor Examples

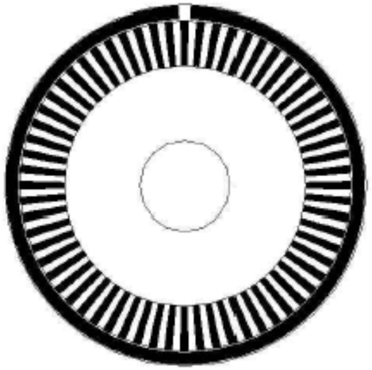
1. Encoders
2. Range Sensors
3. Heading Sensors

Sensors: Encoders

- A digital optical encoder is a device that converts motion into a sequence of digital pulses. By counting a single bit or by decoding a set of bits, the pulses can be converted to relative or absolute position measurements.
  - Optical encoders are Proprioceptive sensors
  - Can integrate signal to obtain robot position

Sensors: Encoders

- Most encoders are composed of a glass or plastic code part with a photographically deposited pattern organized in tracks. As lines in each track interrupt the beam between a photoemitter-detector pair, digital pulses are produced.



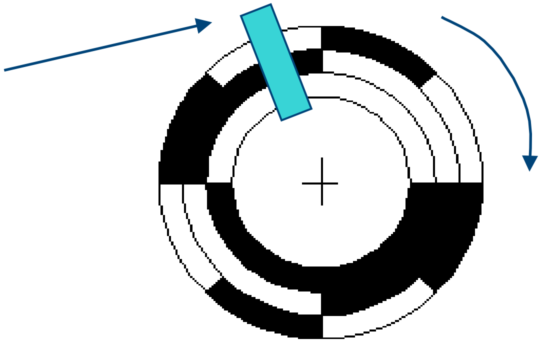
Sensors: Encoders

- There are two main types
  1. Absolute encoders – which measure the current orientation of a wheel.
  2. Incremental encoders – which measure the change in orientation of a wheel.

Sensors: Encoders

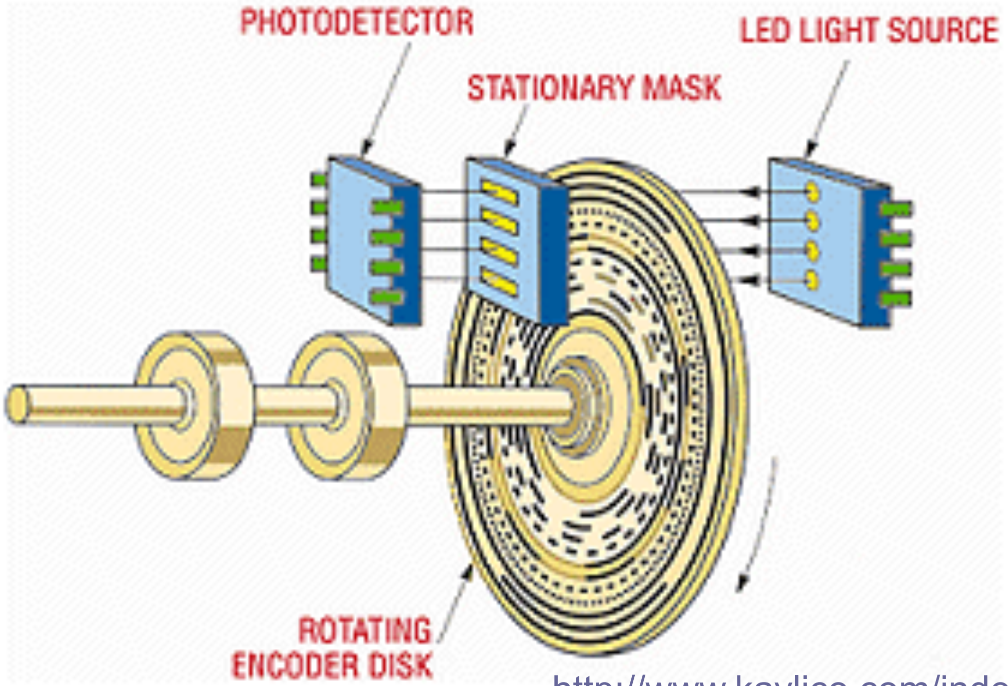
- Absolute Encoder
  - The optical disk of the absolute encoder is designed to produce a digital word that distinguishes *N* distinct positions of the shaft.

Checks each track E.g. 101



Sensors: Encoders

- Absolute Encoder
  - 12 track example:



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Sensors: Encoders

- Absolute Encoder
  - The resolution of the encoder will depend on the number of tracks. Each track is either clear or black (1 or 0), giving 2^T possible combinations for T tracks.
  - For the example above, there are 3 tracks, yielding 8 possible combinations of track readings. Divided among 360 degrees, this leaves a resolution of 360/8 = 45 degrees.
  - *Disadvantage*: Needs a larger disk or strip for higher resolution

Sensors: Encoders

- Gray Code:
  - The most common types of numerical encoding used in the absolute encoder are gray and binary codes
  - Gray code uses an ordering of binary numbers such that only one bit changes from one entry to the next.
  - Gray codes for 4 or more bits are not unique.

Sensors: Encoders

- Gray Code:

Gray Code	Binary
0000	0000
0001	0001
0011	0010
0010	0011
0110	0100
0111	0101
0101	0110
0100	0111
1100	1000
1101	1001
1111	1010
1110	1011
1010	1100
1011	1101
1001	1110
1000	1111

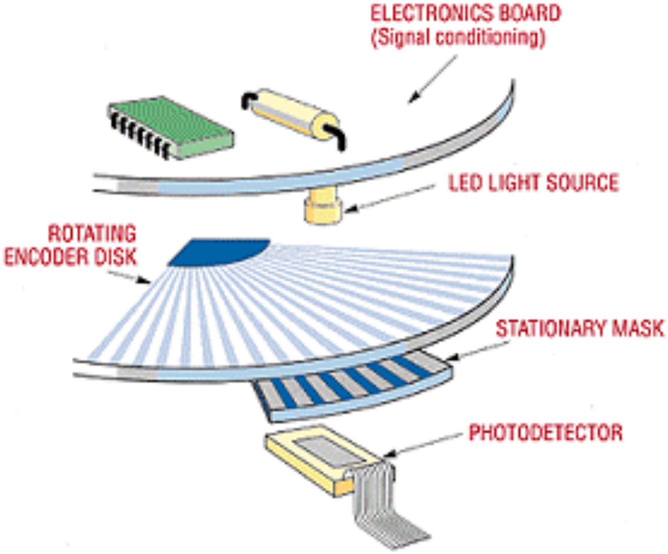
  - Gray codes for 4 or more bits are not unique

Sensors: Encoders

- Why Gray Code?
  - Gray code is used is to eliminate errors that occur due to timing inconsistencies.
  - When a disk moves from one position to the next, the different bit flips will occur at different times.
  - Example:
    - When changing from 0011 to 0100, three different bits get flipped. If these happen at different times, the encoder could spit out 0011, 0111, 0101, 0100. This gives 2 erroneous measurements.

Sensors: Encoders

- Incremental Encoders
  - Incremental encoders operate by means of a grating moving between a light source and a detector.



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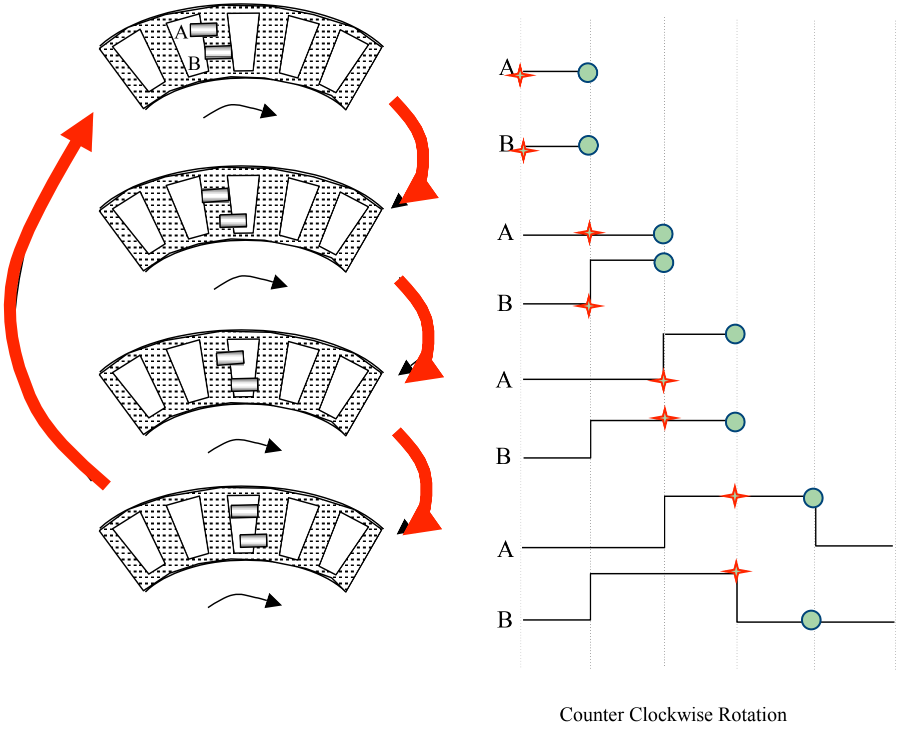
Sensors: Encoders

- Incremental Encoders
  - They need a reference for position measurement.
  - Higher resolution can be obtained more easily.
  - Needs a decoder to detect direction and position/ velocity.

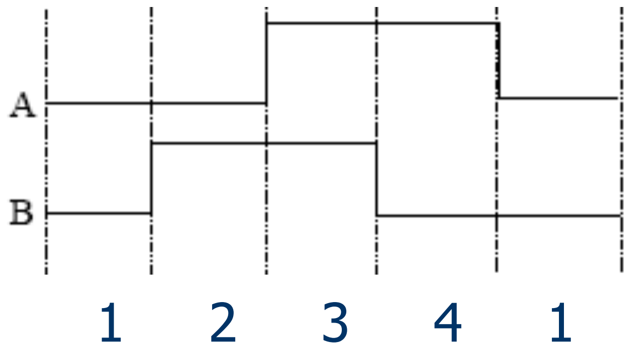
Sensors: Encoders

- Incremental Encoders
  - 4X Decoding:



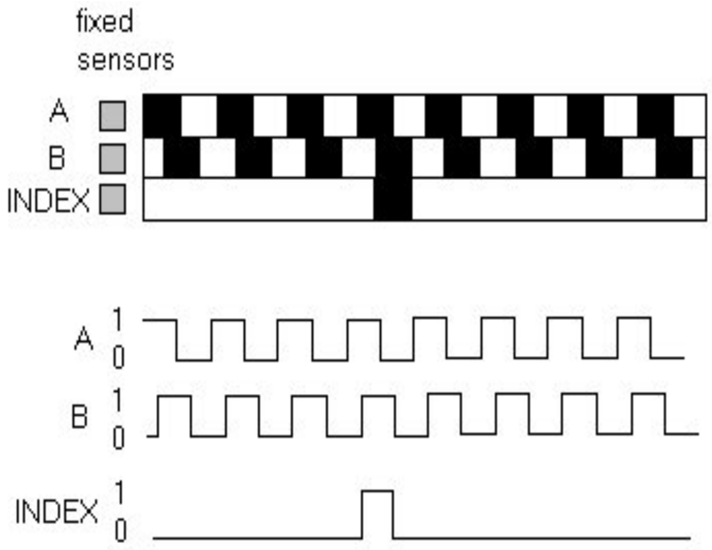
Sensors: Encoders

- Incremental Encoders
  - 4X Decoding: Resolution is 360/4N, where N is the number of gratings.



Sensors: Encoders

- Incremental Encoders
  - Example:
    - Encoder with 2 tracks instead of 2 sensor positions.
    - Home position track.



Sensors: Outline

Sensor Examples

1. Encoders
2. Range Sensors
3. Heading Sensors

Sensors: Range Sensors

- Range sensors make use of propagation speed of sound or electromagnetic waves respectively.
- Distance traveled by a wave is given by:

$$d = c\,t$$

d = distance traveled

c = speed of wave propagation

t = time of flight

Sensors: Range Sensors

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

Sensors: Range Sensors

- Quality of range sensors depend on:
  - *Uncertainties of time of arrival of reflected signal*
  - *Inaccuracies in time of flight measure (laser)*
  - *Opening angle of transmitted beam (sound)*
  - *Interaction with the target (specular reflections)*
  - *Variation of propagation speed*

Sensors: Ultrasonic Range Sensors

- Sensor transmits a packet of ultrasonic pressure waves

$$d = c\,t / 2$$

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

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

γ = *ratio of specific heats*

R = *gas constant*

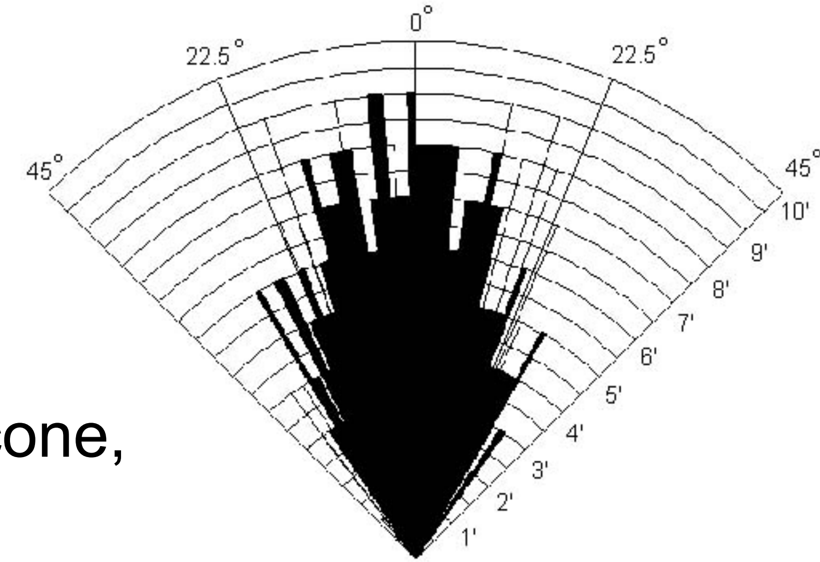
T = *temperature in Kelvin*

Sensors:
Ultrasonic Range Sensors

Signals of an ultrasonic sensor

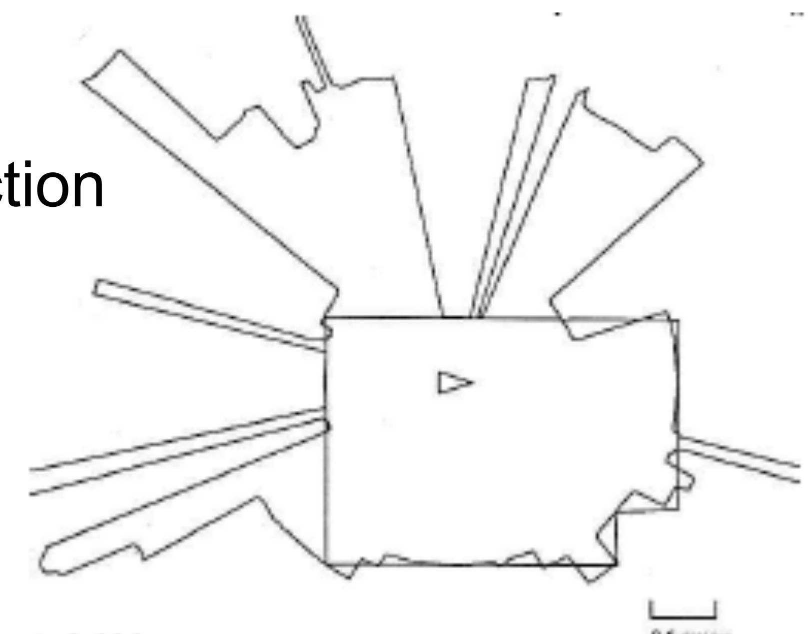
Sensors: Ultrasonic Range Sensors

- Frequency typically 40 – 180 kHz
- Wave generated by piezo transducer
- Receiver may coincide with transmitter
  - Problem with objects too close, Blanking time!
- Sound beam propagates in cone, not points



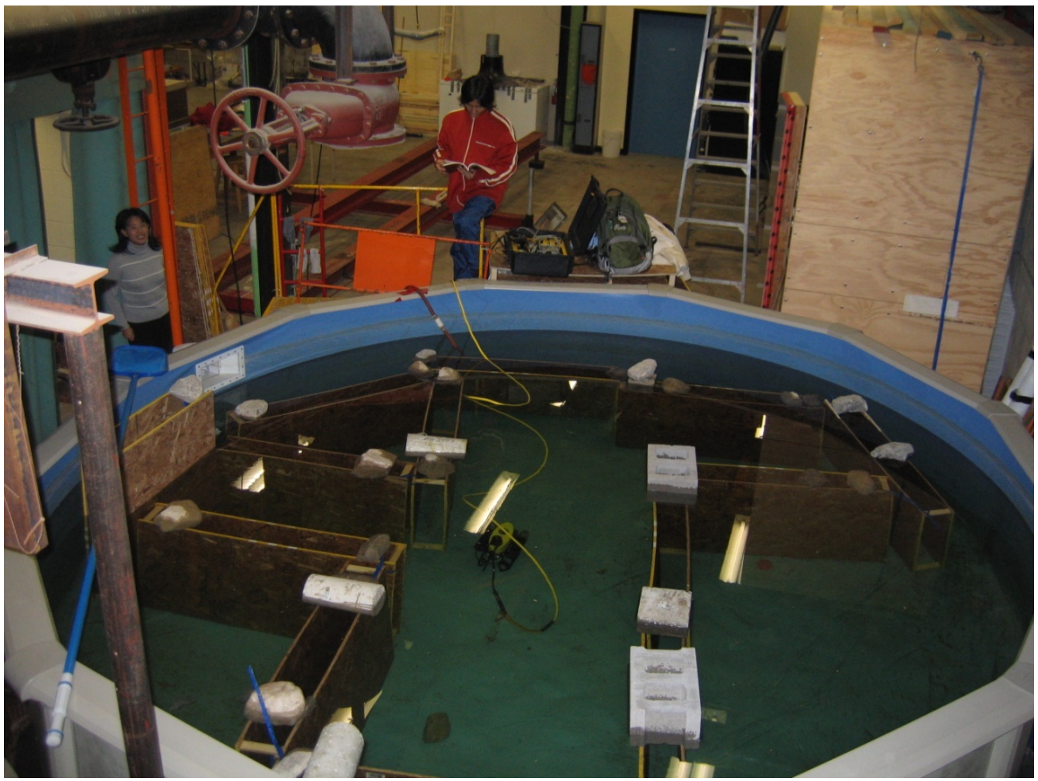
Sensors: Ultrasonic Range Sensors

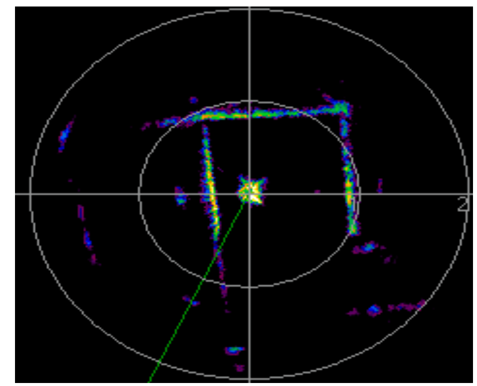
- Other problems
  - Soft surfaces that absorb most of sound energy
  - Surfaces that are not perpendicular to the direction of sound, get specular reflection
  - Low Bandwidth



a) 360° scan

Sensors:
Example Application 1

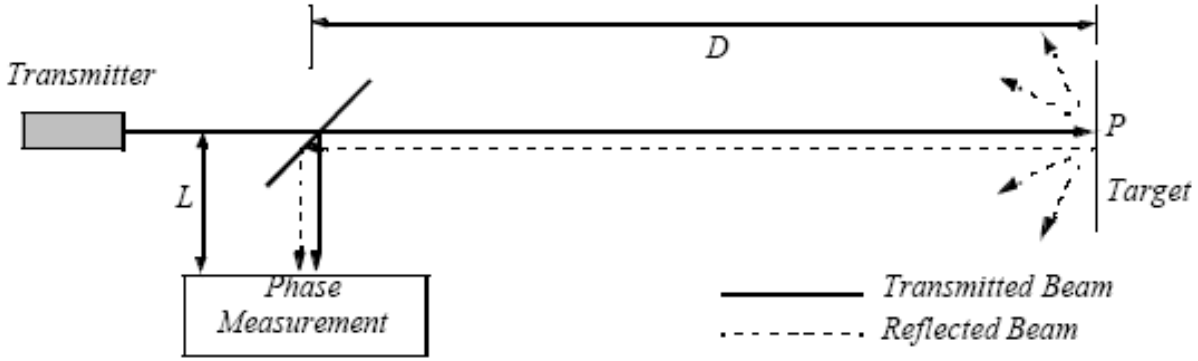




Clark, Cal Poly SLO

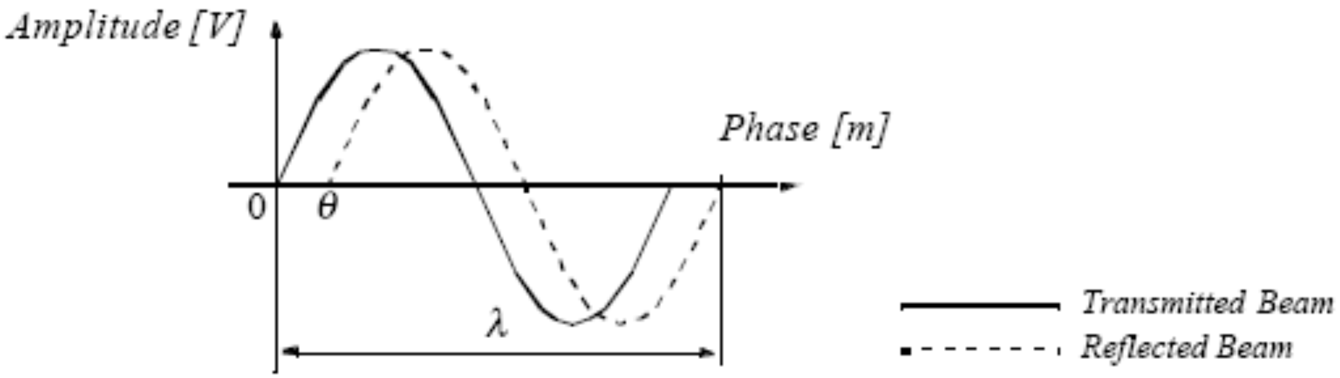
Sensors: Time of Flight Laser Range Sensors

- Transmitted and received beams coaxial
- Transmitter illuminates target with beam
- Receiver detects time needed for round-trip
- Can get 2D or 3D information using mirror sweeps



Sensors: Time of Flight Laser Range Sensors

- Methods for measuring time of flight:
  - Use pulsed laser and measure time of flight directly
  - Measure the phase shift



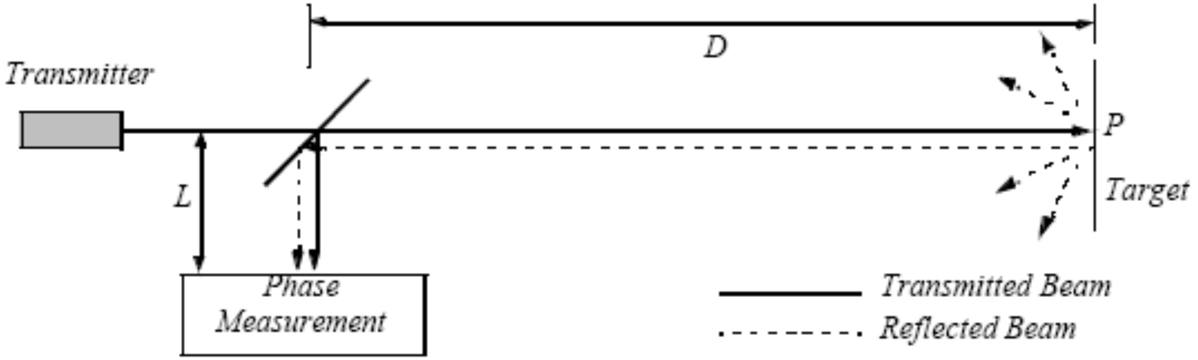
Sensors: Time of Flight Laser Range Sensors

- Phase Shift Measurement:
  - Wavelength λ relates to modulating freq. f as:

$$\lambda = c/f$$

  - Total distance is:

$$D' = L + 2D$$

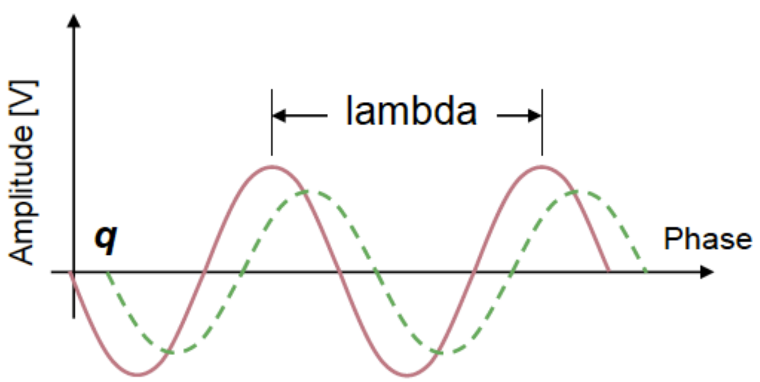


Sensors: Time of Flight Laser Range Sensors

- We want to measure the distance to target

$$2D = \lambda\, \theta / 2\pi$$

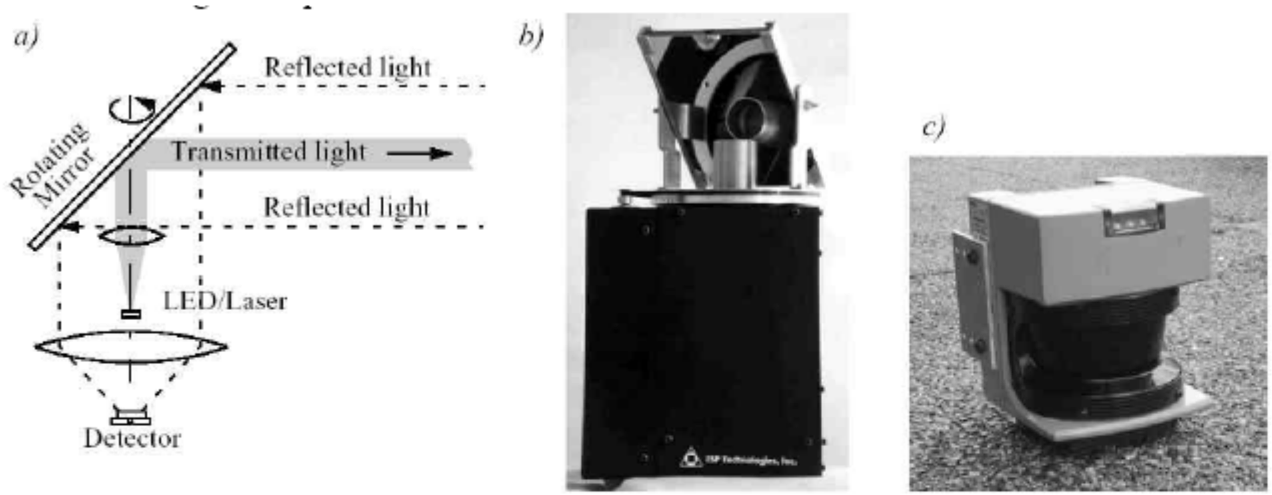
  - Where θ is the phase difference between the transmitted and received beams.



  - Note there is theoretical ambiguity in range estimates

Sensors: Time of Flight Laser Range Sensors

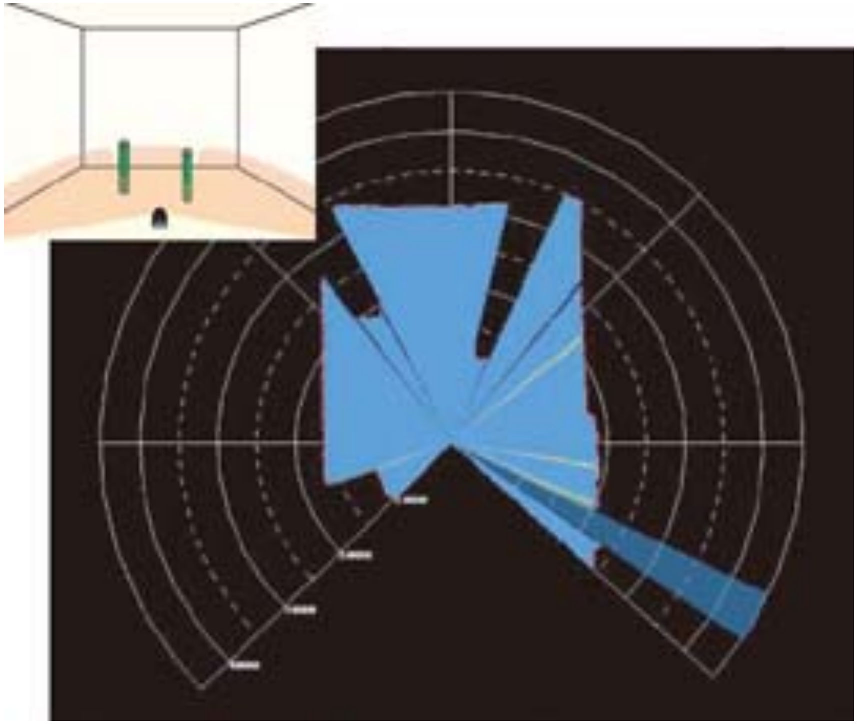
- Schematic and examples:



a) Schematic *b) EPS Technologies* *c) SICK*

Sensors: Time of Flight Laser Range Sensors

- Schematic and examples (cont’):



d) Hokuyo URG Scanning laser range finder

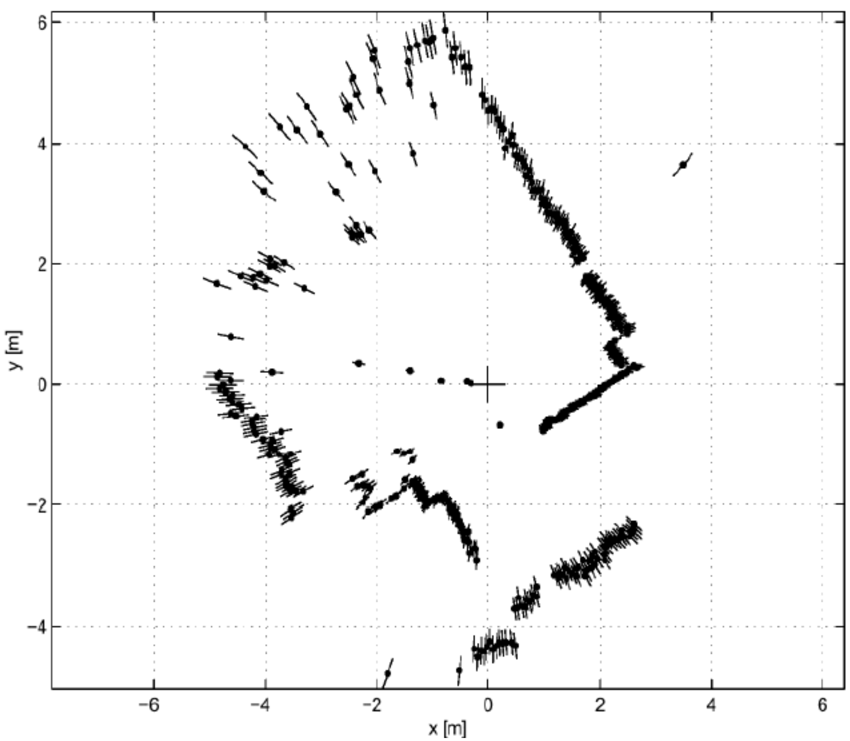
Sensors:
Time of Flight Laser Range Sensors

- Schematic and examples (cont’):

e) SICK in 3D scanning configuration

Sensors: Time of Flight Laser Range Sensors

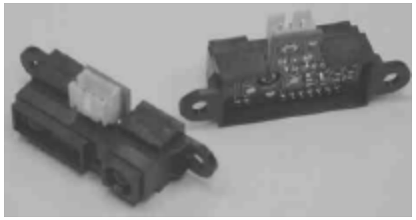
- Uncertainty
  - Uncertainty of the range is inversely proportional to the square of the received signal amplitude.
  - Dark, distant objects will not produce such good range estimated as closer brighter objects …

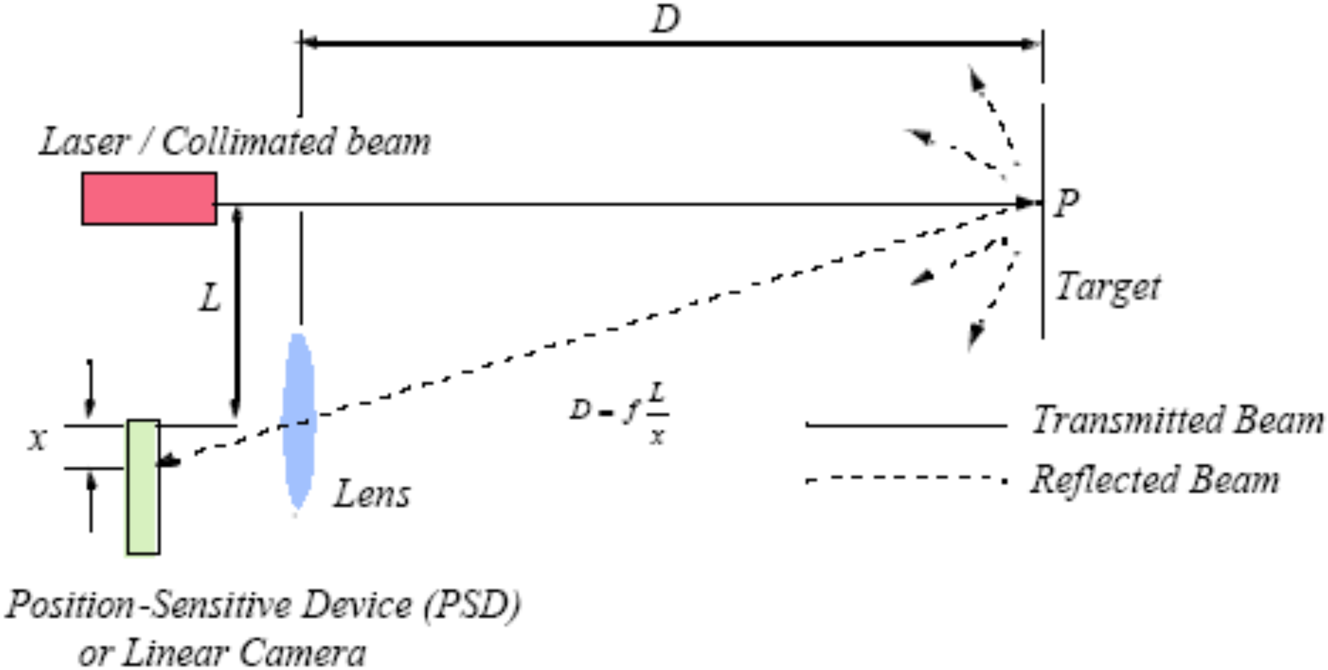


Sensors: Triangulation Laser Range Sensors

- Distance is proportional to *1/x*

$$D = f\,L / x$$

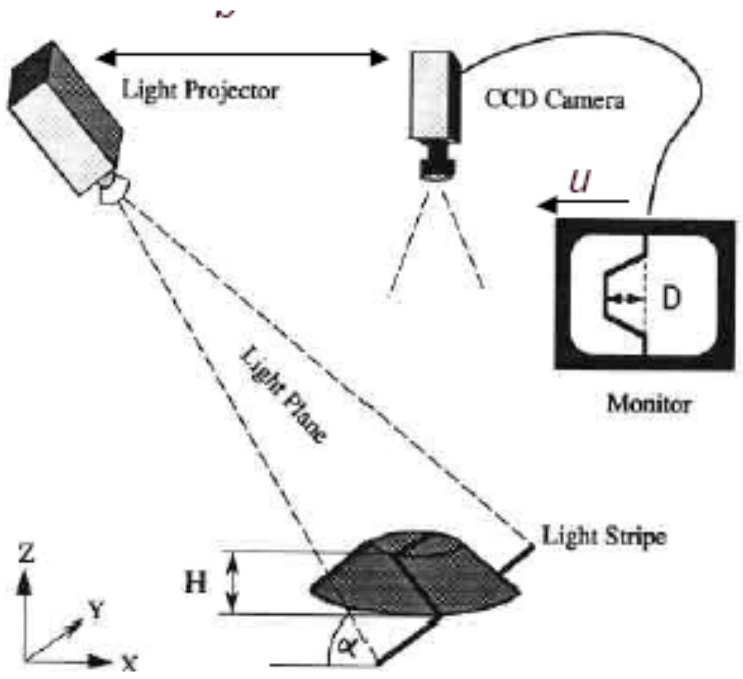




Sensors: Structured Light Range Sensors

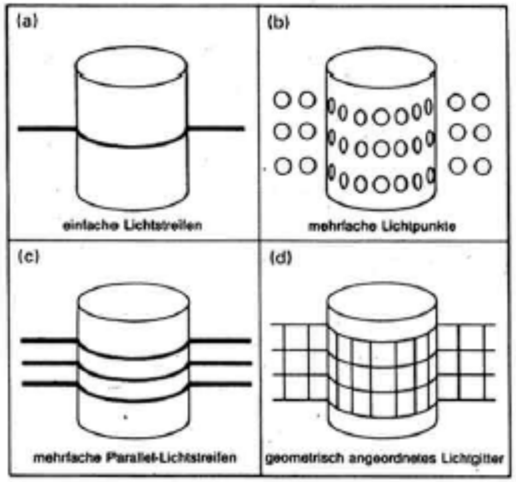
- Project structured light on target
- Use camera to perceive light
- Simple geometry will determine range

$$H = D \tan\alpha$$

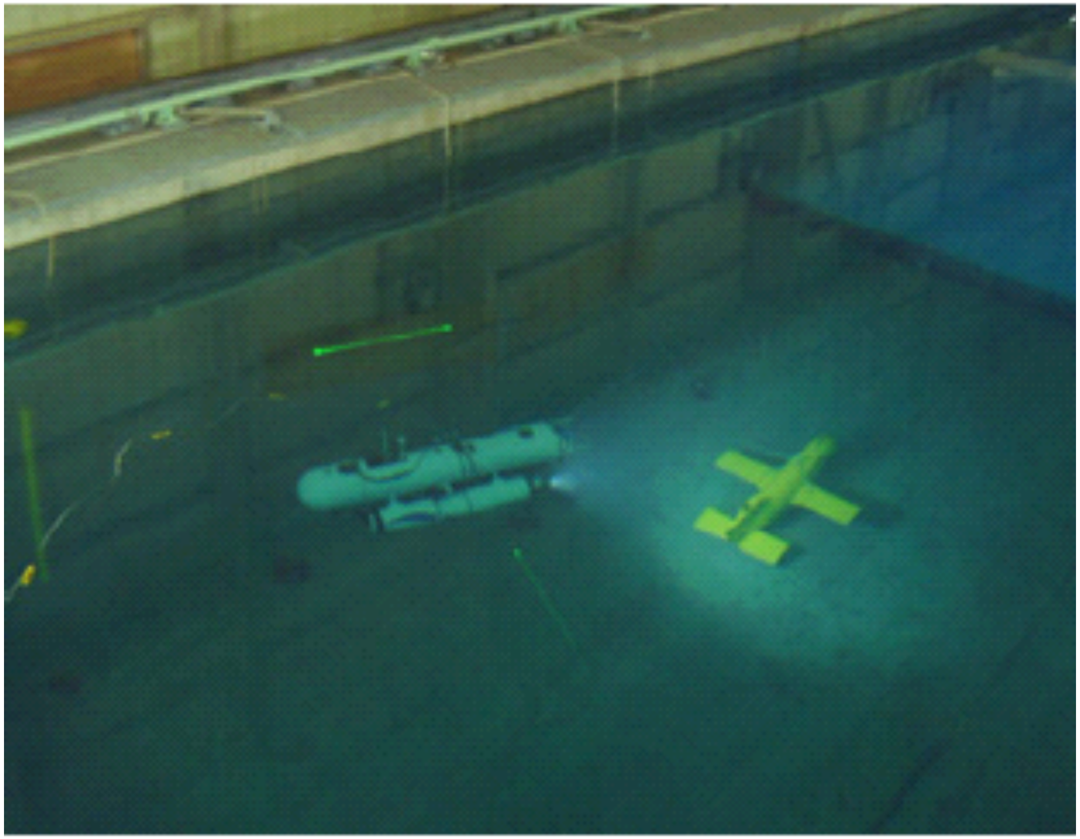


Sensors: Structured Light Range Sensors

- Project structured light on target
- No correspondence problem



Sensors: Example Application 2



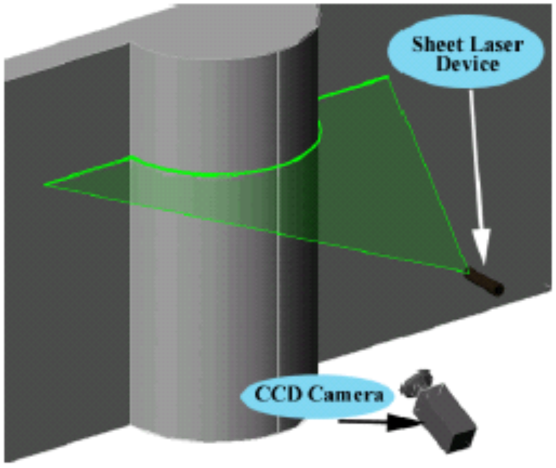
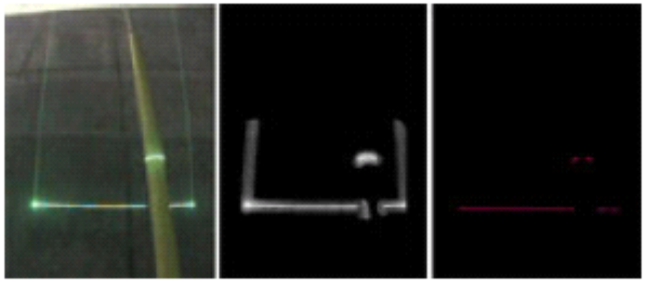


Figure 1. Arrangement of the profiling system.



Kondo, Tokyo University of Marine Science & Technology

Sensors: Outline

Sensor Examples

1. Encoders
2. Range Sensors
3. Heading Sensors

Sensors: Heading Sensors

- Can determine orientation and inclination
- Can be Proprioceptive (e.g. gyroscope) or Exteroceptive (e.g. compass).
- Used with velocity information from encoders to obtain robot position estimate

"Dead Reckoning"

Sensors: Heading Sensors

- Compass
  - Over 4000 years old
  - Uses earth's magnetic field to provide absolute measure for orientation
  - Disadvantages:
    - Earth's magnetic field is weak
    - Field is easily disturbed by other magnetic objects
    - Not dependable for indoor environments

Sensors: Heading Sensors

- Example: Deventech Compass
  - good precision (0.1 degrees).
  - poor accuracy (within 3-4 degrees)