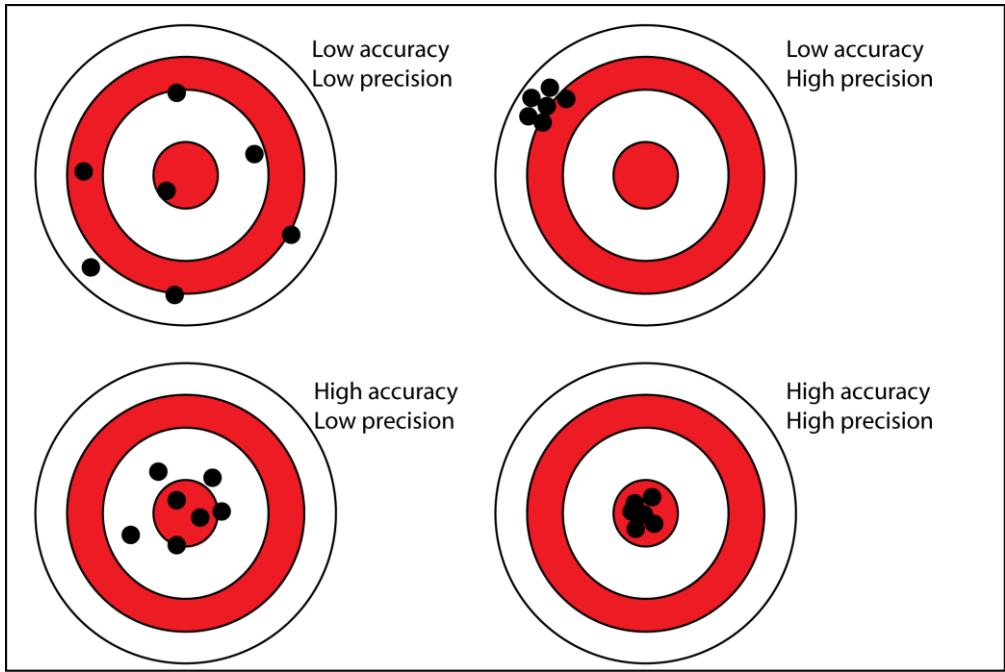
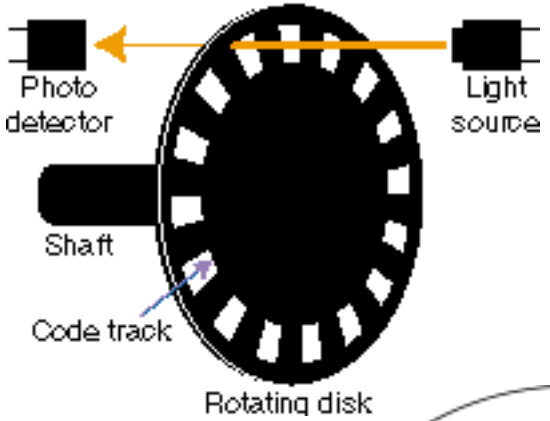
- Lab 2
  - Installing all the packages
- Logistics & Travel
  - Makeup class
  - Recorded class
  - Class time to work on lab
  - Remote class

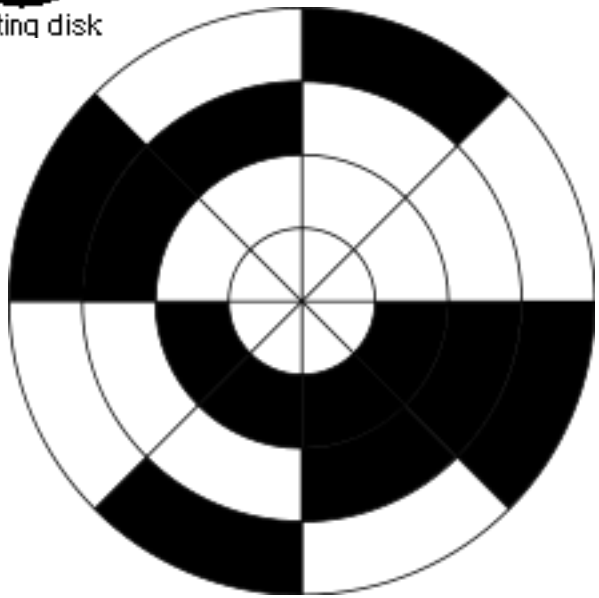
Classification of Sensors

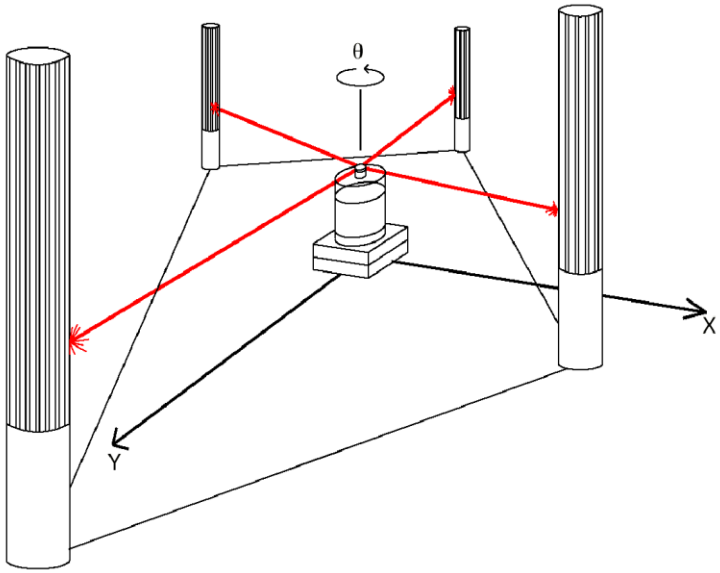
- Proprioceptive sensors
  - internal to robot
- Exteroceptive sensors
  - information from robot's environment
- Passive sensors
- Active sensors



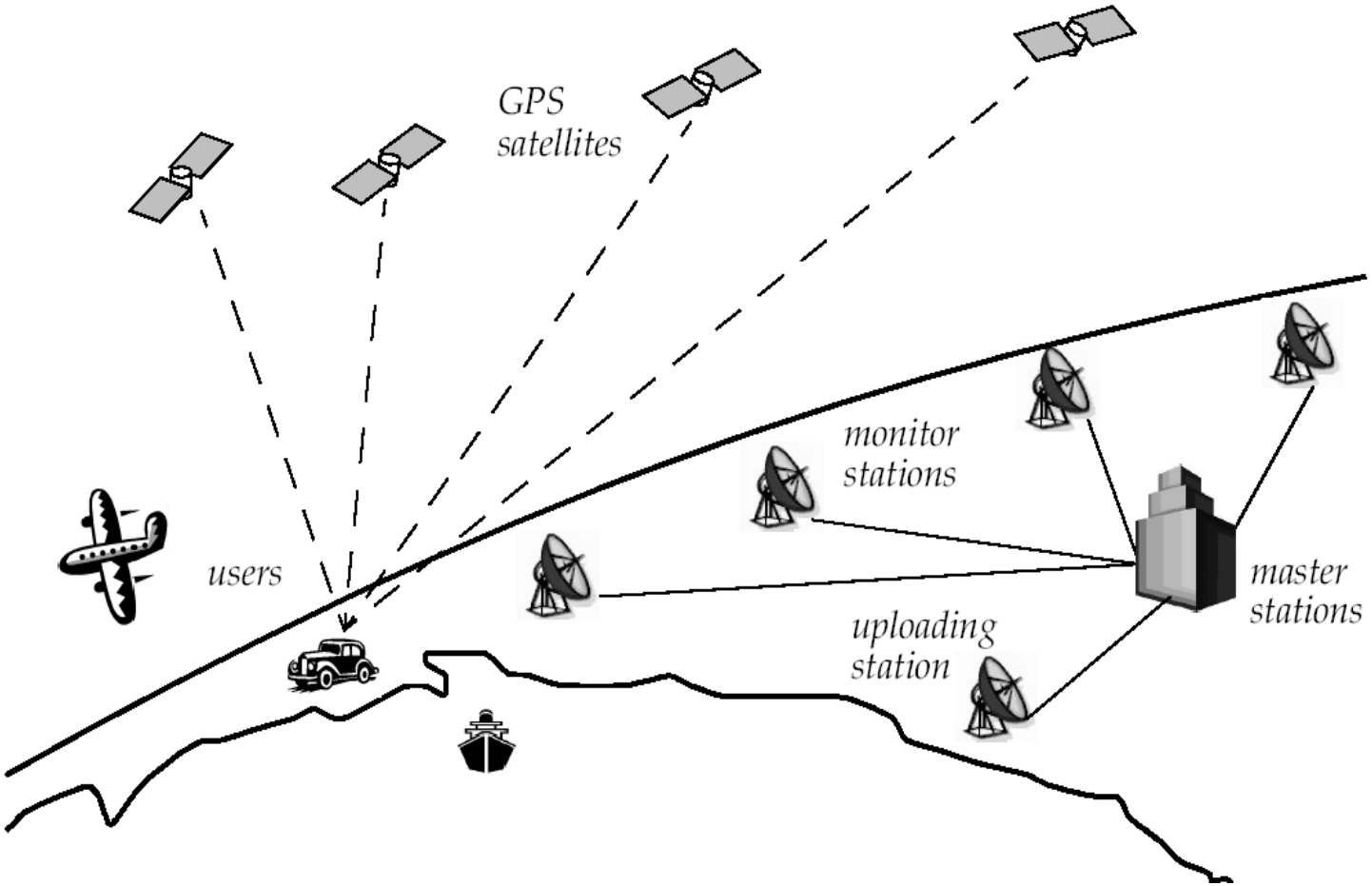
Wheel Encoders, Beacon Systems







GPS


GPS
satellites
monitor
stations
users
master
stations
uploading
station

“Indoor GPS”

- Sound
  - http://www.marvelmind.com/

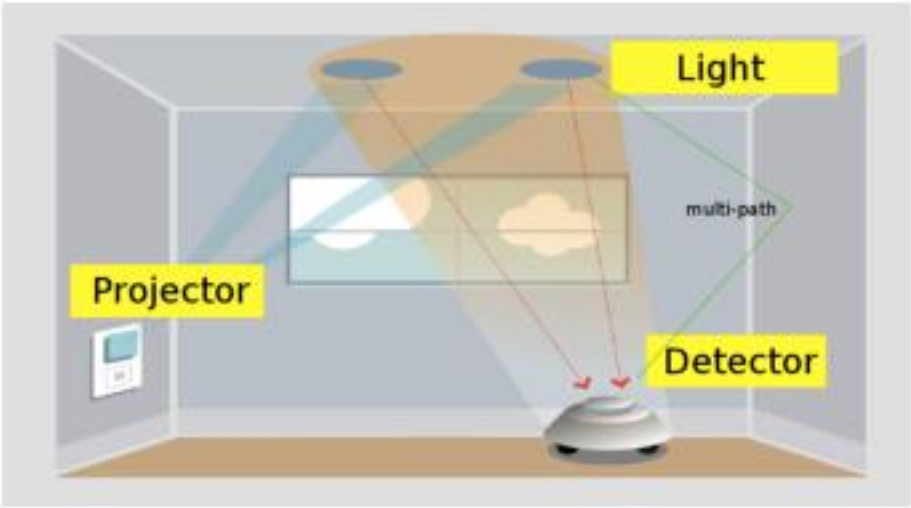
- Wi-Fi
  - RSSI (Received Signal Strength Indication)
  - Fingerprinting (lookup table)
  - Angle of arrival
  - Time of Flight
  - https://en.wikipedia.org/wiki/Wi-Fi_positioning_system

Neato

- On-board Room Positioning System (RPS) technology
- Maps with only one projector!

Neato

- https://www.researchgate.net/publication/221070323_Vector_field_SLAM



(From 2011)

So Far…

- Compass
- Wheel encoders
- Gyroscope
  - v.s. Accelerometer?
- GPS
  - Beacons
  - Sound
  - WiFi
  - Etc.

Range Sensors

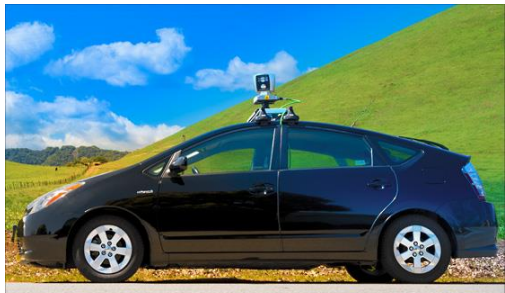
- How do “time of flight” sensors work?
- What problems would there be?
- Differences between using sound vs. light?

Range Sensors (time of flight) (1)

- Large range distance measurement: *range sensors*
- Range information:
  - key element for localization and environment modeling
  - Ultrasonic sensors: Sound
  - Laser sensors: electromagnetic waves

Range Sensors (time of flight) (2)

- Propagation speed v of sound: 0.3 m/ms
- Propagation speed v of of electromagnetic signals: 0.3 m/ns, one million times faster
- time of flight t with electromagnetic signals is not an easy task
  - laser range sensors expensive and delicate
- Quality of time of flight range sensors manly depends on:
  - Uncertainties about the exact time of arrival of the reflected signal
  - Inaccuracies in the time of fight measure (laser range sensors)
  - Opening angle of transmitted beam (ultrasonic range sensors)
  - Interaction with the target (surface, specular reflections)
  - Variation of propagation speed
  - Speed of mobile robot and target (if not at standstill)



Ultrasonic Sensor (1)

- Transmit 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*

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

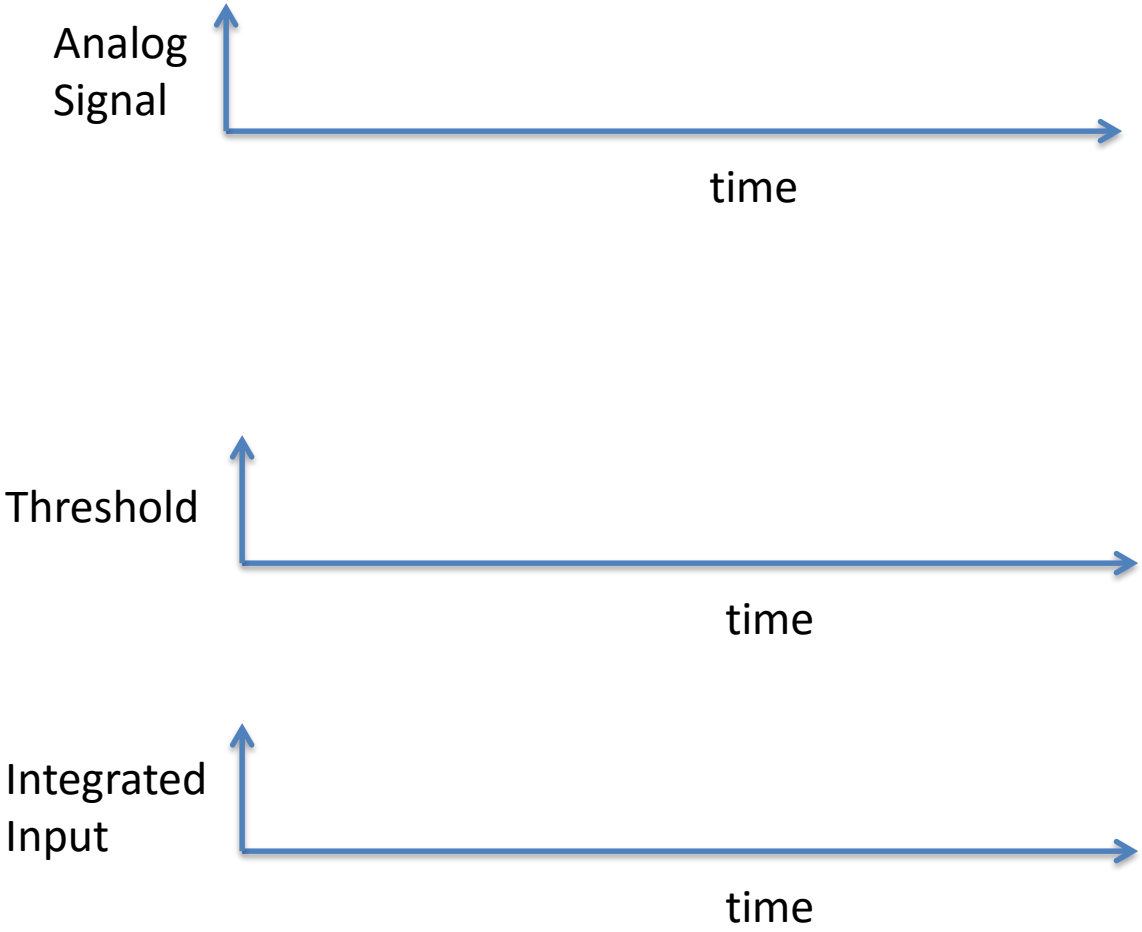
where

γ : ratio of specific heats

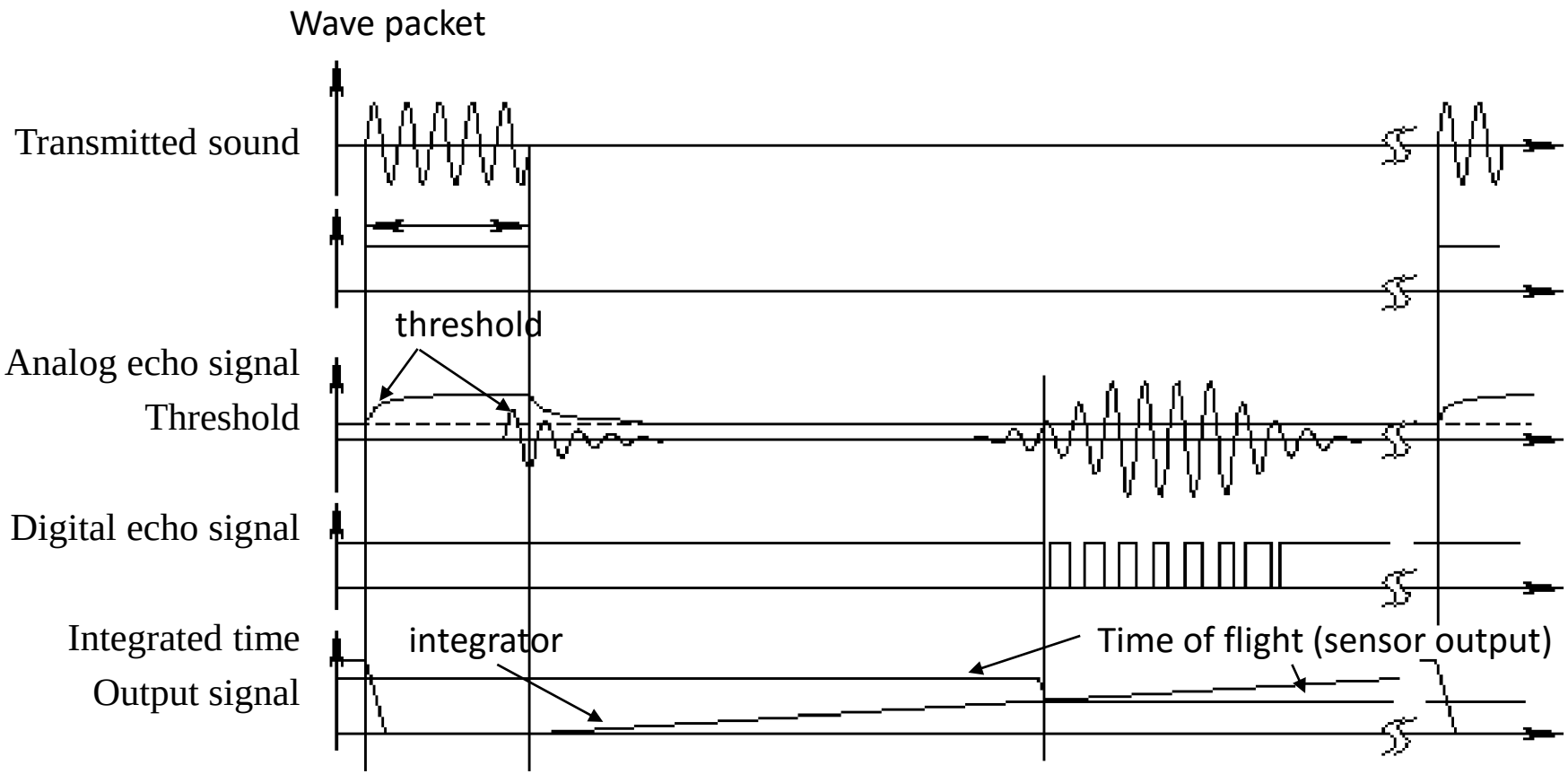
R: gas constant

T: temperature in degree Kelvin

Ultrasonic Sensor (2)



Ultrasonic Sensor (3)

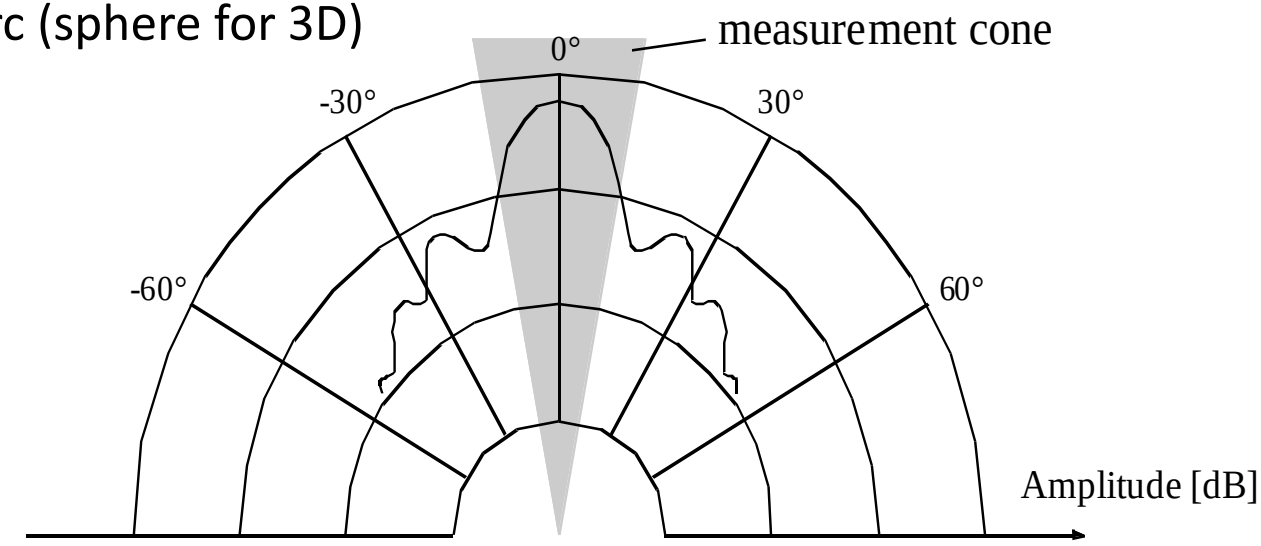


Threshold: high initially (avoid ringing) then decreases over time

Very close objects = trouble!

Ultrasonic Sensor (4)

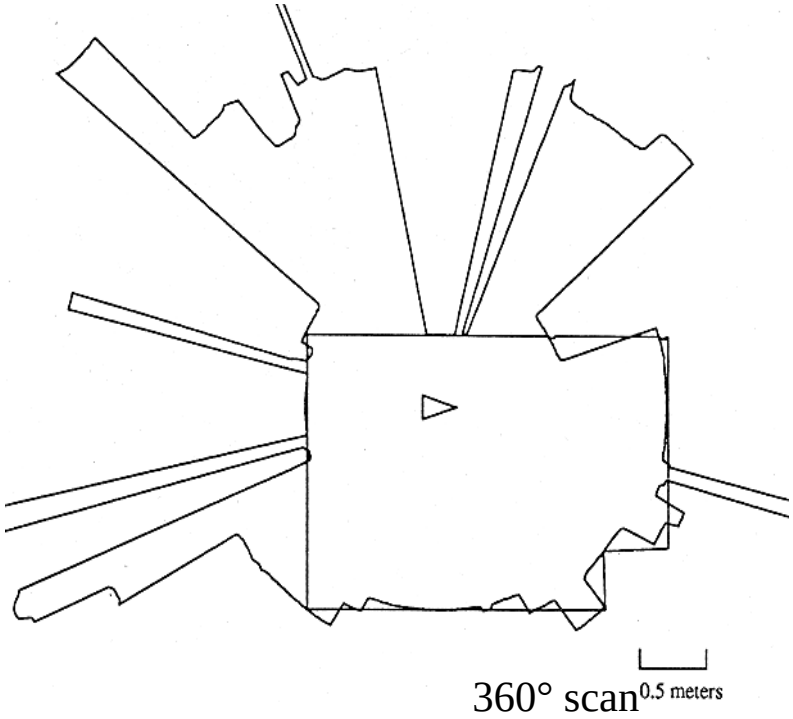
- typically a frequency 40 - 180 kHz
- generation of sound wave: piezoelectric transducer
  - Early application: WWI sonar
- sound beam propagates in a cone-like manner
  - opening angles around 20 to 40 degrees
  - segments of an arc (sphere for 3D)



Typical intensity distribution of a ultrasonic sensor

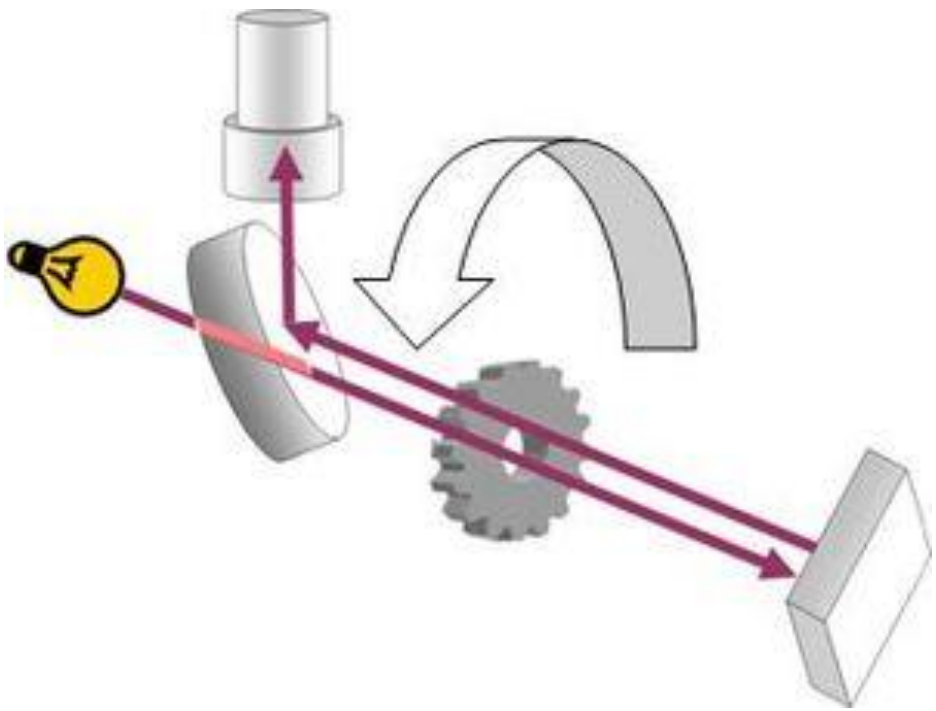
Ultrasonic Sensor (5)

- Soft surfaces that absorb most of the sound energy
- Surfaces far from perpendicular to the direction of sound: specular reflection



Speed of Light

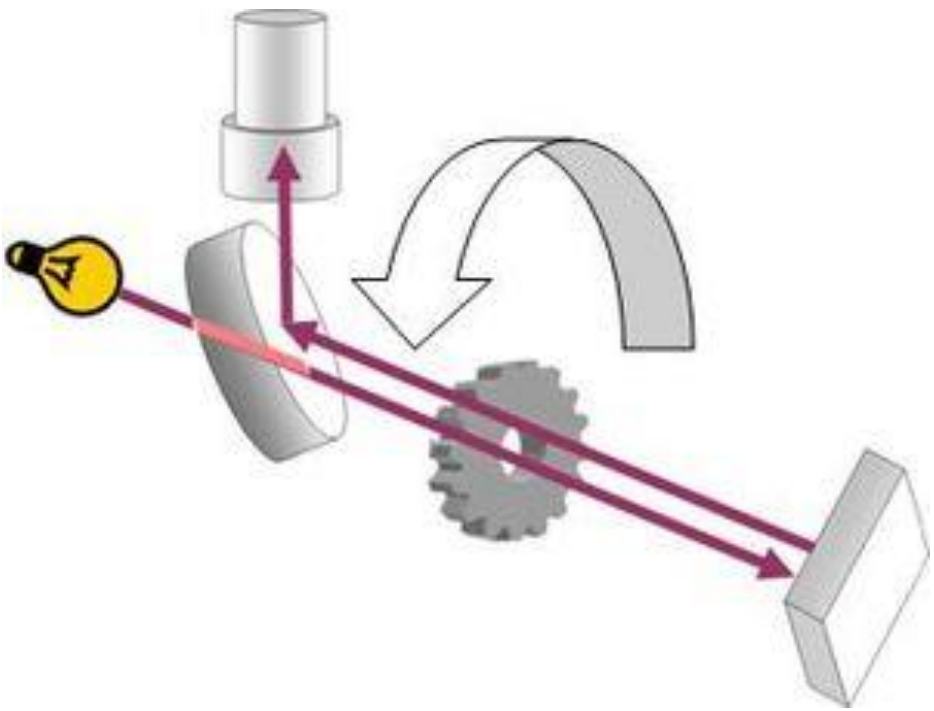
Fizeau apparatus

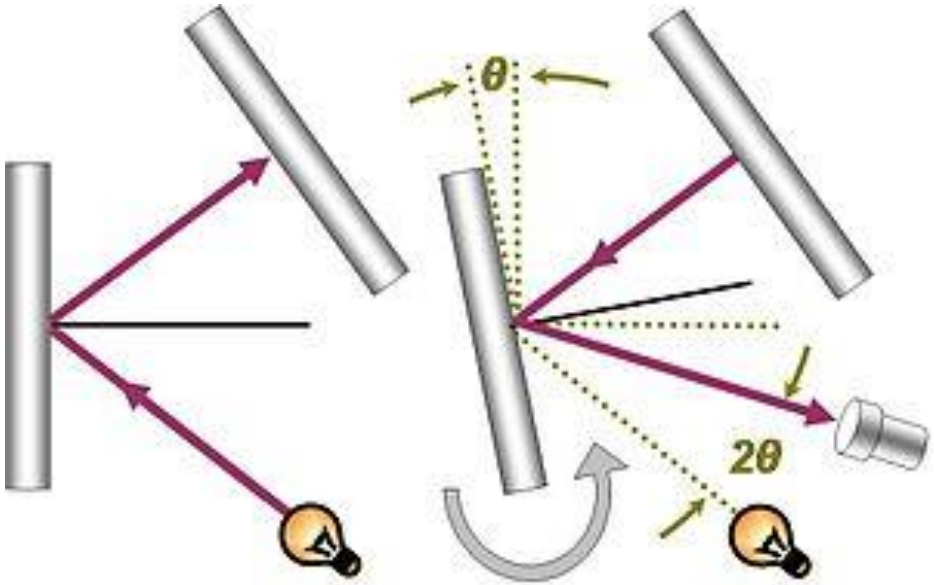


Speed of Light

Fizeau apparatus

Foucault apparatus



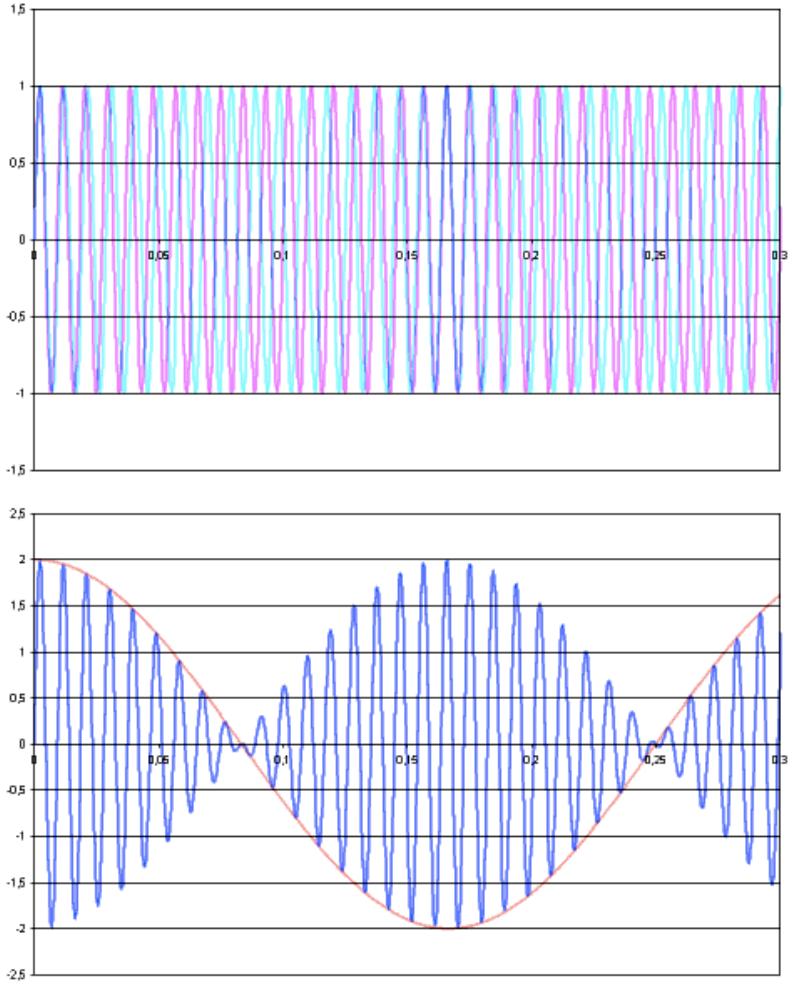


Laser Range Sensor (1)

- Transmitted and received beams coaxial
- Transmitter illuminates a target with a collimated beam
- Received detects the time needed for round-trip
- A mechanical mechanism with a mirror sweeps
  - 2 or 3D measurement

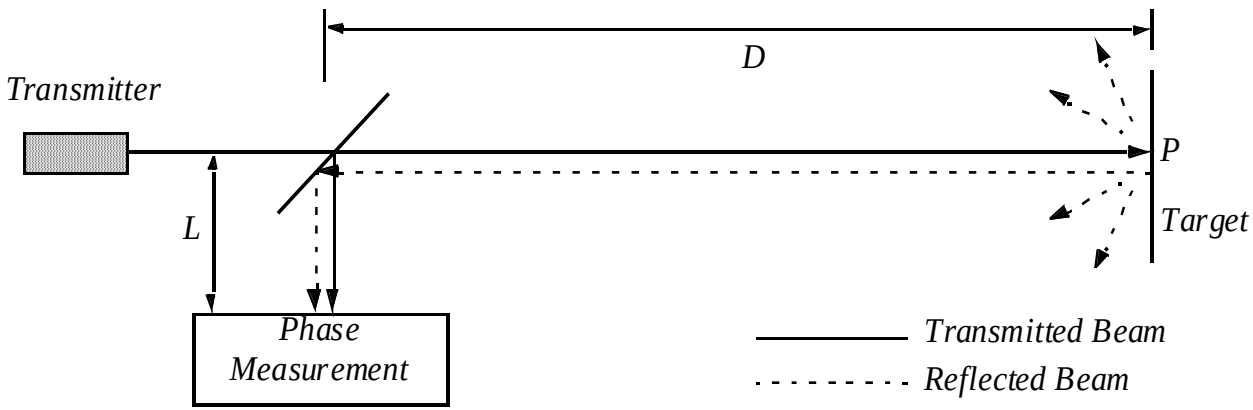
Laser Range Sensor (2)

- Pulsed laser
  - measurement of elapsed time directly
- Beat frequency
  - between a frequency modulated continuous wave and received reflection



Laser Range Sensor (3)

Phase-Shift Measurement (easier than other 2 methods)



$\lambda = c/f$

$$L + 2D = L + \frac{q}{2p} l$$

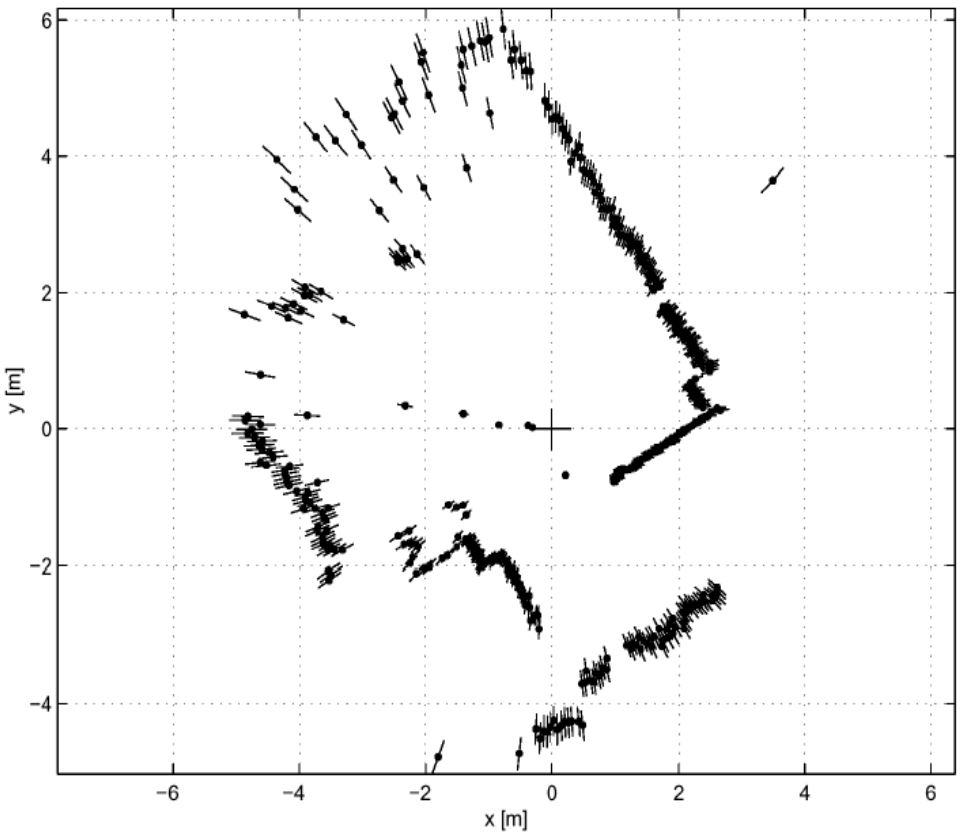
c: speed of light; *f*: modulating frequency, θ: phase measurement

for f = 5 Mhz, λ = 60 meters

Example Laser Range Sensor

Length of lines through the measurement points indicate the uncertainties

http://www.youtube.com/watch?v=NC1F0TwJ_Q8

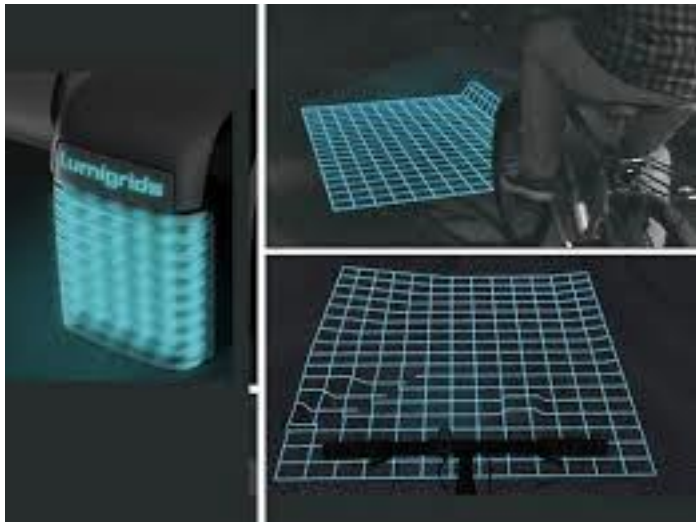


Structured Light Projection

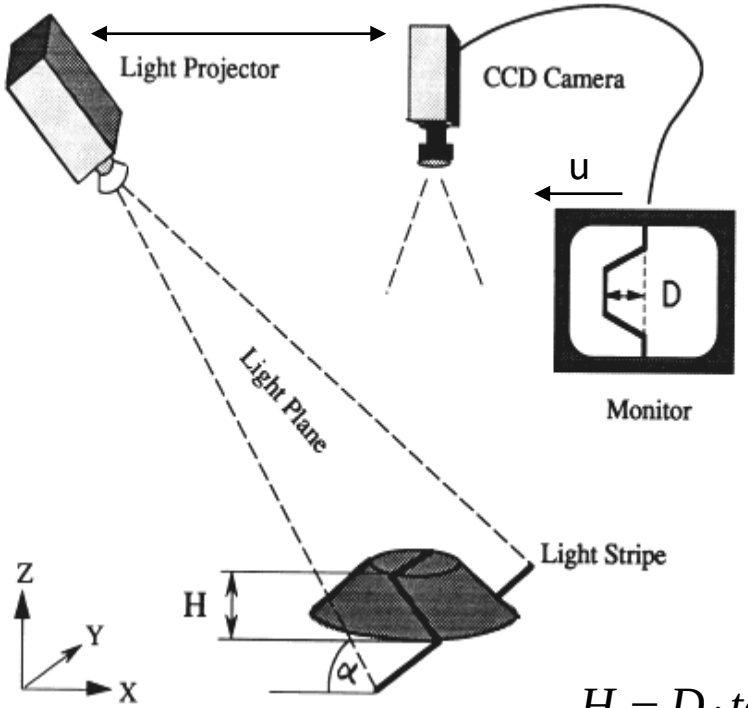
- What if you projected a pattern instead of a point. How would this be useful?

Triangulation Ranging

- Geometrical properties of image establish a distance measurement
- Project a well defined light pattern (e.g. point, line) onto the environment
  - Reflected light captured by a photo-sensitive line or matrix (camera) sensor device
  - Triangulation establishes distance



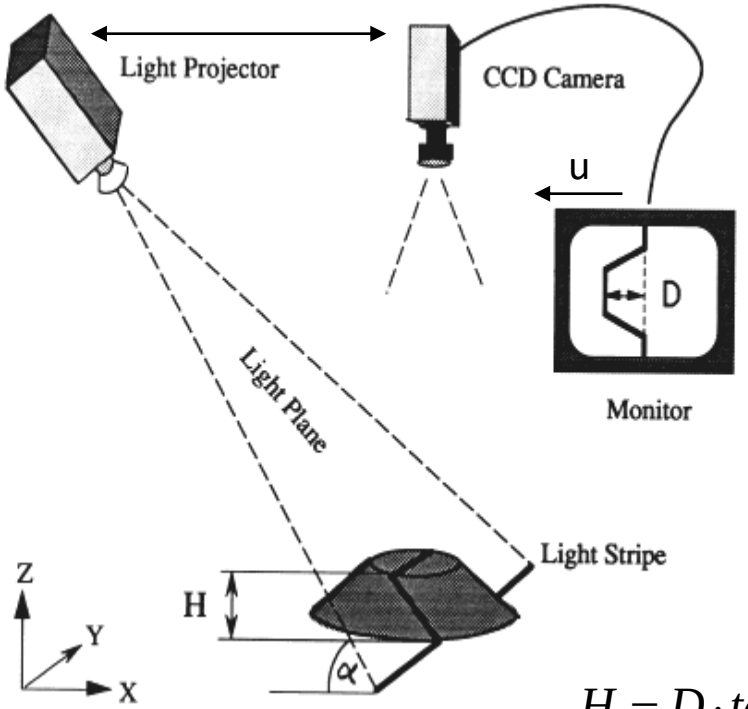
Structured Light (vision, 2 or 3D)



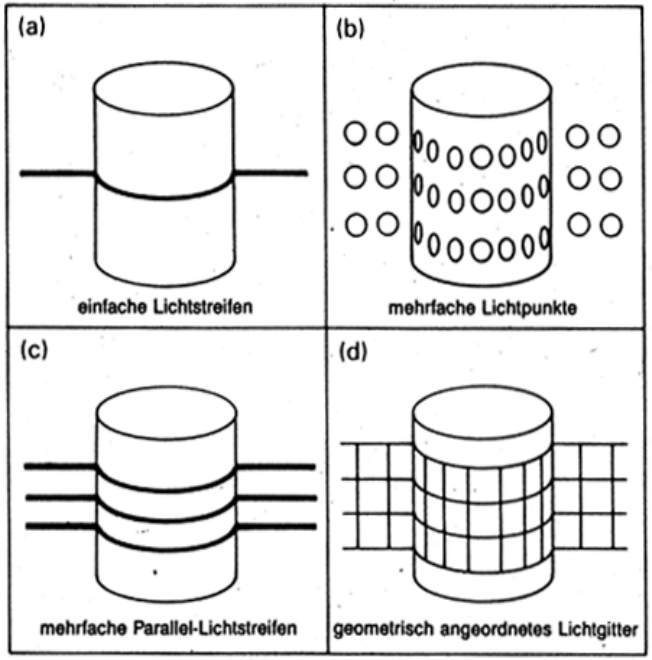
$$H = D \cdot tan\alpha$$

- Eliminate correspondence problem by projecting structured light on the scene
- Slits of light / emit collimated light (laser) by means of rotating mirror
- Light perceived by camera
- Range to an illuminated point can then be determined from simple geometry.

Structured Light (vision, 2 or 3D)

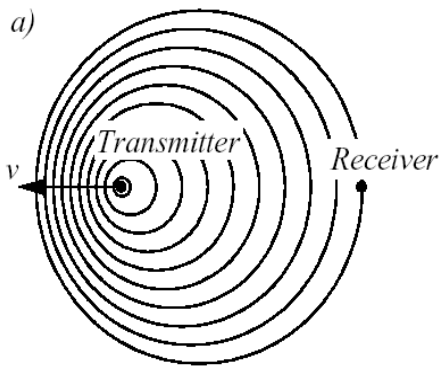


$$H = D \cdot tan\alpha$$

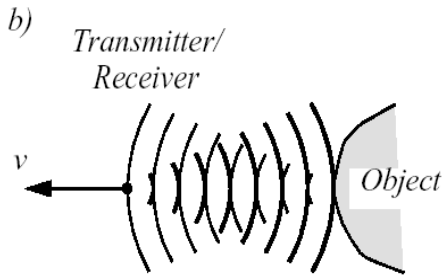


- Eliminate correspondence problem by projecting structured light on the scene
- Slits of light / emit collimated light (laser) by means of rotating mirror
- Light perceived by camera
- Range to an illuminated point can then be determined from simple geometry.

Doppler Effect Based (Radar or Sound)



a) between two moving objects



b) between a moving and a stationary object

transmitter is moving

$$f_r = f_t(1 + v/c)$$

receiver is moving

$$f_r = f_t \frac{1}{1 + v/c}$$

Doppler frequency shift

$$\Delta f = f_t - f_r = \frac{2 f_t v \cos\theta}{c}$$

relative speed

$$v = \frac{\Delta f \cdot c}{2 f_t \cos\theta}$$

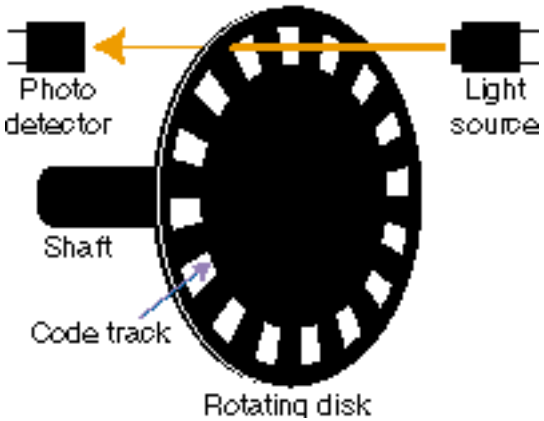
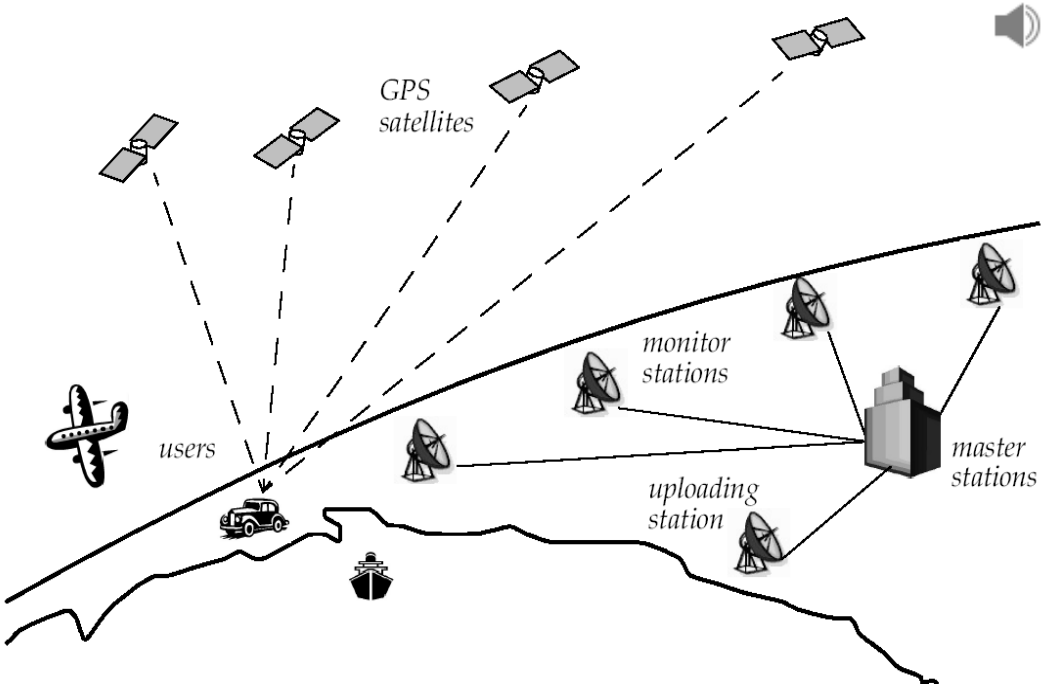
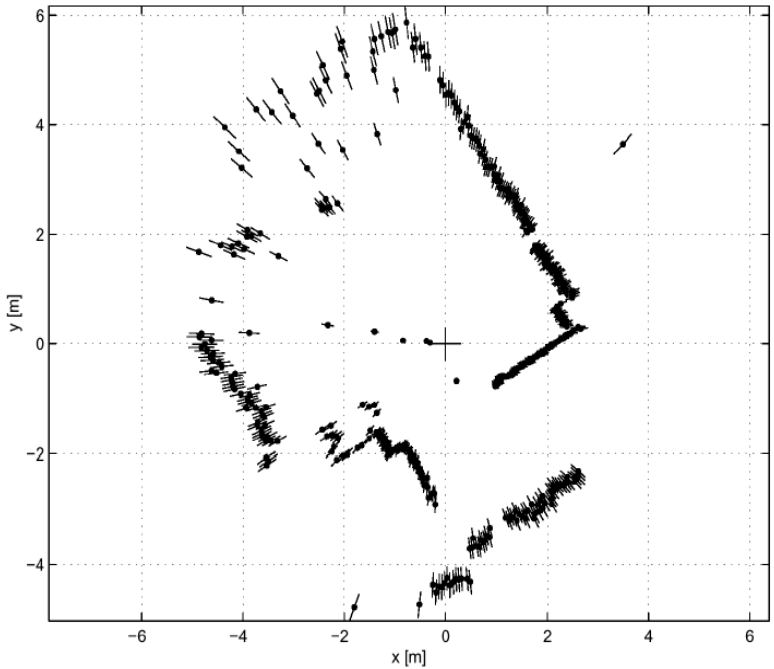


Photo detector
Light source
Shaft
Code track
Rotating disk


GPS satellites
monitor stations
users
master stations
uploading station


y [m]
x [m]
6
4
2
0
−2
−4
−6
−4
−2
0
2
4
6