Introduction to ROBOTICS

Robot Sensing and Sensors

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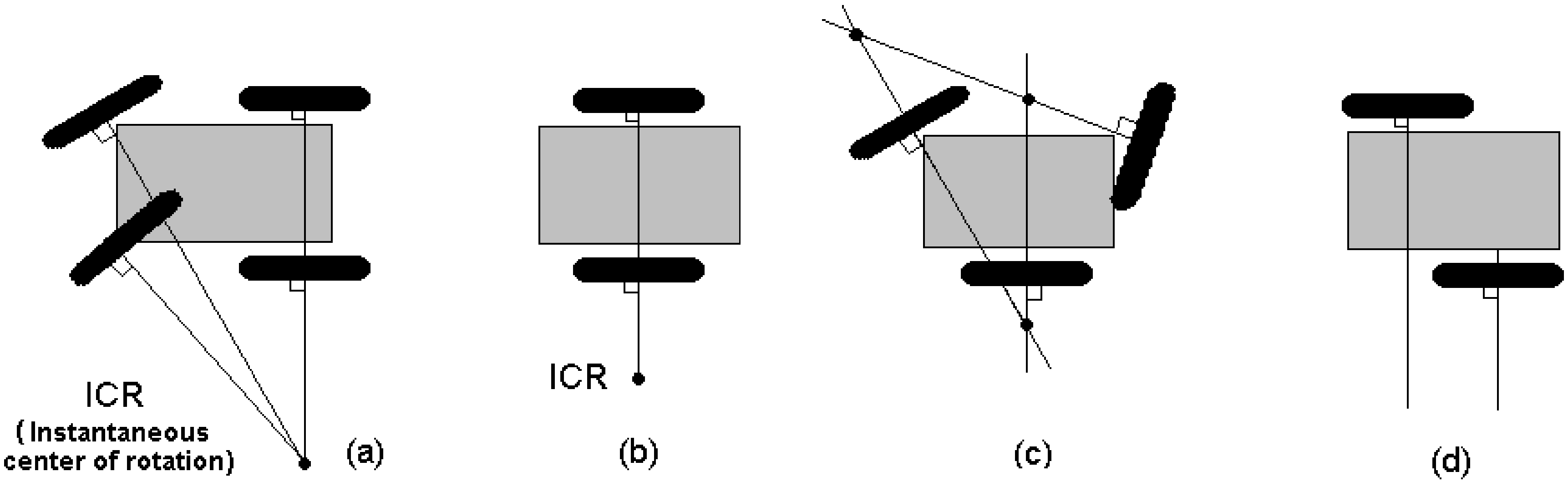
Brief Review
(Mobot Locomotion)

ICR of wheeled mobile robot

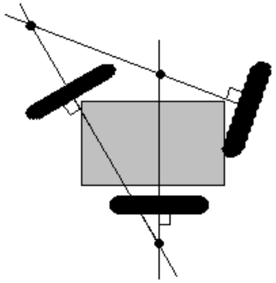
- Instantaneous center of rotation (ICR)
  - A cross point of all axes of the wheels



Degree of Mobility

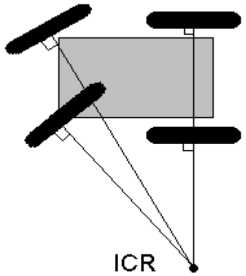
- **Degree of mobility**

  The degree of freedom of the robot motion



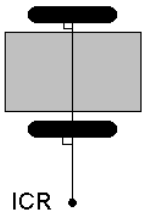
Cannot move anywhere (No ICR)

- Degree of mobility : 0



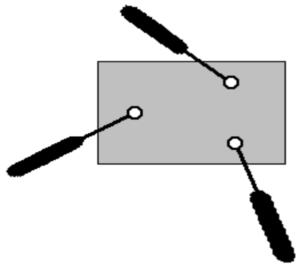
Fixed arc motion (Only one ICR)

- Degree of mobility : 1



Variable arc motion (line of ICRs)

- Degree of mobility : 2



Fully free motion

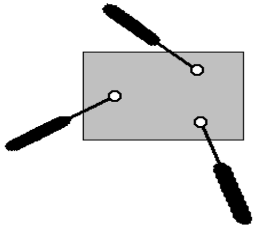
(ICR can be located at any position)

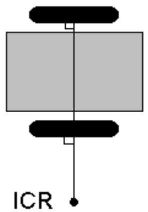
- Degree of mobility : 3

Degree of Steerability

- **Degree of steerability**

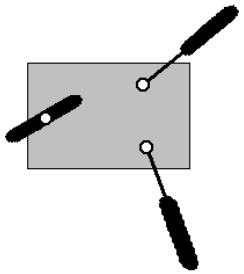
The number of centered orientable wheels that can be steered independently in order to steer the robot



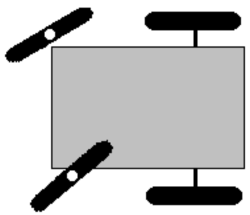


No centered orientable wheels

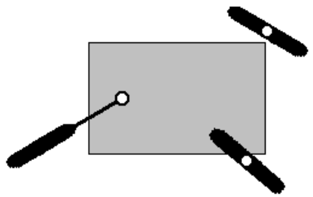
- Degree of steerability : 0



One centered orientable wheel



Two mutually dependent centered orientable wheels



Two mutually independent centered orientable wheels

- Degree of steerability : 1
- Degree of steerability : 2

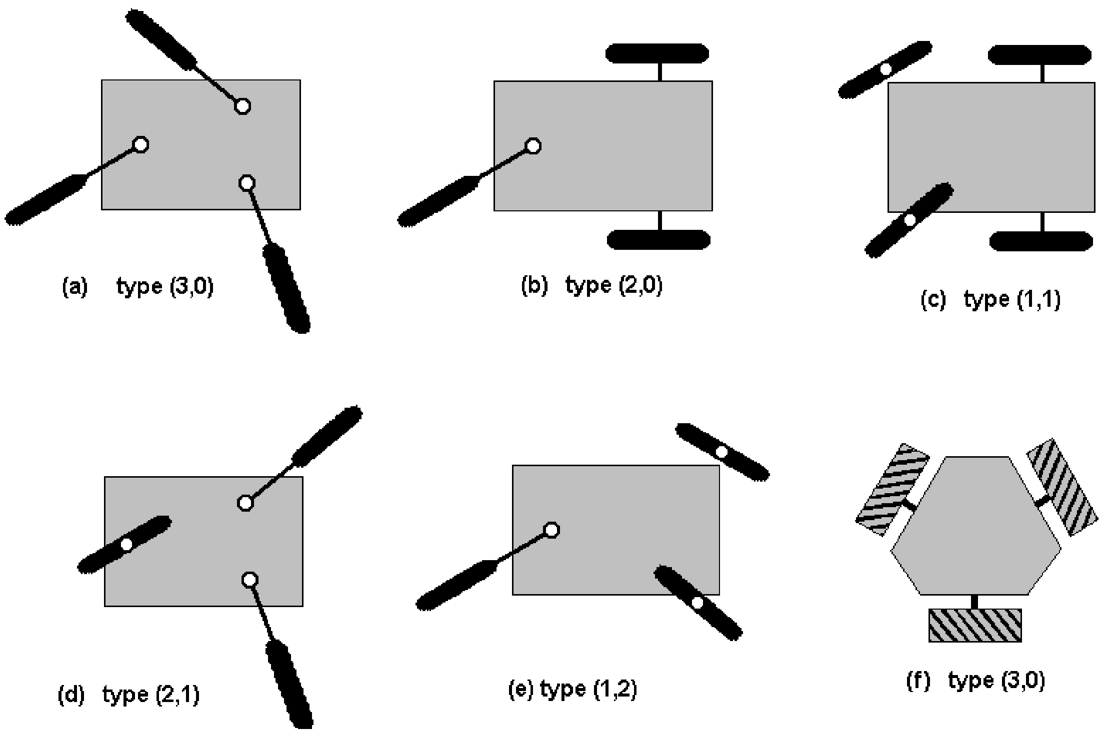
Degree of Maneuverability

- The overall degrees of freedom that a robot can manipulate:

$$\delta_M = \delta_m + \delta_s$$

Degree of Mobility	3	2	2	1	1
Degree of Steerability	0	0	1	1	2

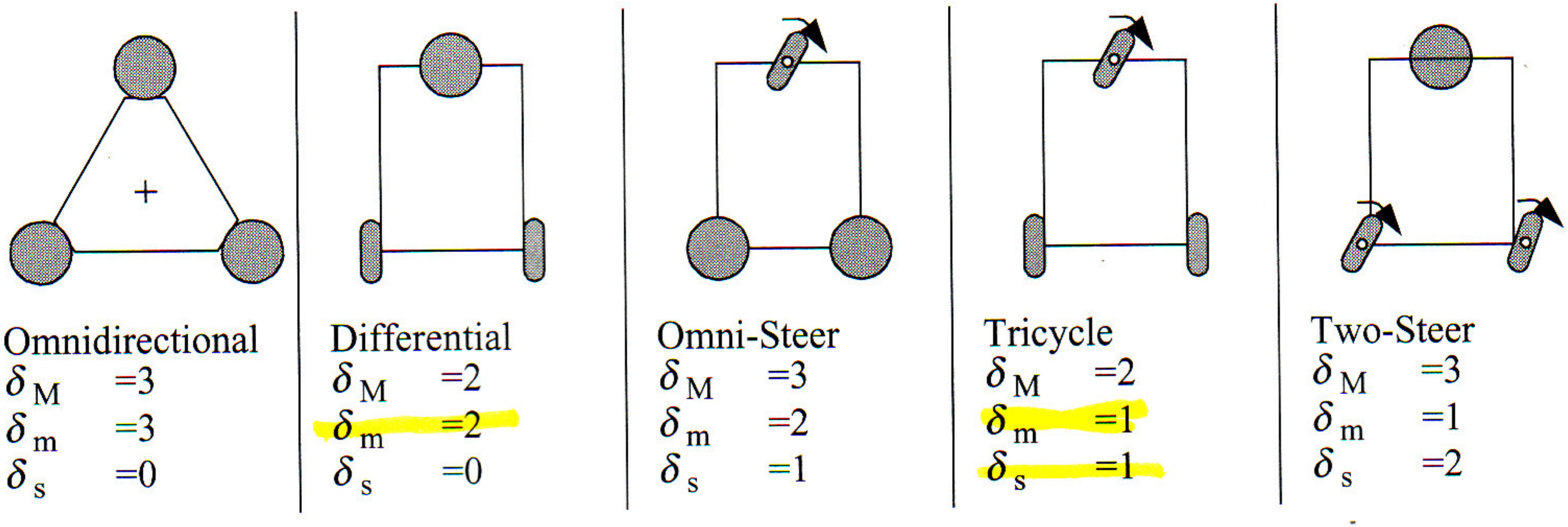
- Examples of robot types (degree of mobility, degree of steerability)



(a) type (3,0)
(b) type (2,0)
(c) type (1,1)
(d) type (2,1)
(e) type (1,2)
(f) type (3,0)

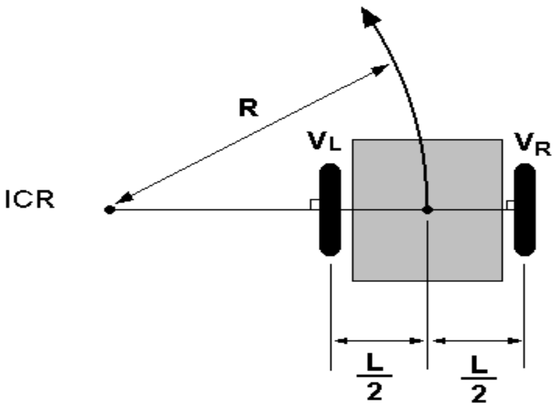
Degree of Maneuverability

$$\delta_M = \delta_m + \delta_s$$

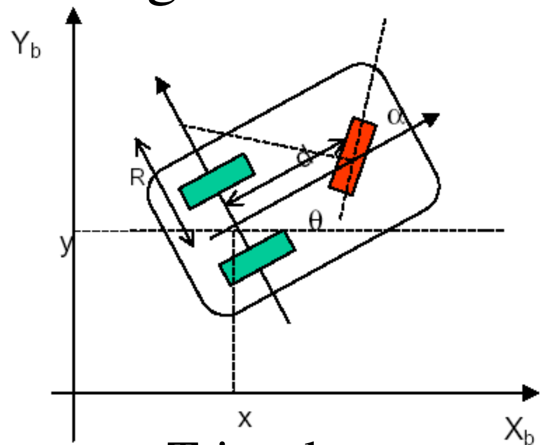


Mobile Robot Locomotion

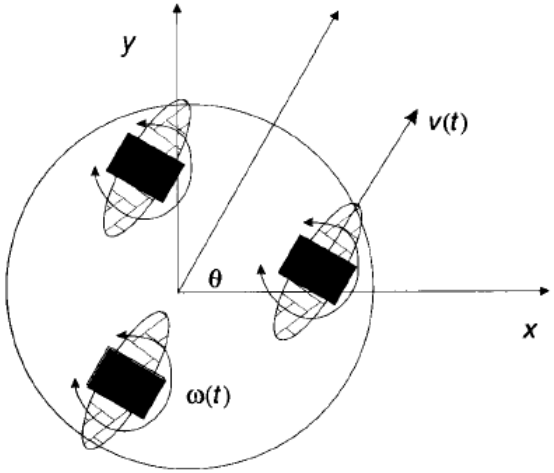
Locomotion: the process of causing a robot to move



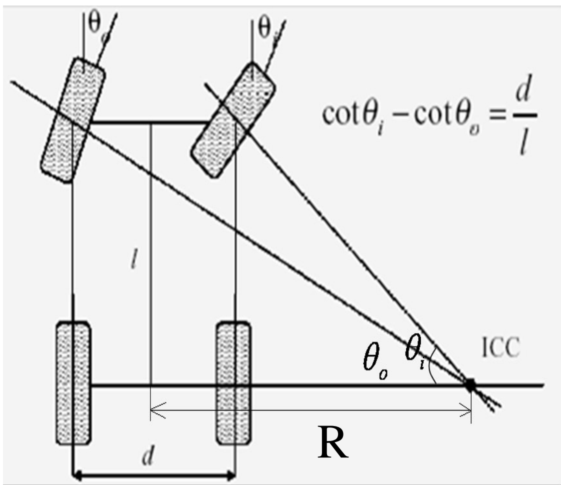
- Differential Drive



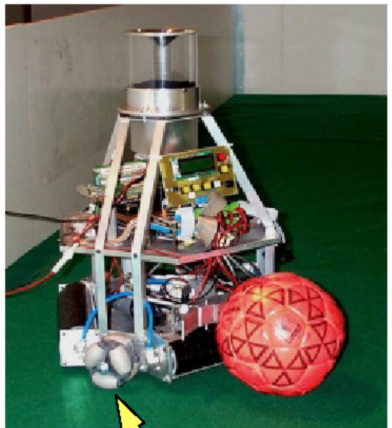
- Tricycle



- Synchronous Drive



- Ackerman Steering



Swedish Wheel

- Omni-directional

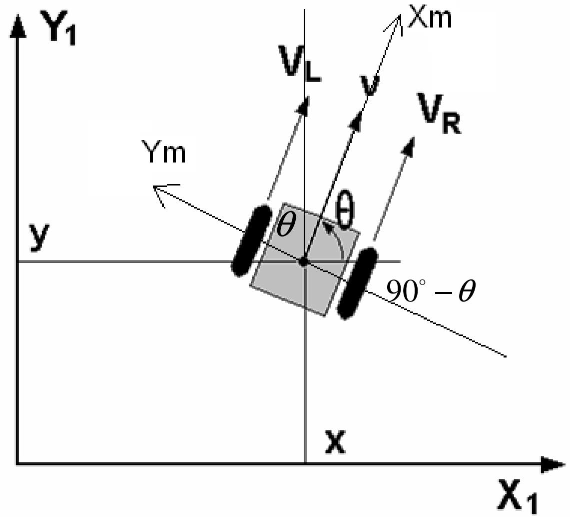
Differential Drive

Property: At each time instant, the left and right wheels must follow a trajectory that moves around the ICC at the same angular rate ω, i.e.,

$$\boxed{\omega(R+\frac{L}{2})=V_R \qquad \omega(R-\frac{L}{2})=V_L}$$

$$V_L = r\ \omega_L \qquad V_R = r\ \omega_R$$

$$\omega = \frac{V_R - V_L}{L} \qquad v = \frac{V_R + V_L}{2}$$



- Kinematic equation

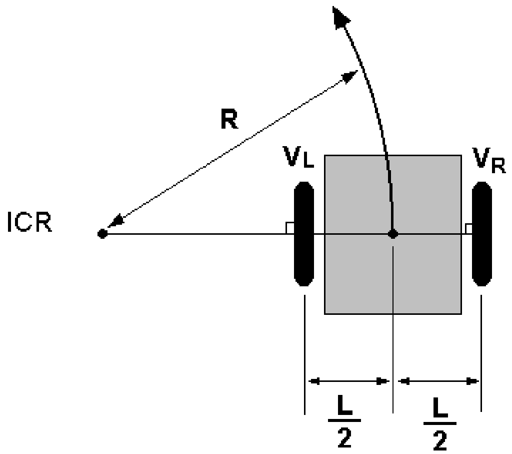
$$\begin{pmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{pmatrix} = \begin{pmatrix} \cos\theta & 0 \\ \sin\theta & 0 \\ 0 & 1 \end{pmatrix} \begin{pmatrix} v \\ \omega \end{pmatrix}$$

- Nonholonomic Constraint

$$[\sin\theta \quad -\cos\theta]\begin{bmatrix} \dot{x} \\ \dot{y} \end{bmatrix} = \dot{x}\sin\theta - \dot{y}\cos\theta = 0$$

Differential Drive

- Basic Motion Control



$$(V_R - V_L)/\ L = V_R\ /(R + \frac{L}{2})$$

$$R = \frac{L}{2}\,\frac{V_R + V_L}{V_R - V_L}$$

R : Radius of rotation

- Straight motion

  R = Infinity → $V_R = V_L$

- Rotational motion

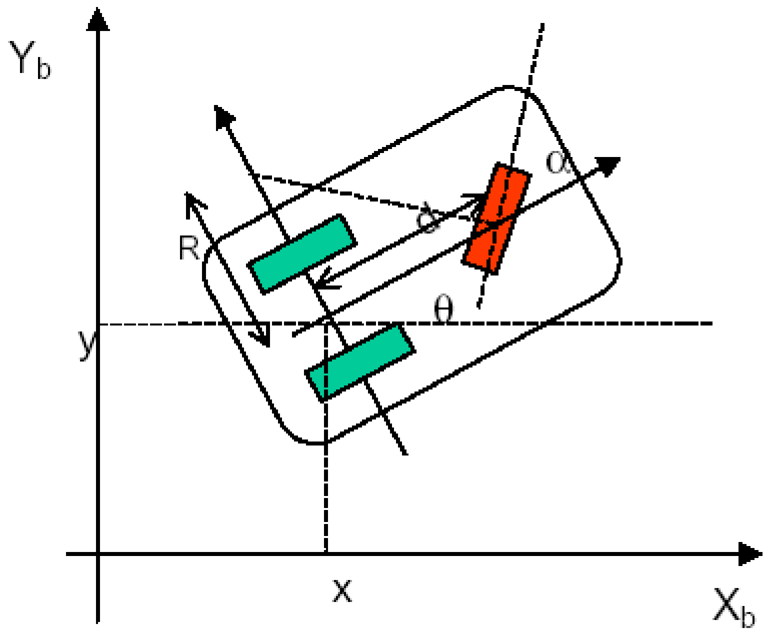
  R = 0 → $V_R = -V_L$

Tricycle

- Steering and power are provided through the front wheel
- control variables:
  - angular velocity of steering wheel $w_s(t)$
  - steering direction α(t)

r = steering wheel radius

$$v_s(t) = w_s(t)\, r$$ linear velocity of steering wheel



$$R(t) = d\, tg\left(\pi/2 - \alpha(t)\right)$$

$$w(t) = \frac{w_s(t)\, r}{\sqrt{d^2 + R(t)^2}}$$ angular velocity of the moving fram relative to the base frame

$$w(t) = \frac{v_s(t)}{d} \sin\alpha(t)$$

d: distance from the front wheel to the rear axle

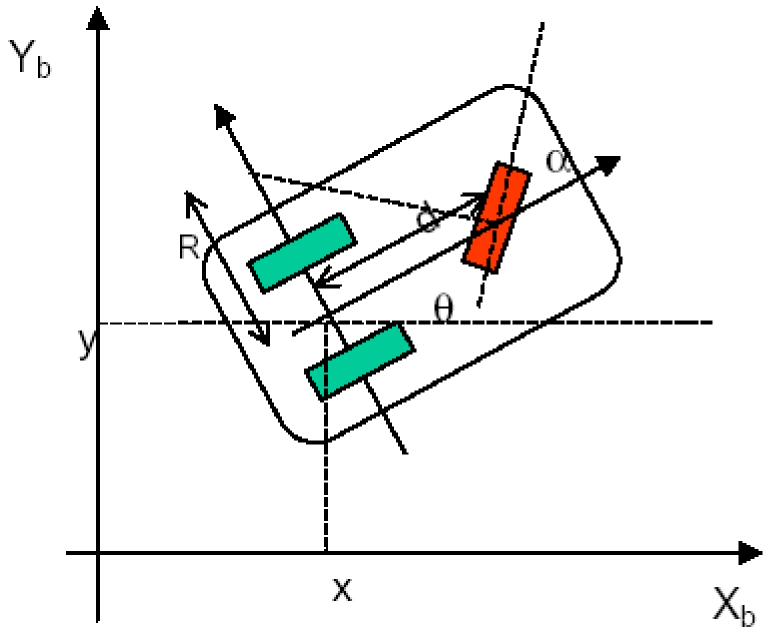
Tricycle

Kinematics model in the world frame
---Posture kinematics model

$$\dot{x}(t) = v_s(t)\cos\alpha(t)\cos\theta(t)$$
$$\dot{y}(t) = v_s(t)\cos\alpha(t)\sin\theta(t)$$
$$\dot{\theta}(t) = \frac{v_s(t)}{d}\sin\alpha(t)$$

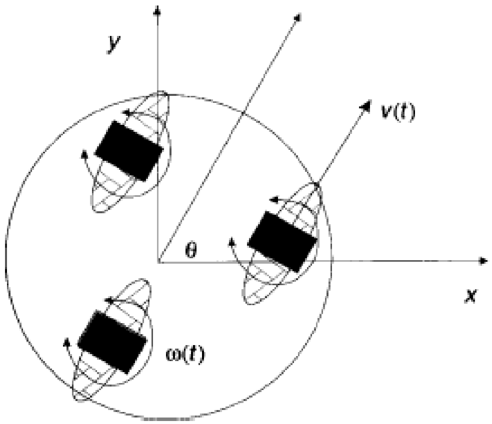
$$\begin{bmatrix}\dot{x}(t)\\ \dot{y}(t)\\ \dot{\theta}(t)\end{bmatrix} = \begin{bmatrix}\cos\theta(t) & 0\\ \sin\theta(t) & 0\\ 0 & 1\end{bmatrix}\begin{bmatrix}v(t)\\ w(t)\end{bmatrix}$$

$$v(t) = v_s(t)\cos\alpha(t)$$
$$w(t) = \frac{v_s(t)}{d}\sin\alpha(t)$$



Synchronous Drive

- All the wheels turn in unison
  - All wheels point in the same direction and turn at the same rate
  - Two independent motors, one rolls all wheels forward, one rotate them for turning
- Control variables (independent)
  - v(t), ω(t)



$$x(t) = \int_0^t v(\sigma)\cos(\theta(\sigma))d\sigma$$

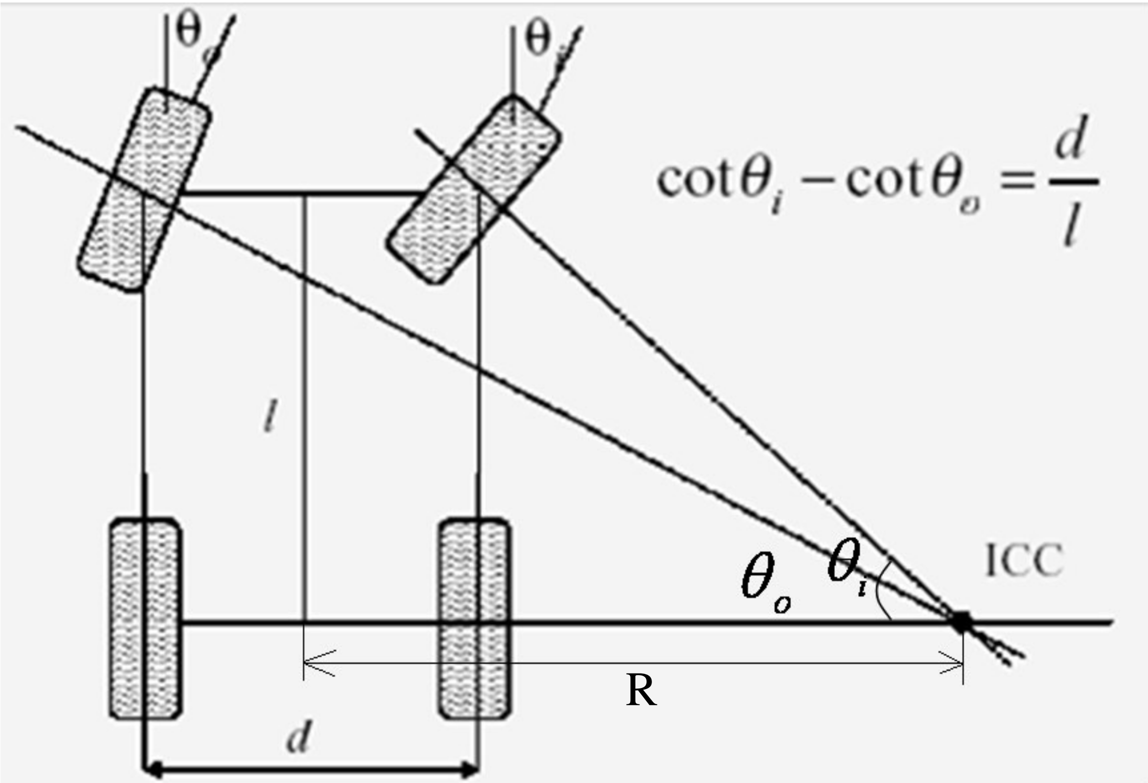
$$y(t) = \int_0^t v(\sigma)\sin(\theta(\sigma))d\sigma$$

$$\theta(t) = \int_0^t w(\sigma)d\sigma$$

Ackerman Steering (Car Drive)

- The Ackerman Steering equation:
  - : $$\cot\theta_i - \cot\theta_o = \frac{d}{l}$$

$$\cot\theta = \frac{\cos\theta}{\sin\theta}$$



$$\cot\theta_i - \cot\theta_o$$
$$= \frac{R+d/2}{l} - \frac{R-d/2}{l}$$
$$= \frac{d}{l}$$

Car-like Robot

Driving type: Rear wheel drive, front wheel steering

$$\dot{\theta} \cdot R = u_1 \Rightarrow \dot{\theta}\frac{l}{\tan\varphi} = u_1$$

Rear wheel drive car model:

$$\dot{x} = u_1 \cos\theta$$

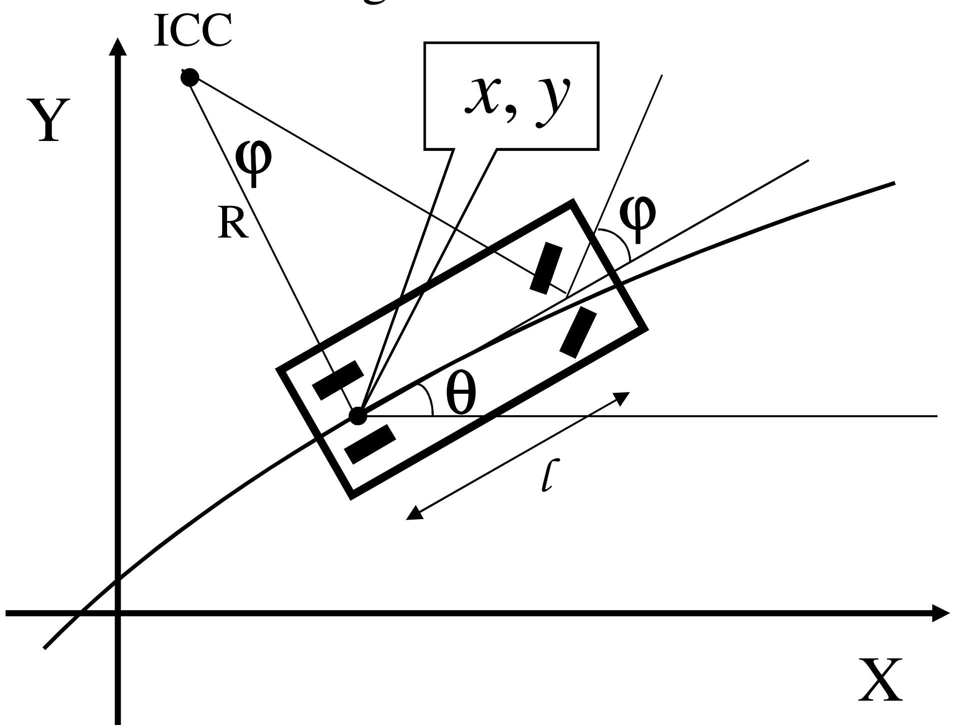
$$\dot{y} = u_1 \sin\theta$$

$$\dot{\theta} = \frac{u_1}{l}\tan\varphi$$

$$\dot{\varphi} = u_2$$

non-holonomic constraint:

$$\dot{x}\sin\theta - \dot{y}\cos\theta = 0$$



u_1 : forward velocity of the rear wheels

u_2 : angular velocity of the steering wheels

l : length between the front and rear wheels

Robot Sensing and Sensors

References

- *Sensors for mobile robots: theory and applications, H. R. Everett, A. K. Peters Ltd, C1995, ISBN: 1-56881-048-2*

- *Handbook of Modern Sensors: Physics, Designs and Applications*, 2nd edition, Jacob Fraden, AIP Press/Springer, 1996. ISBN 1-56396-538-0.

Some websites

- http://www.omega.com/ (sensors + hand-helds)
- http://www.extech.com/ (hand-helds)
- http://www.agilent.com/ (instruments, enormous)
- http://www.keithley.com/ (instruments, big)
- http://www.tegam.com/ (instruments, small)
- http://www.edsci.com/ (optics ++)
- http://www.pacific.net/~brooke/Sensors.html (comprehensive listing of sensors etc. and links)

What is Sensing ?

- Collect information about the world
- Sensor - an electrical/mechanical/chemical device that maps an environmental attribute to a quantitative measurement
- Each sensor is based on a ***transduction principle*** - conversion of energy from one form to another

Human sensing and organs

- Vision: eyes (optics, light)
- Hearing: ears (acoustics, sound)
- Touch: skin (mechanics, heat)
- Odor: nose (vapor-phase chemistry)
- Taste: tongue (liquid-phase chemistry)

Counterpart?

Extended ranges and modalities

- Vision outside the RGB spectrum
  - Infrared Camera, see at night
- Active vision
  - Radar and optical (laser) range measurement
- Hearing outside the 20 Hz – 20 kHz range
  - Ultrasonic range measurement
- Chemical analysis beyond taste and smell
- Radiation: α, β, γ-rays, neutrons, etc

Transduction to electronics

- Thermistor: temperature-to-resistance
- Electrochemical: chemistry-to-voltage
- Photocurrent: light intensity-to-current
- Pyroelectric: thermal radiation-to-voltage
- Humidity: humidity-to-capacitance
- Length (LVDT: Linear variable differential transformers) : position-to-inductance
- Microphone: sound pressure-to-<anything>

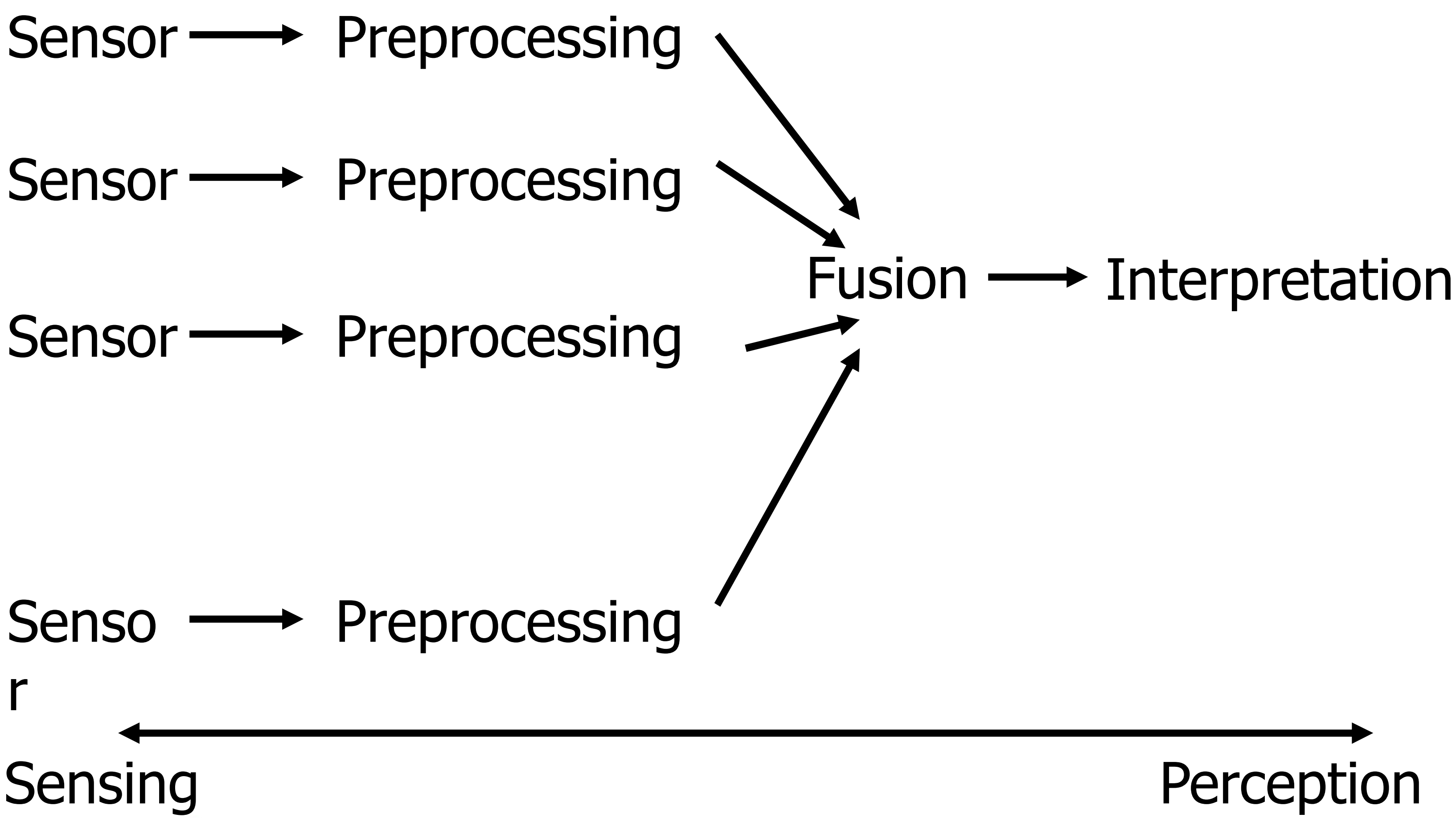
Sensor Fusion and Integration

- Human: One organ ⇔one sense?
  - Not necessarily
    - Balance: ears
    - Touch: tongue
    - Temperature: skin
- Robot:
  - Sensor fusion:
    - Combine readings from several sensors into a (uniform) data structure
  - Sensor integration:
    - Use information from several sensors to do something useful

Sensor Fusion

- One sensor is (usually) not enough
  - Real sensors are noisy
  - Limited Accuracy
  - Unreliable - Failure/redundancy
  - Limited point of view of the environment
    - Return an incomplete description of the environment
  - The sensor of choice may be expensive - might be cheaper to combine two inexpensive sensors

General Processing



Preprocessing

- Colloquially - ‘cleanup’ the sensor readings before using them

- Noise reduction - filtering
- Re-calibration
- ‘Basic’ stuff - e.g. edge detection in vision
- Usually unique to each sensor
- Change (transform) data representation

Sensor/Data Fusion

- Combine data from different sources
  - measurements from different sensors
  - measurements from different positions
  - measurements from different times

- Often a mathematical technique that takes into account uncertainties in data sources
  - Discrete Bayesian methods
  - Neural networks
  - Kalman filtering

- Produces a merged data set (as though there was one 'virtual sensor')

Interpretation

- Task specific
- Often modeled as a best fit problem given some *a priori* knowledge about the environment
- Tricky

Classification of Sensors

- Proprioception (Internal state) v.s. Exteroceptive (external state)
  - *measure values internally to the system (robot),* e.g. battery level, wheel position, joint angle, etc,
  - observation of environments, objects
- Active v.s. Passive
  - emitting energy into the environment, e.g., radar, sonar
  - passively receive energy to make observation, e.g., camera
- Contact v.s. non-contact
- Visual v.s. non-visual
  - vision-based sensing, image processing, video camera

Proprioceptive Sensors

- Encoders, Potentiometers
  - measure angle of turn via change in resistance or by counting optical pulses
- Gyroscopes
  - measure rate of change of angles
  - fiber-optic (newer, better), magnetic (older)
- Compass
  - measure which way is north
- GPS: measure location relative to globe

Touch Sensors

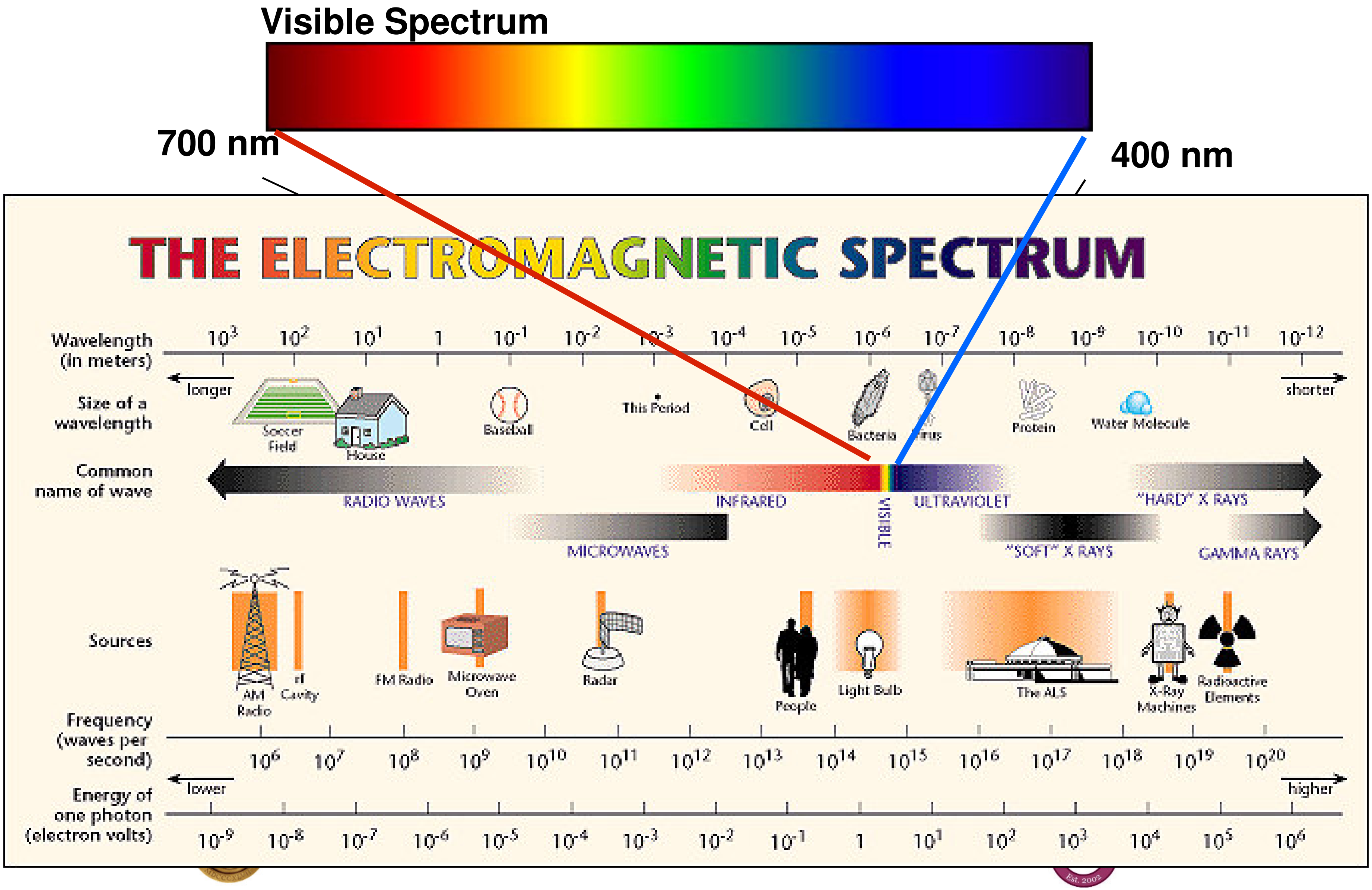
- Whiskers, bumpers etc.
  - mechanical contact leads to
    - closing/opening of a switch
    - change in resistance of some element
    - change in capacitance of some element
    - change in spring tension
    - ...

Sensors Based on Sound

- SONAR: **So**und **N**avigation **a**nd **R**anging
  - bounce sound off of objects
  - measure time for reflection to be heard - gives a range measurement
  - measure change in frequency - gives the relative speed of the object (Doppler effect)
  - bats and dolphins use it with amazing results
  - robots use it w/ less than amazing results

Sensors Based on EM Spectrum

Electromagnetic Spectrum



Sensors Based on EM Spectrum

- Radio and Microwave
  - RADAR: **Ra**dio **D**etection **a**nd **R**anging
  - Microwave radar: insensitive to clouds
- Coherent light
  - all photons have same phase and wavelength
  - LASER: **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation
  - LASER RADAR: LADAR - accurate ranging

Sensors Based on EM Spectrum

- Light sensitive
  - eyes, cameras, photocells etc.
  - Operating principle
    - CCD - charge coupled devices
    - photoelectric effect
- IR sensitive
  - Local Proximity Sensing
    - Infrared LEDs (cheap, active sensing)
    - usually low resolution - normally used for presence/absence of obstacles rather than ranging, operate over small range
  - Sense heat differences and construct images
    - Human detection sensors
    - night vision application

General Classification (1)

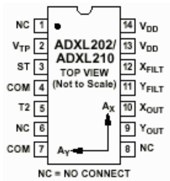
General classification (typical use)	Sensor Sensor System	PC or EC	A or P
Tactile sensors (detection of physical contact or closeness; security switches)	Contact switches, bumpers	EC	P
	Optical barriers	EC	A
	Noncontact proximity sensors	EC	A
Wheel/motor sensors (wheel/motor speed and position)	Brush encoders	PC	P
	Potentiometers	PC	P
	Synchros, resolvers	PC	A
	Optical encoders	PC	A
	Magnetic encoders	PC	A
	Inductive encoders	PC	A
	Capacitive encoders	PC	A
Heading sensors (orientation of the robot in relation to a fixed reference frame)	Compass	EC	P
	Gyroscopes	PC	P
	Inclinometers	EC	A/P

A, active; P, passive; P/A, passive/active; PC, proprioceptive; EC, exteroceptive.

General Classification (2)

General classification (typical use)	Sensor Sensor System	PC or EC	A or P
Ground-based beacons (localization in a fixed reference frame)	GPS Active optical or RF beacons Active ultrasonic beacons Reflective beacons	EC EC EC EC	A A A A
Active ranging (reflectivity, time-of-flight, and geometric triangulation)	Reflectivity sensors Ultrasonic sensor Laser rangefinder Optical triangulation (1D) Structured light (2D)	EC EC EC EC EC	A A A A A
Motion/speed sensors (speed relative to fixed or moving objects)	Doppler radar Doppler sound	EC EC	A A
Vision-based sensors (visual ranging, whole-image analysis, segmentation, object recognition)	CCD/CMOS camera(s) Visual ranging packages Object tracking packages	EC	P

Sensors Used in Robot



Accelerometer


Gyro


Pendulum Resistive Tilt Sensors

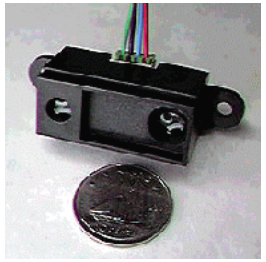

Metal Detector

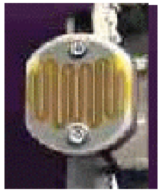

Gas Sensor

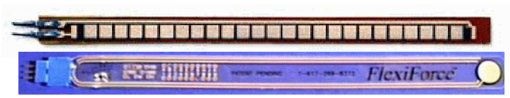

Gieger-Muller Radiation Sensor


Piezo Bend Sensor


Pyroelectric Detector

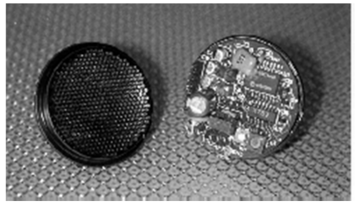

Digital Infrared Ranging

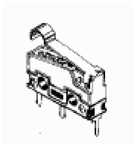

CDS Cell Resistive Light Sensor

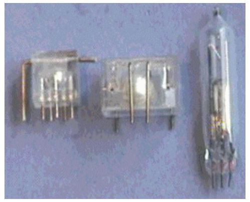


Resistive Bend Sensors

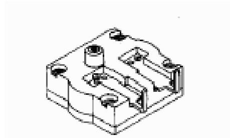

UV Detector

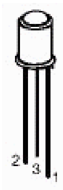

Miniature Polaroid Sensor

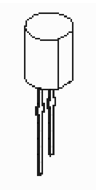

Limit Switch

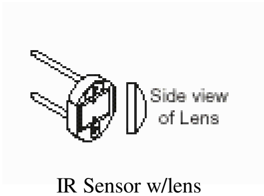

Mechanical Tilt Sensors


Touch Switch

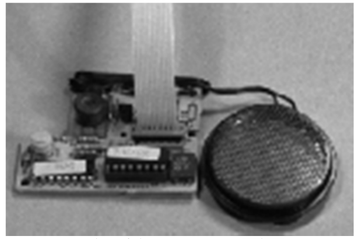

Pressure Switch

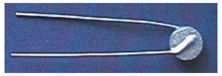


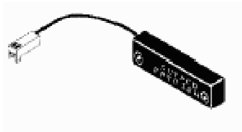

IR Pin Diode

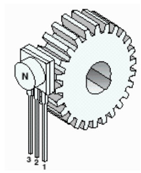


IR Sensor w/lens


Polaroid Sensor Board

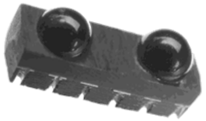

Thyristor


Magnetic Sensor

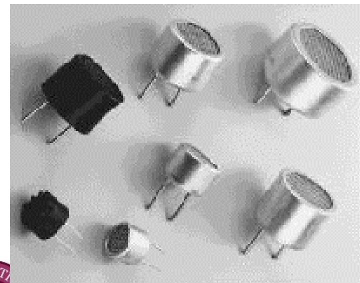

Hall Effect Magnetic Field Sensors

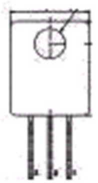

IR Reflection Sensor

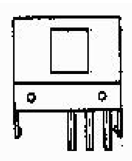

IR Amplifier Sensor

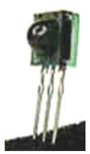

IRDA Transceiver


Magnetic Reed Switch

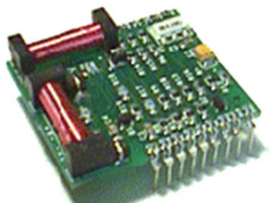

Piezo Ultrasonic Transducers

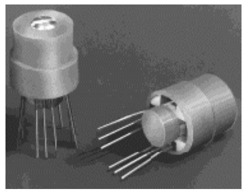

Lite-On IR Remote Receiver


Radio Shack Remote Receiver


IR Modulator Receiver


Solar Cell


Compass


Compass

Sensors Used in Robot

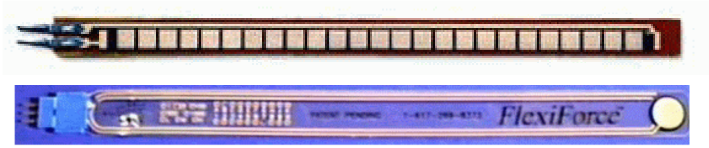
- Resistive sensors
  - bend sensors, potentiometer, resistive photocells, ...
- Tactile sensors
  - contact switch, bumpers…
- Infrared sensors
  - Reflective, proximity, distance sensors…
- Ultrasonic Distance Sensor
- Inertial Sensors (measure the second derivatives of position)
  - Accelerometer, Gyroscopes,
- Orientation Sensors
  - Compass, Inclinometer
- Laser range sensors
- Vision, GPS, …

Resistive Sensors

Resistive Sensors

Bend Sensors

- Resistance = 10k to 35k
- As the strip is bent, resistance increases



Resistive Bend Sensor

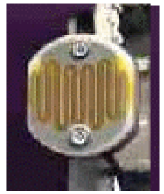
Potentiometers

- Can be used as position sensors for sliding mechanisms or rotating shafts
- Easy to find, easy to mount

Potentiometer

Light Sensor (Photocell)

- Good for detecting direction/presence of light
- Non-linear resistance
- Slow response to light changes

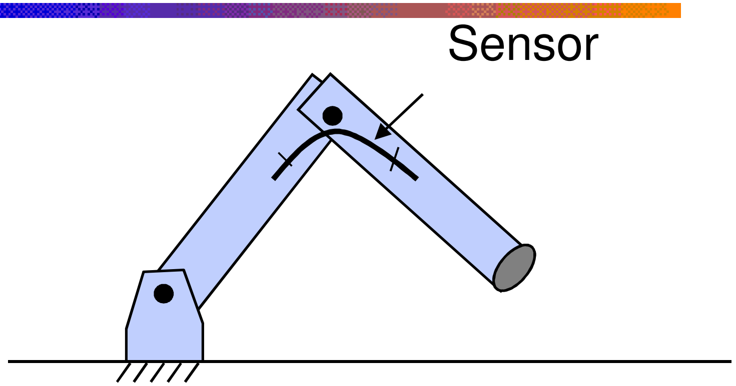


Photocell

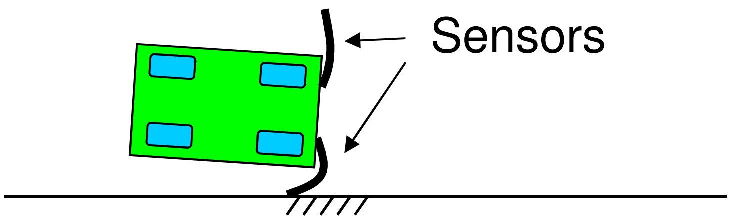
R is small when brightly illuminated

Applications

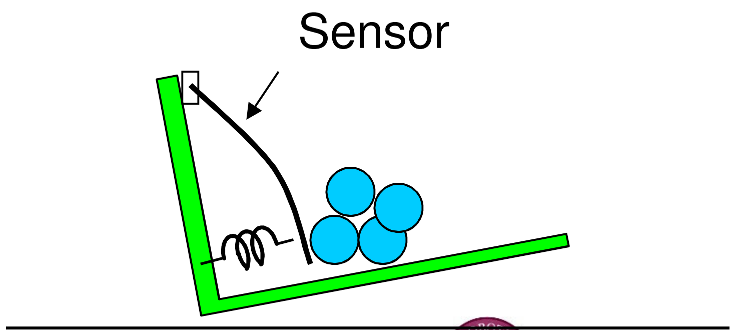
- Measure bend of a joint



- Wall Following/Collision Detection



- Weight Sensor

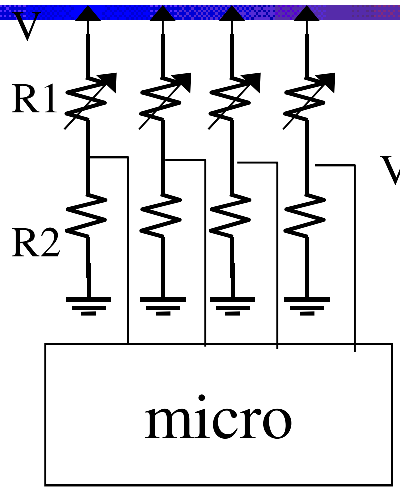


Inputs for Resistive Sensors

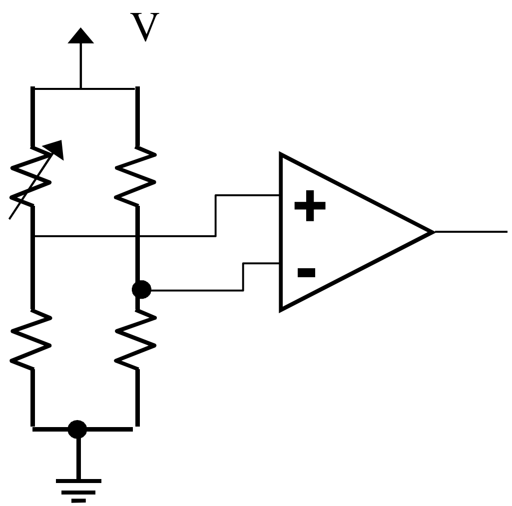
Voltage divider:

You have two resisters, one is fixed and the other varies, as well as a constant voltage

$$V_{sense} = \frac{R_2}{R_1 + R_2} V$$



A/D converter



Binary Threshold

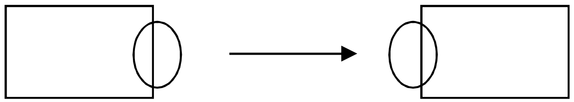
Digital I/O

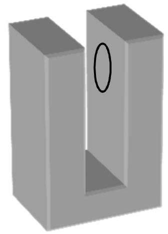
Comparator:
If voltage at + is greater than at -, digital high out

Infrared Sensors

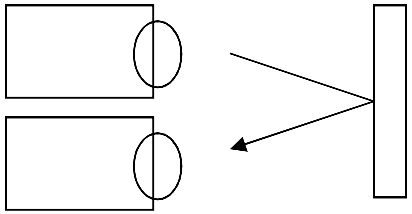
- Intensity based infrared
  - Reflective sensors
  - Easy to implement
  - susceptible to ambient light
- Modulated Infrared
  - Proximity sensors
  - Requires modulated IR signal
  - Insensitive to ambient light
- Infrared Ranging
  - Distance sensors
  - Short range distance measurement
  - Impervious to ambient light, color and reflectivity of object

Intensity Based Infrared

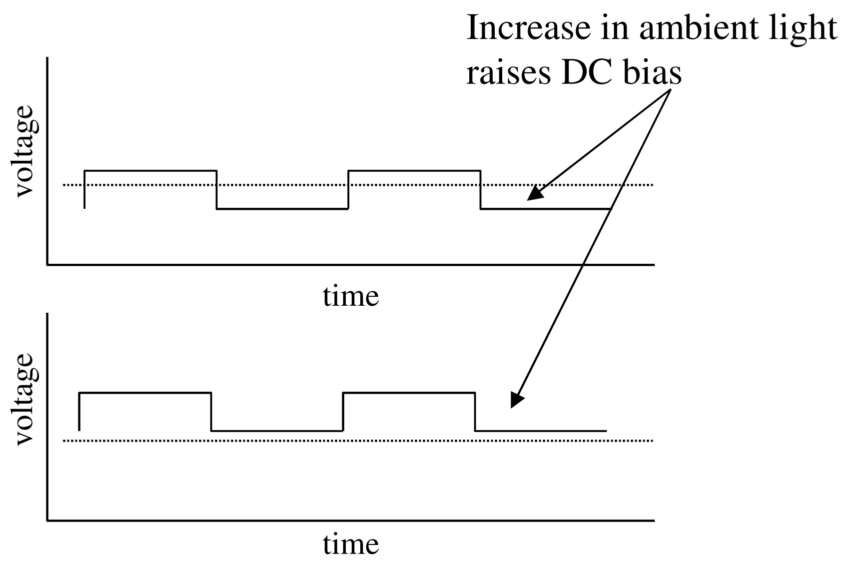




Break-Beam sensor



Reflective Sensor

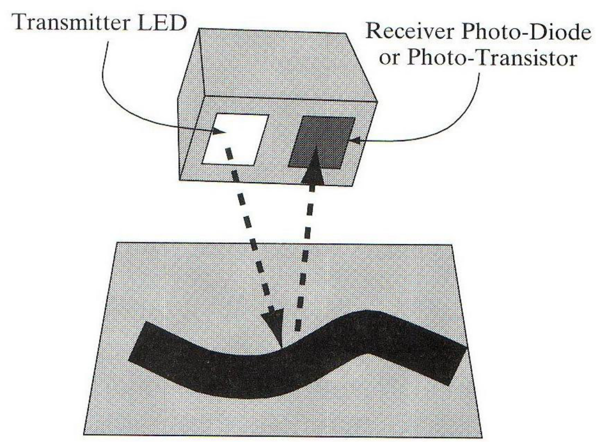


- Easy to implement (few components)
- Works very well in controlled environments
- Sensitive to ambient light

IR Reflective Sensors

- Reflective Sensor:
  - Emitter IR LED + detector photodiode/phototransistor
  - Phototransistor: the more light reaching the phototransistor, the more current passes through it
  - A beam of light is reflected off a surface and into a detector
  - Light usually in infrared spectrum, IR light is invisible

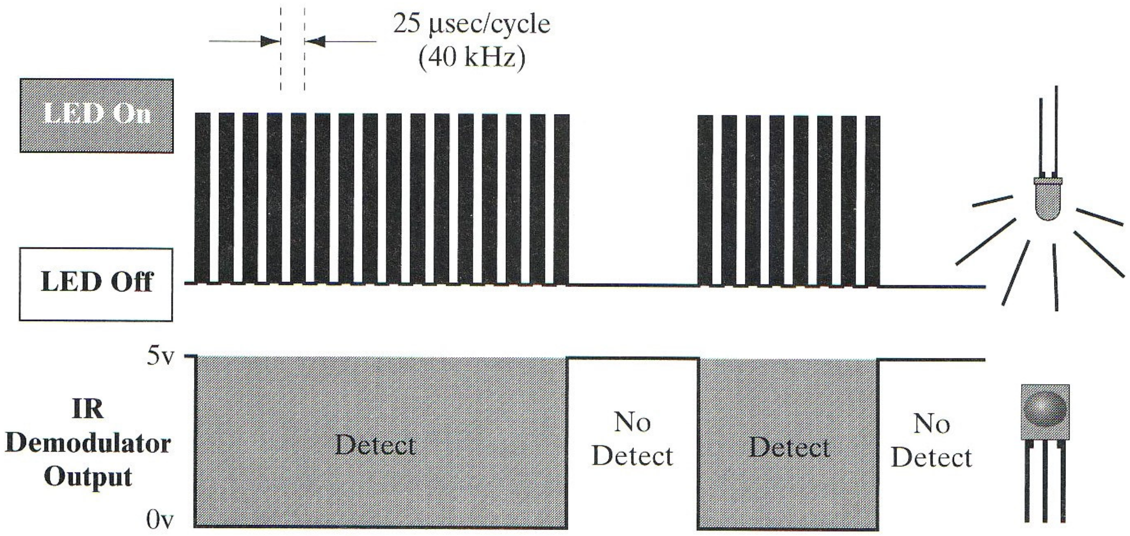
- Applications:
  - Object detection,
  - Line following, Wall tracking
  - Optical encoder (Break-Beam sensor)



- Drawbacks:
  - Susceptible to ambient lighting
    - Provide sheath to insulate the device from outside lighting
  - Susceptible to reflectivity of objects
  - Susceptible to the distance between sensor and the object

Modulated Infrared

- Modulation and Demodulation
  - Flashing a light source at a particular frequency
  - Demodulator is tuned to the specific frequency of light flashes. (32kHz~45kHz)
  - Flashes of light can be detected even if they are very week
  - Less susceptible to ambient lighting and reflectivity of objects
  - Used in most IR remote control units, proximity sensors

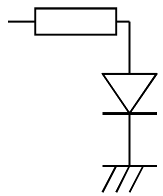


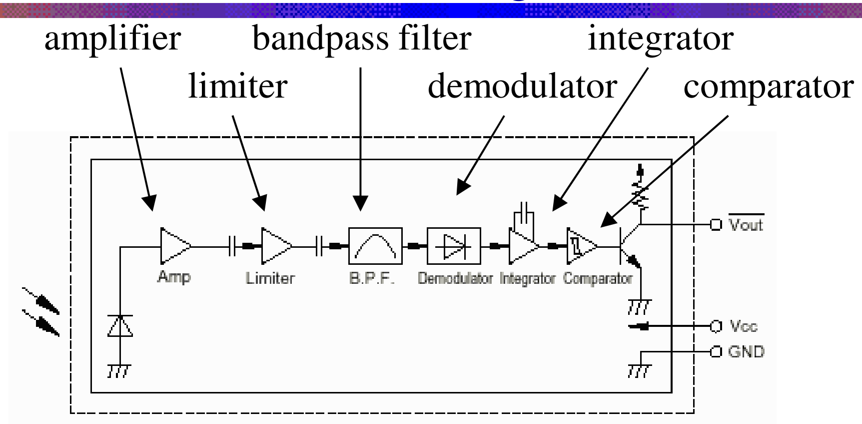
Negative true logic:

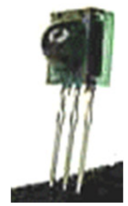
Detect = 0v

No detect = 5v

IR Proximity Sensors



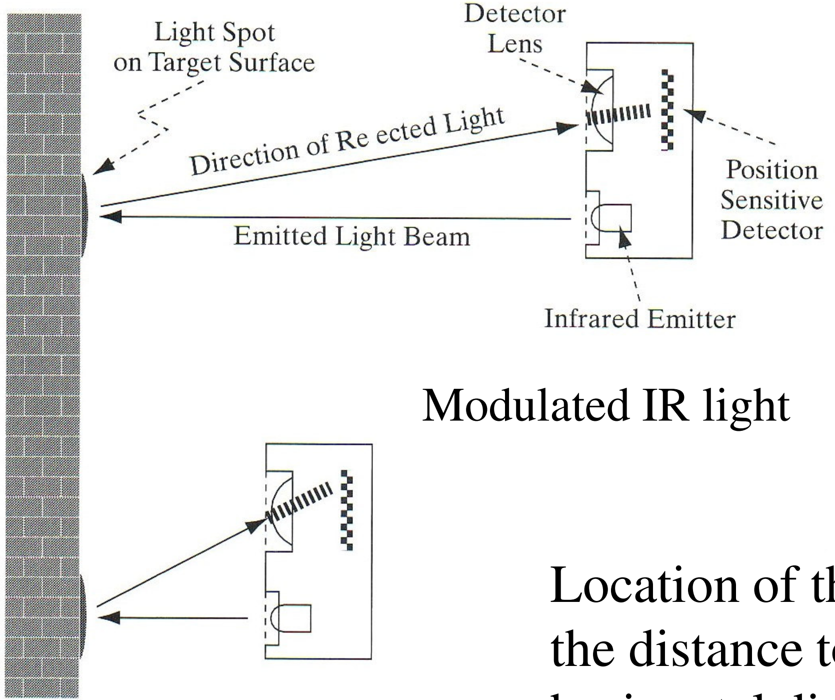




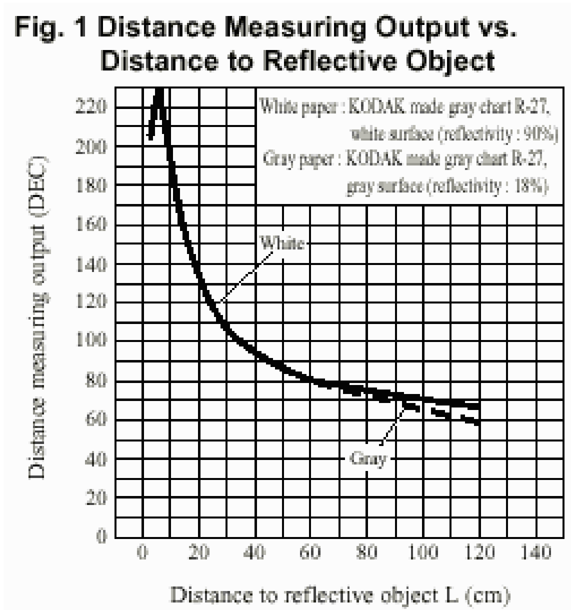
- Proximity Sensors:
  - Requires a modulated IR LED, a detector module with built-in modulation decoder
  - Current through the IR LED should be limited: adding a series resistor in LED driver circuit
  - Detection range: varies with different objects (shiny white card vs. dull black object)
  - Insensitive to ambient light
- Applications:
  - Rough distance measurement
  - Obstacle avoidance
  - Wall following, line following

IR Distance Sensors

- Basic principle of operation:
  - IR emitter + focusing lens + position-sensitive detector



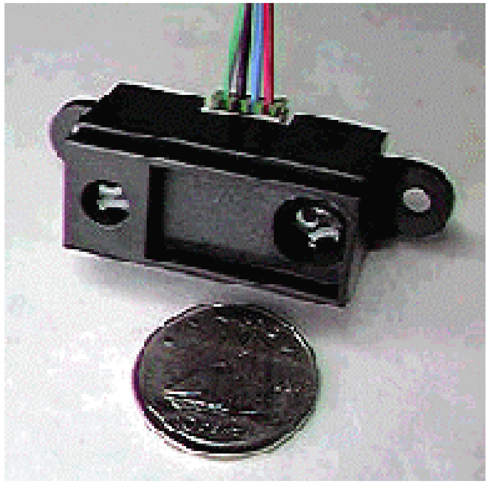
Modulated IR light



Location of the spot on the detector corresponds to the distance to the target surface, Optics to covert horizontal distance to vertical distance

IR Distance Sensors

- Sharp GP2D02 IR Ranger
  - Distance range: 10cm (4") ~ 80cm (30").
  - Moderately reliable for distance measurement
  - Immune to ambient light
  - Impervious to color and reflectivity of object
  - Applications: distance measurement, wall following, …



Basic Navigation Techniques

- Relative Positioning (called ***Dead-reckoning***)
  - Information required: incremental (internal)
    - Velocity
    - heading
  - With this technique the position can be updated with respect to a starting point
  - Problems: unbounded accumulation error
- Absolute Positioning
  - Information Required: absolute (external)
  - Absolute references (wall, corner, landmark)
  - Methods
    - Magnetic Compasses (absolute heading, earth's magnetic field)
    - Active Beacons
    - Global Positioning Systems (GPS)
    - Landmark Navigation (absolute references: wall, corner, artificial landmark)
    - Map-based positioning

Dead Reckoning

Cause of unbounded accumulation error:

Systematic Errors:

a) Unequal wheel diameters

b) Average of both wheel diameters differs from nominal diameter

c) Misalignment of wheels

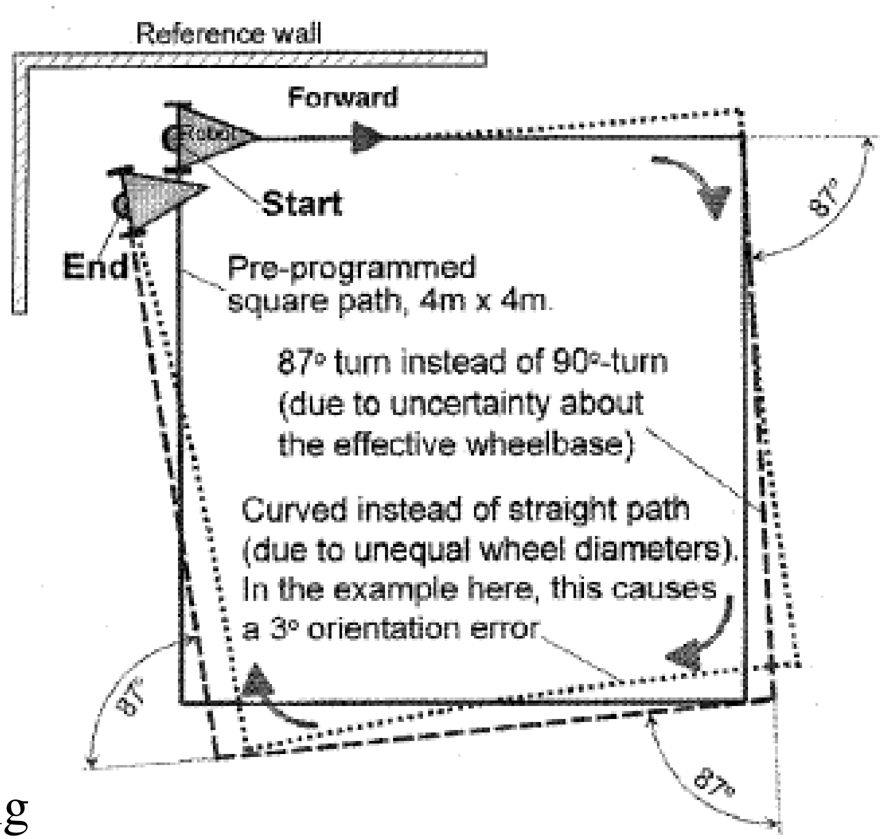
d) Limited encoder resolution, sampling rate, …

Nonsystematic Errors:

a) Travel over uneven floors

b) Travel over unexpected objects on the floor

c) Wheel-slippage due to : slippery floors; over-acceleration, fast turning (skidding), non-point wheel contact with the floor



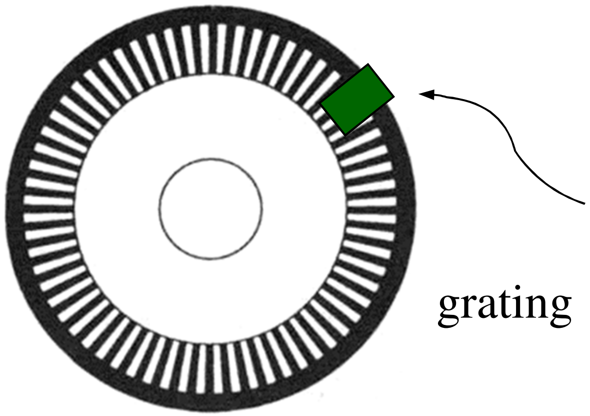
Sensors used in navigation

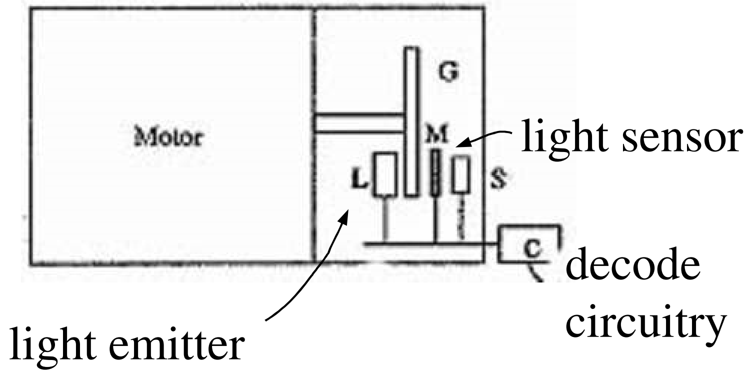
- Dead Reckoning
  - Odometry (monitoring the wheel revolution to compute the offset from a known starting position)
    - Encoders,
    - Potentiometer,
    - Tachometer, …
  - Inertial Sensors (measure the second derivative of position)
    - Gyroscopes,
    - Accelerometer, …
- External Sensors
  - Compass
  - Ultrasonic
  - Laser range sensors
  - Radar
  - Vision
  - Global Positioning System (GPS)

Motor Encoder

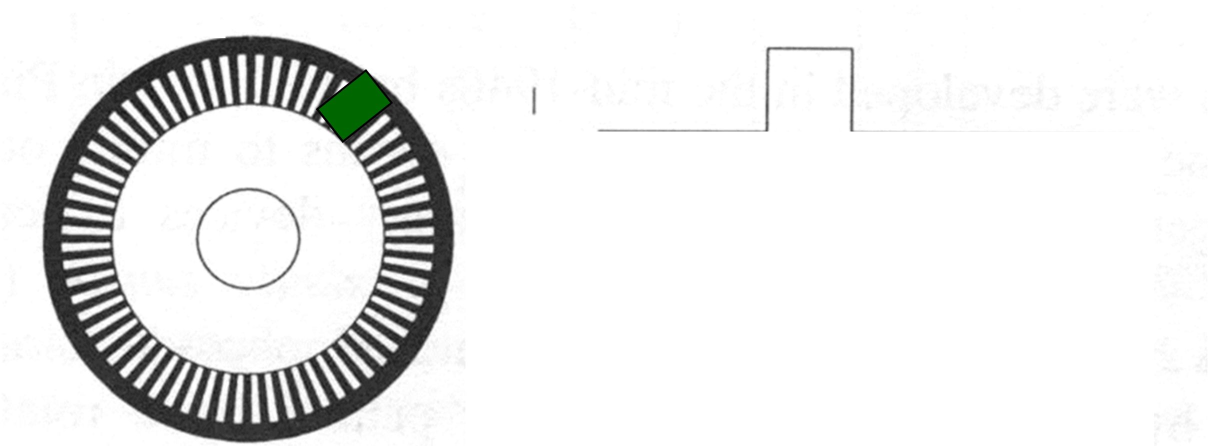
Incremental Optical Encoders

- Relative position





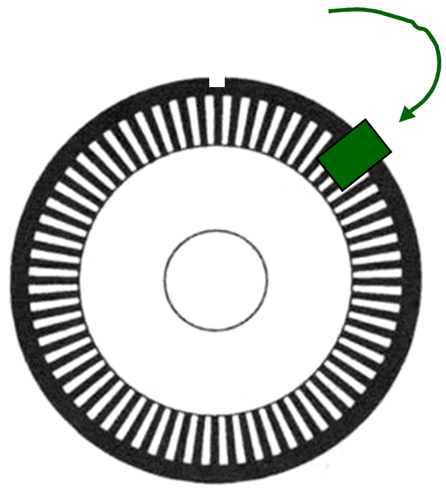
- calibration ?
- direction ?
- resolution ?



Incremental Optical Encoders

Quiz 1:

If there are 100 lines in the grating, what is the smallest detectable change in motor-shaft angle?



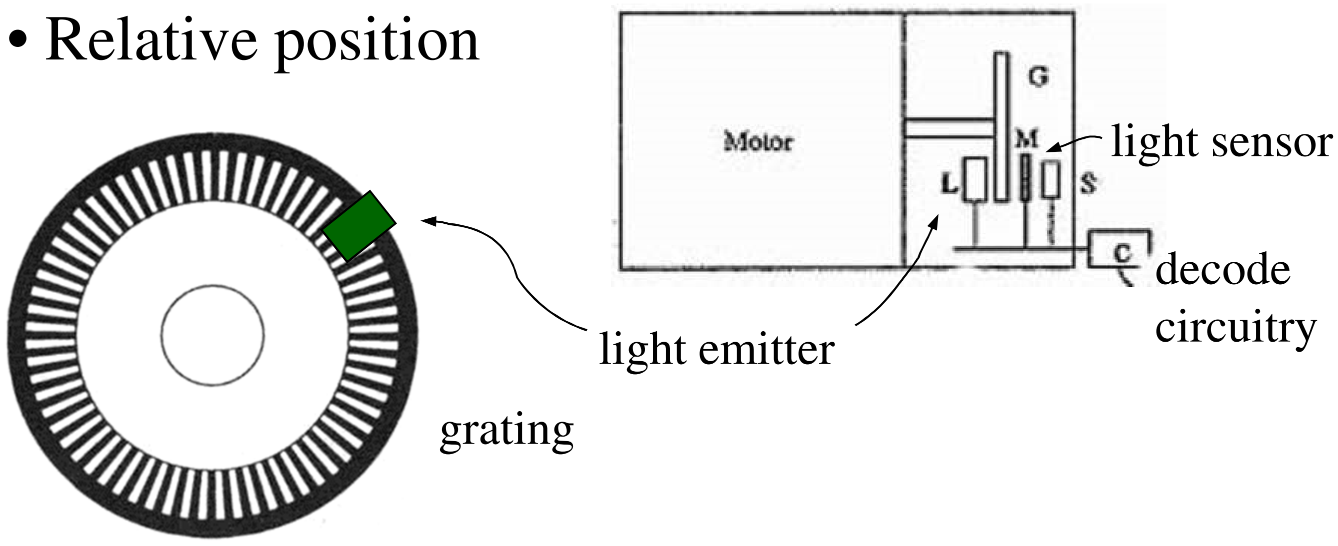
light emitter/detector

Quiz 2:

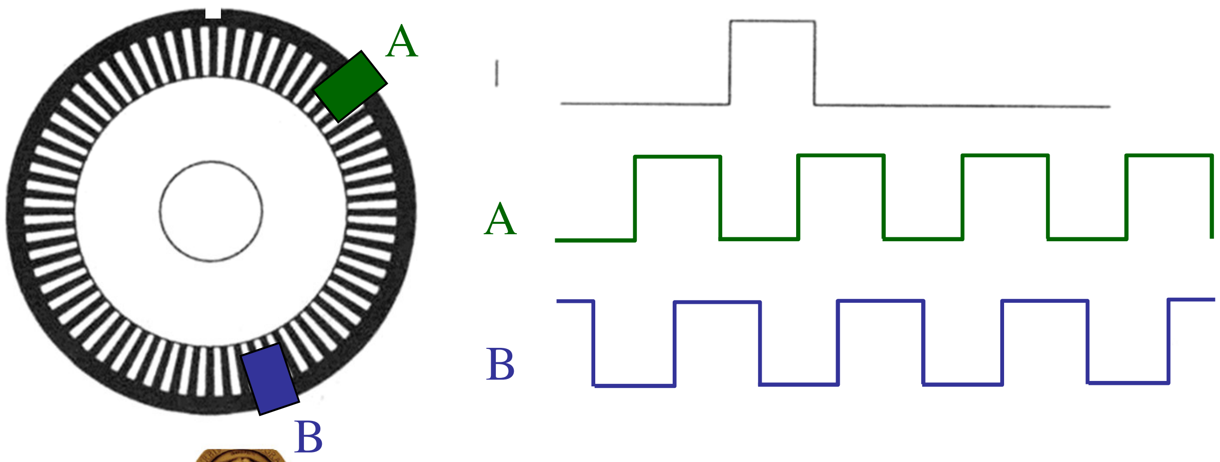
How could you augment a grating-based (relative) encoder in order to detect the *direction* of rotation?

Incremental Optical Encoders

- Relative position



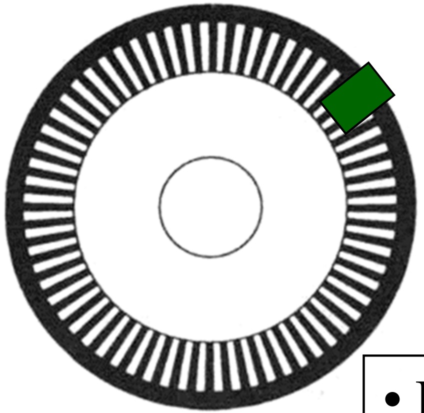
- calibration ?
- direction ?
- resolution ?

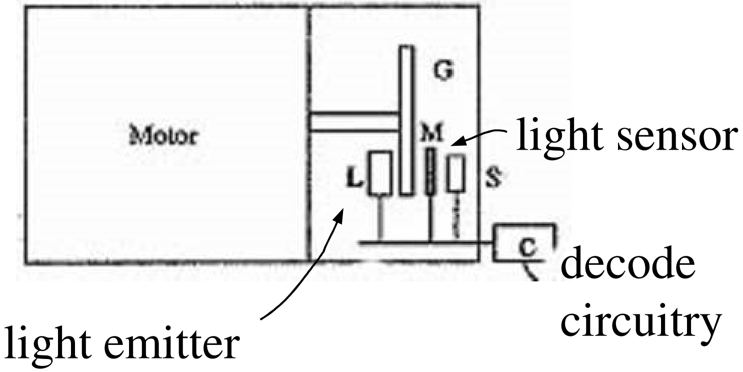


A leads B

Incremental Optical Encoders

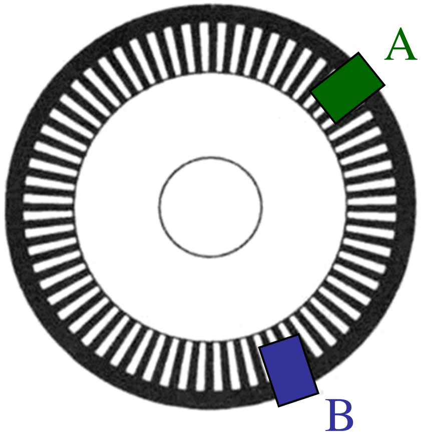
- Incremental Encoder:

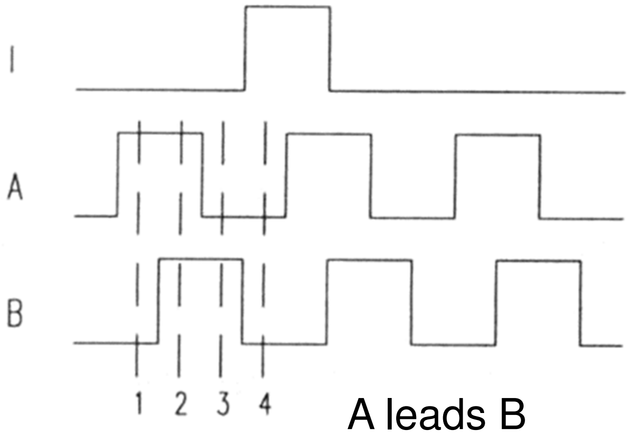




- direction
- resolution

- It generates pulses proportional to the rotation speed of the shaft.
- **Direction** can also be indicated with a two phase encoder:



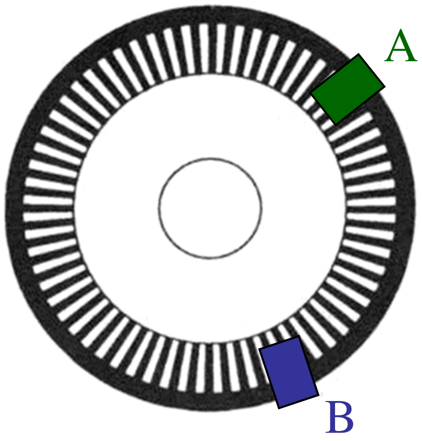


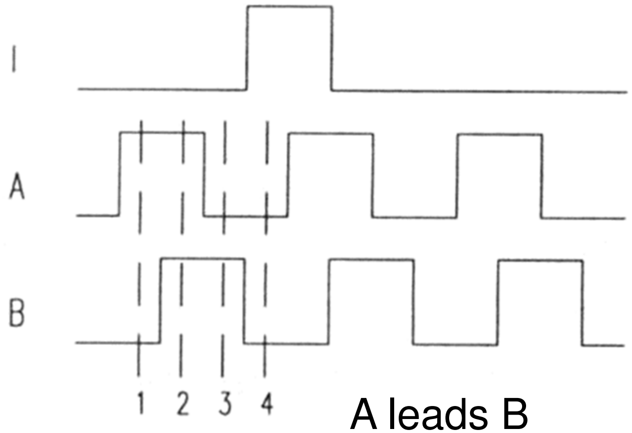
A leads B

State	Ch A	Ch B
S_1	High	Low
S_2	High	High
S_3	Low	High
S_4	Low	Low

Incremental Optical Encoders

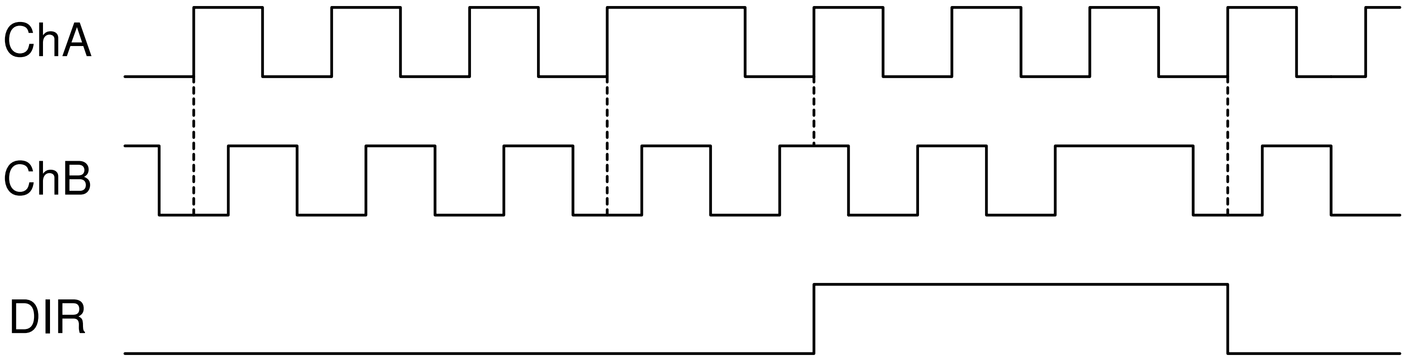
- Incremental Encoder:





A leads B

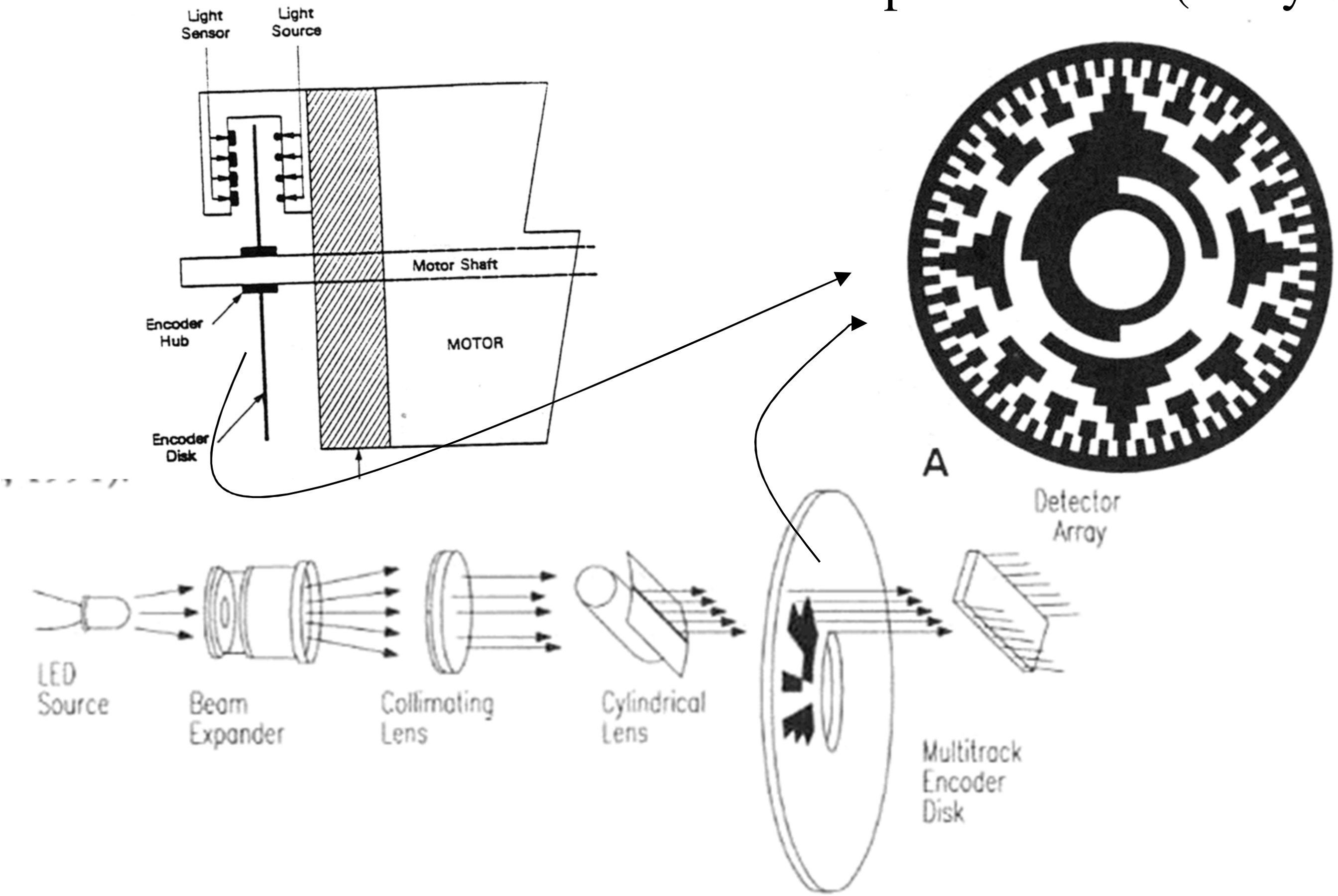
State	Ch A	Ch B
S_1	High	Low
S_2	High	High
S_3	Low	High
S_4	Low	Low



Encoder pulse and motor direction

Absolute Optical Encoders

- Used when loss of reference is not possible.
- Gray codes: only one bit changes at a time (less uncertainty).
- The information is transferred in parallel form (many wires are necessary).



Binary	Gray Code
000	000
001	001
010	011
011	010
100	110
101	111
110	101
111	100

Other Odometry Sensors

- **Resolver**

It has two stator windings positioned at 90 degrees. The output voltage is proportional to the sine or cosine function of the rotor's angle. The rotor is made up of a third winding, winding C

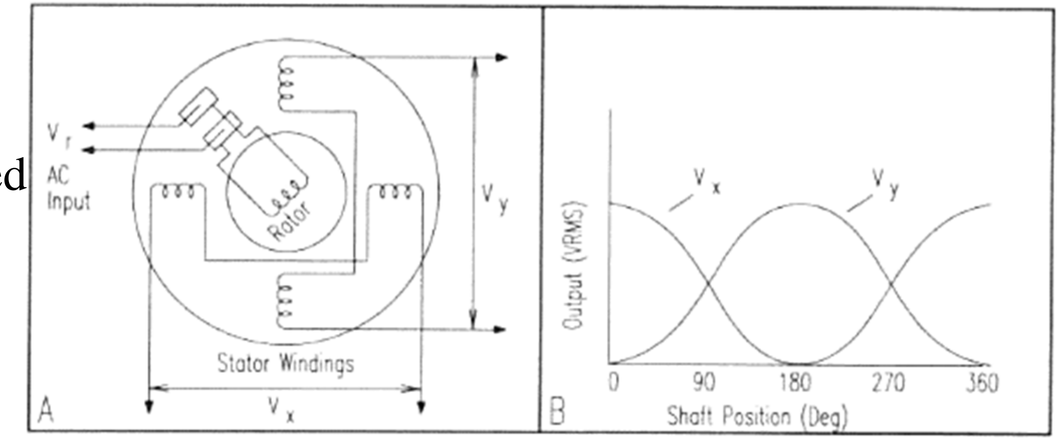


Figure 2-4. The outputs of the two orthogonal stator windings in a *resolver* are proportional to the sine and cosine of the applied rotor excitation (adapted from Tiwari, 1993).

- **Potentiometer**

= varying resistance

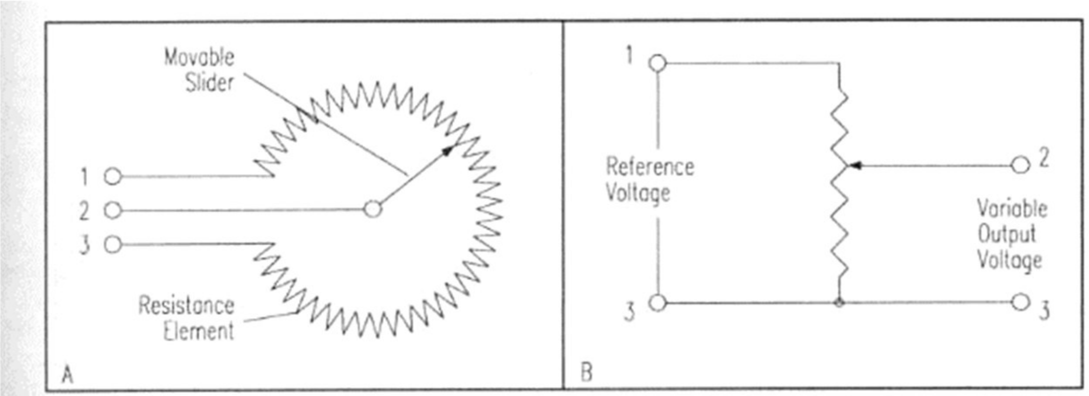


Figure 2-1. For a linear-taper pot, the output voltage V_o is directly related to the ratio of actual to full scale displacement.

Range Finder

(Ultrasonic, Laser)

Range Finder

- Time of Flight

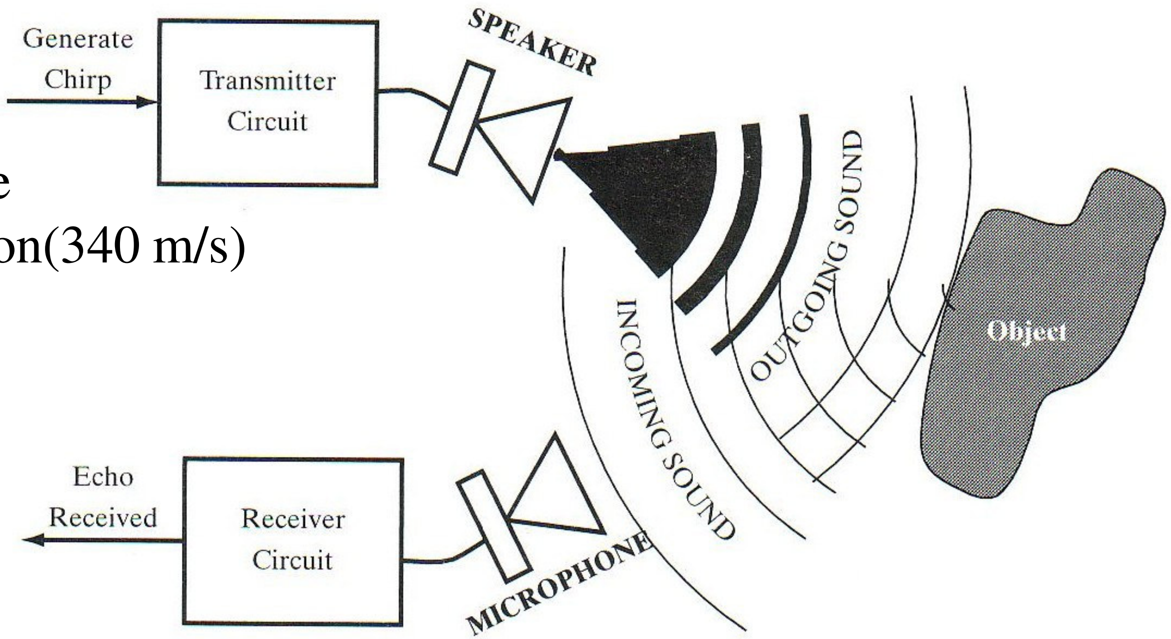
- The measured pulses typically come form ultrasonic, RF and optical energy sources.
  - **D = v * t**
  - D = round-trip distance
  - v = speed of wave propagation
  - t = elapsed time
- Sound = 0.3 meters/msec
- RF/light = 0.3 meters / ns (Very difficult to measure short distances 1-100 meters)

Ultrasonic Sensors

- Basic principle of operation:
  - Emit a quick burst of ultrasound (50kHz), (human hearing: 20Hz to 20kHz)
  - Measure the elapsed time until the receiver indicates that an echo is detected.
  - Determine how far away the nearest object is from the sensor

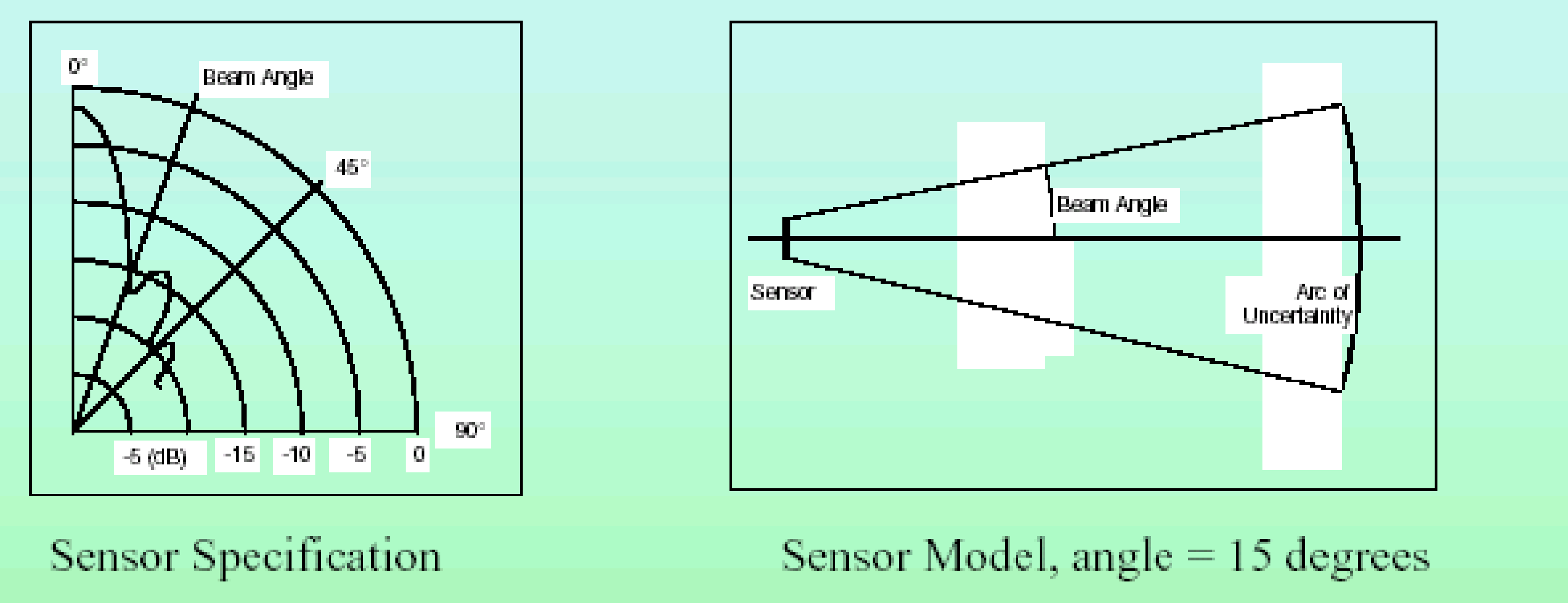
- **D = v * t**

D = round-trip distance
v = speed of propagation(340 m/s)
t = elapsed time



Bat, dolphin, …

Ultrasonic Sensors



- Ranging is accurate but bearing has a 30 degree uncertainty. The object can be located anywhere in the arc.
- Typical ranges are of the order of several centimeters to 30 meters.
- Another problem is the propagation time. The ultrasonic signal will take 200 msec to travel 60 meters. (30 meters roundtrip @ 340 m/s)

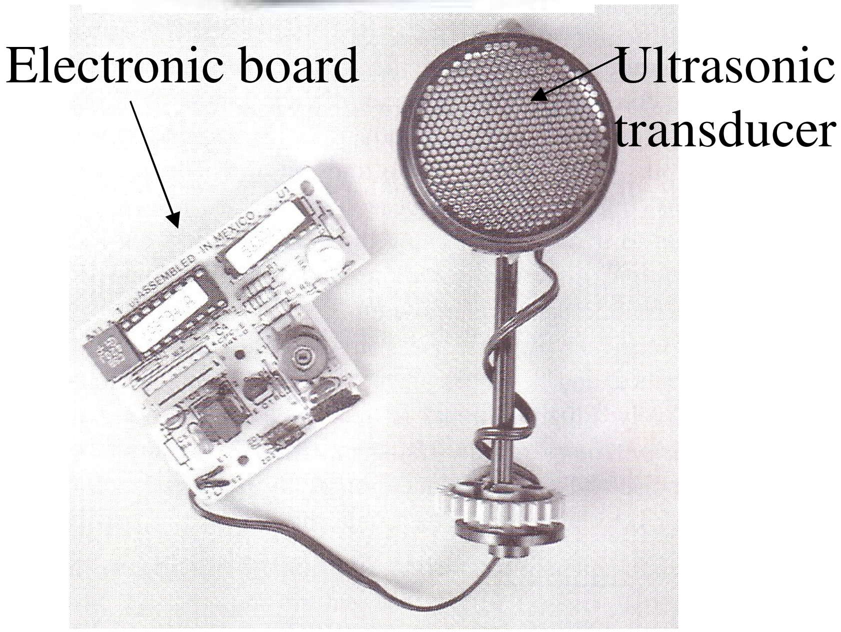
Polaroid Ultrasonic Sensors

–It was developed for an automatic camera focusing system

–Range: 6 inches to 35 feet

Transducer Ringing:

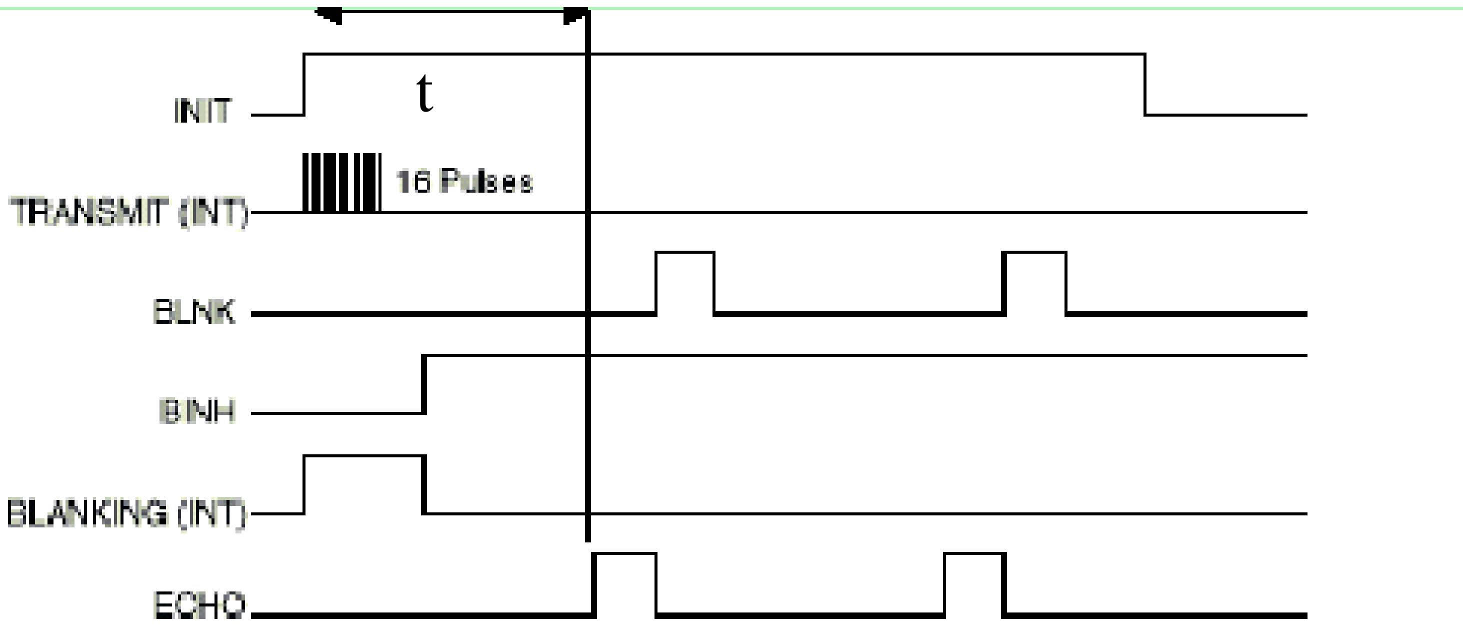
– transmitter + receiver @ 50 KHz
– Residual vibrations or ringing may be interpreted as the echo signal
– Blanking signal to block any return signals for the first 2.38ms after transmission



http://www.acroname.com/robotics/info/articles/sonar/sonar.html

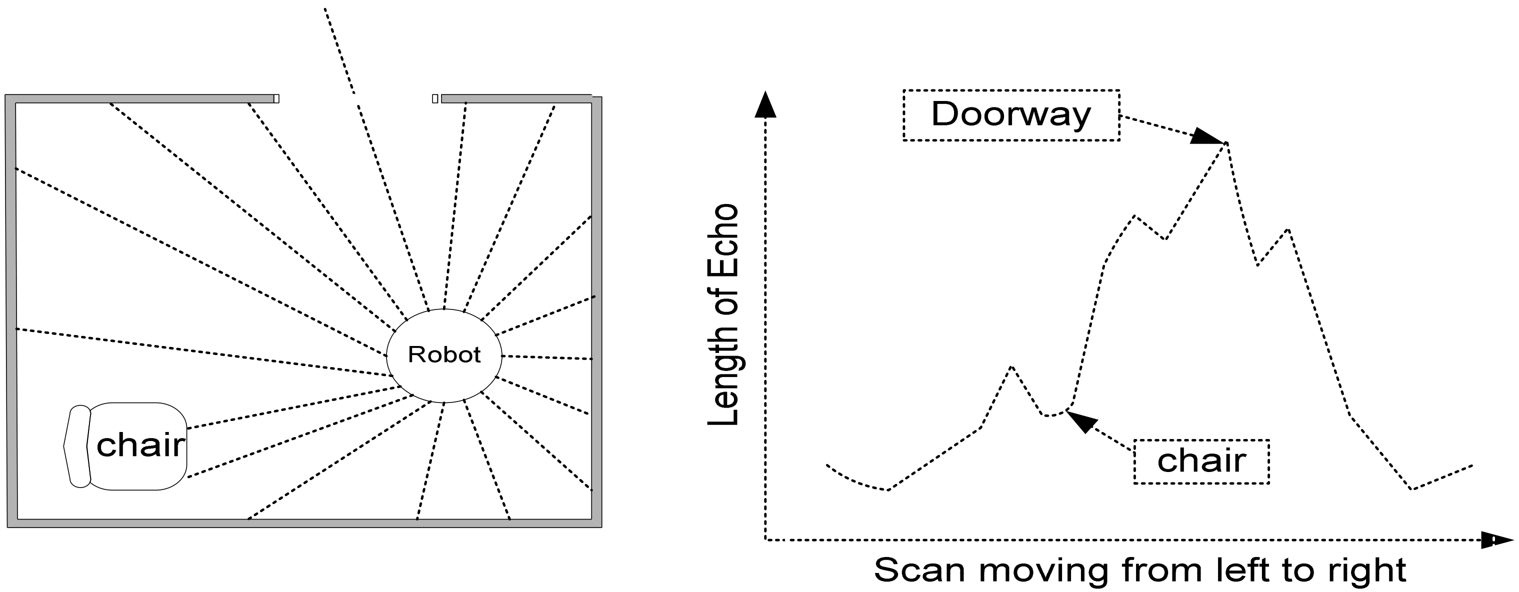
Operation with Polaroid Ultrasonic

- The Electronic board supplied has the following I/0
  - **INIT** : trigger the sensor, (16 pulses are transmitted)
  - **BLANKING** : goes high to avoid detection of own signal
  - **ECHO** : echo was detected.
  - **BINH** : goes high to end the blanking (reduce blanking time < 2.38 ms)
  - **BLNK** : to be generated if multiple echo is required



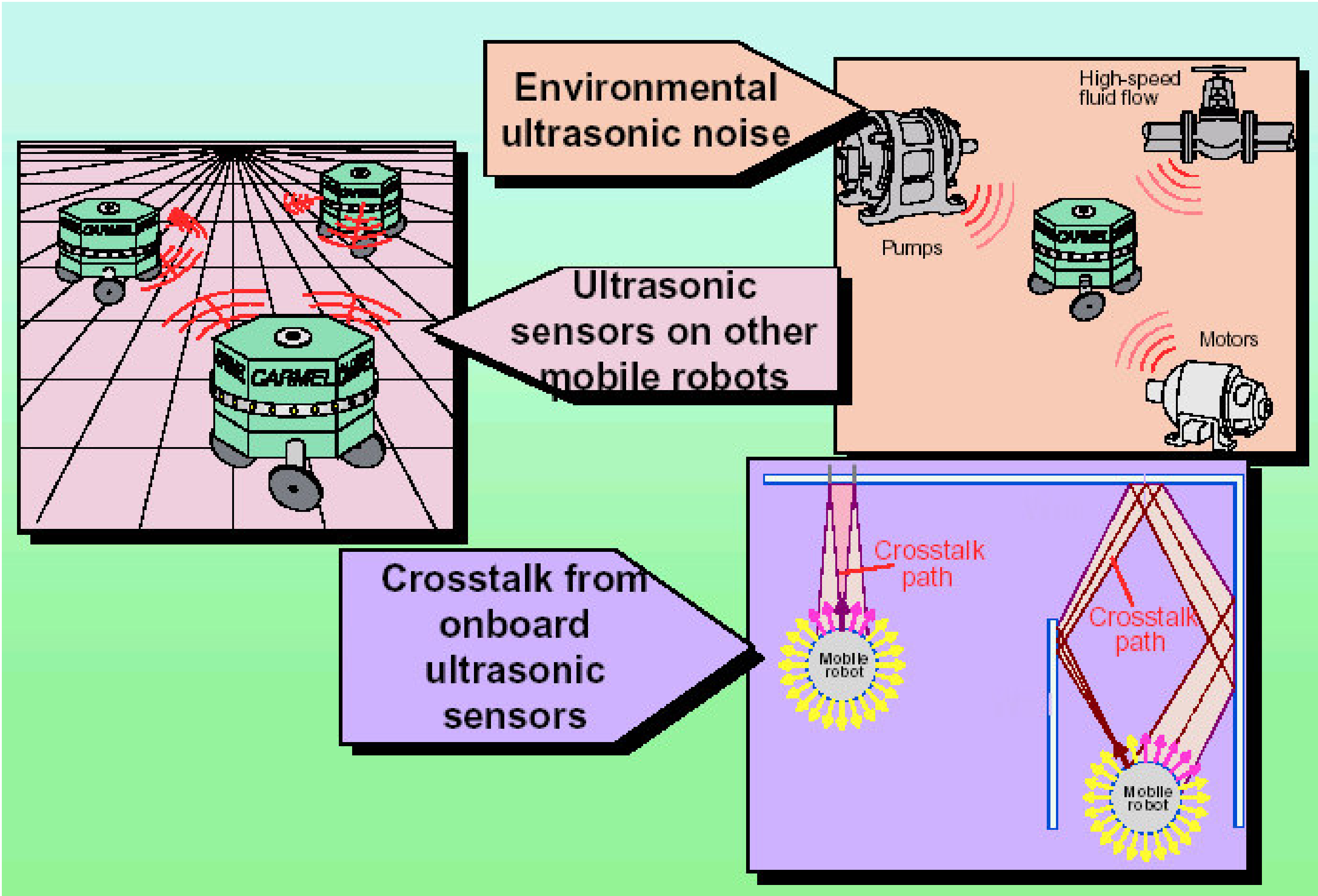
Ultrasonic Sensors

- Applications:
  - Distance Measurement
  - Mapping: Rotating proximity scans (maps the proximity of objects surrounding the robot)



Scanning at an angle of 15º apart can achieve best results

Noise Issues



Laser Ranger Finder

- Range 2-500 meters
- Resolution : 10 mm
- Field of view : 100 - 180 degrees
- Angular resolution : 0.25 degrees
- Scan time : 13 - 40 msec.
- These lasers are more immune to Dust and Fog

http://www.sick.de/de/products/categories/safety/

Inertial Sensors

- **Gyroscopes**
  - Measure the rate of rotation independent of the coordinate frame
  - Common applications:
    - Heading sensors, Full Inertial Navigation systems (INS)
- **Accelerometers**
  - Measure accelerations with respect to an inertial frame
  - Common applications:
    - Tilt sensor in static applications, Vibration Analysis, Full INS Systems

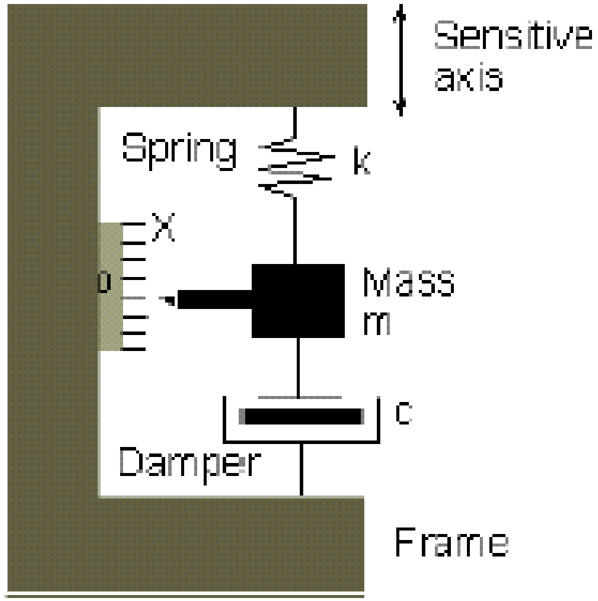
Accelerometers

- They measure the inertia force generated when a mass is affected by a change in velocity.
- This force may change
  - The tension of a string
  - The deflection of a beam
  - The vibrating frequency of a mass

Accelerometer

- Main elements of an accelerometer:

1. Mass 2. Suspension mechanism 3. Sensing element

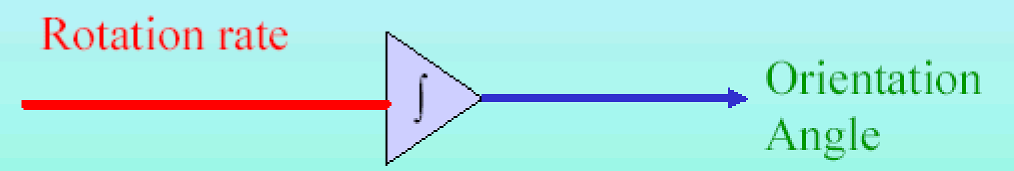


$$F = m\frac{d^2x}{d^2t} + c\frac{dx}{dt} + kx$$

High quality accelerometers include a servo loop to improve the linearity of the sensor.

Gyroscopes

- These devices return a signal proportional to the rotational velocity.
- There is a large variety of gyroscopes that are based on different principles

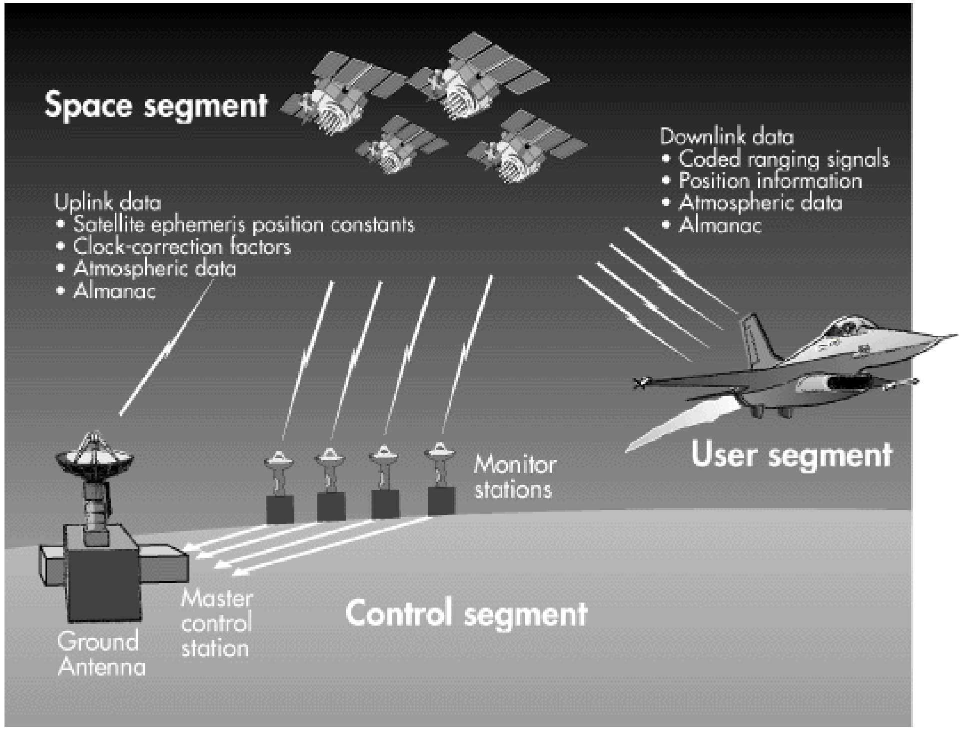


$$\theta\ (t) = \int \dot{\theta}\ (t)\ dt$$

Global Positioning System (GPS)

24 satellites (+several spares)

broadcast time, identity, orbital parameters (latitude, longitude, altitude)



Space Segment

http://www.cnde.iastate.edu/staff/swormley/gps/gps.html

Noise Issues

- Real sensors are noisy
- Origins: natural phenomena + less-than-ideal engineering
- Consequences: limited accuracy and precision of measurements
- Filtering:
  - software: averaging, signal processing algorithm
  - hardware tricky: capacitor