


Sensor Principles

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Outline

- Part I: Distance sensor using NIR
  - Using reflected intensity method
  - Using triangulation method
- Part II: Odometry
  - Using gyro
  - Using accelerometer
  - Using IMU

Part I
Infrared Sensing

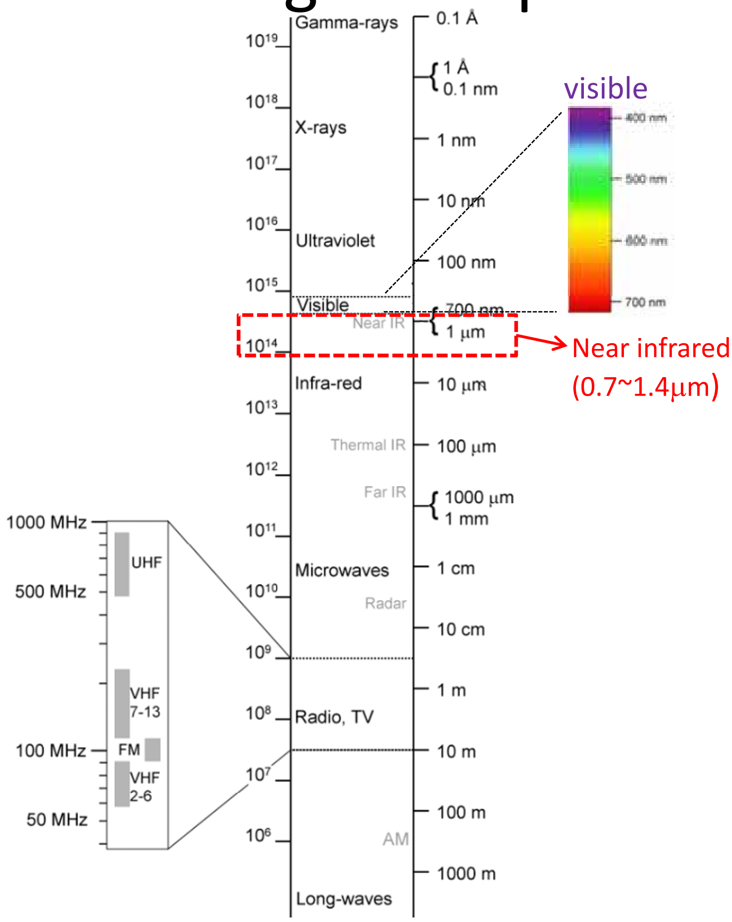
Infrared sensor as distance measurement

AX-S1
(Integrated Sensor Module
Includes: 3 IR sensors,
Remote control sensor,
Microphone, Buzzer)

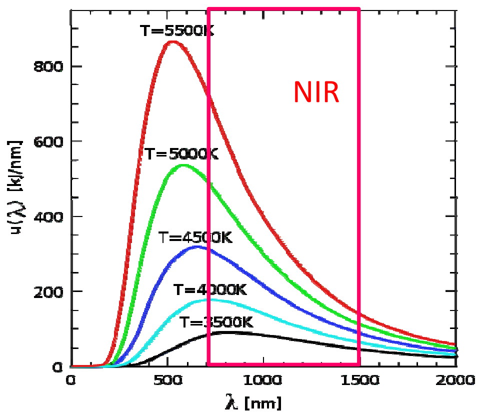
DMS (Distance Measurement Sensor)

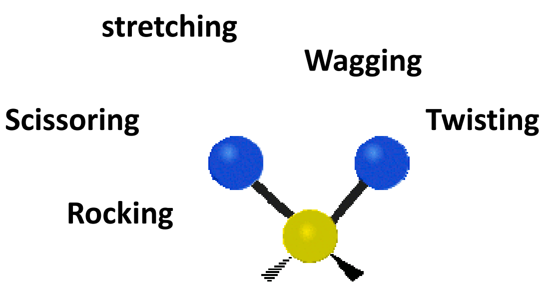
IR Sensor

Electromagnetic Spectrum



Thermal radiation emits infrared



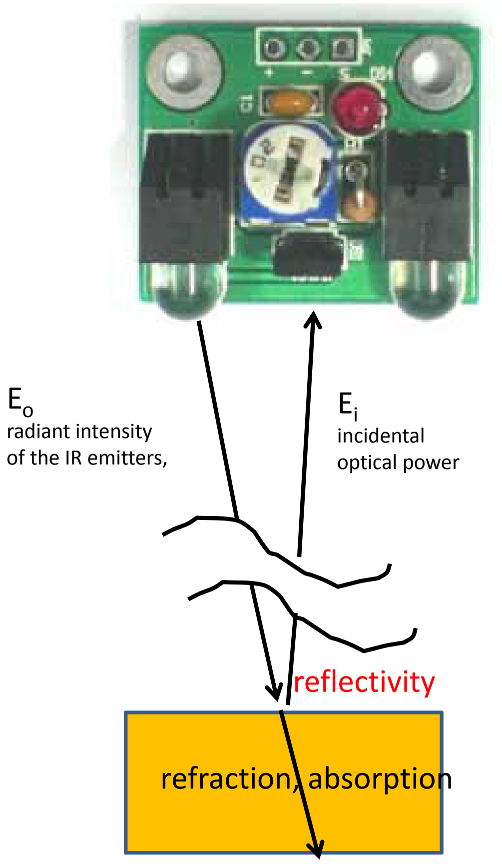


CH_2

emitted or absorbed by molecules

Infrared can penetrate fog and rain

Reflected IR Light



The inverse square law for intensity

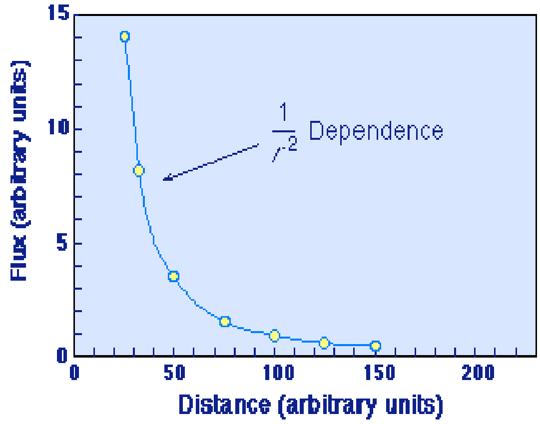
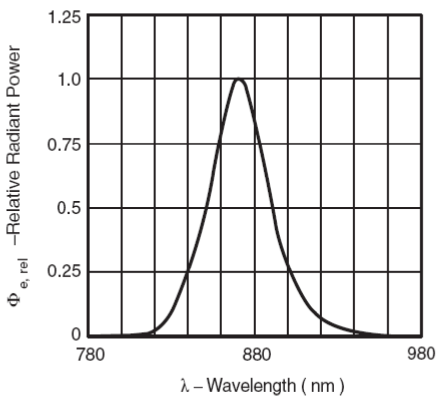
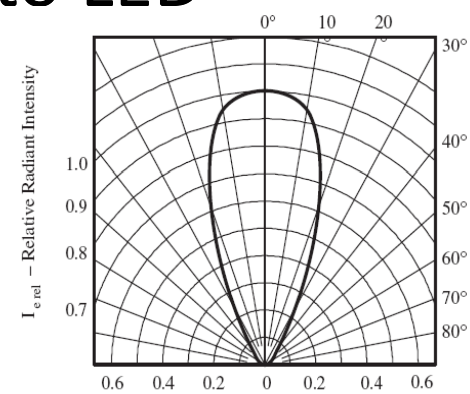


Photo LED

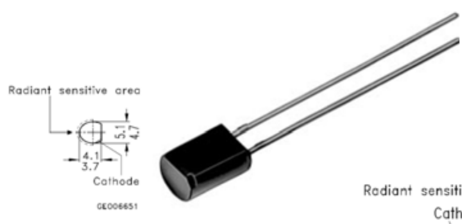
±10°

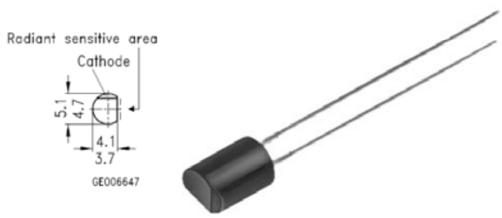


intensity vs wavelength

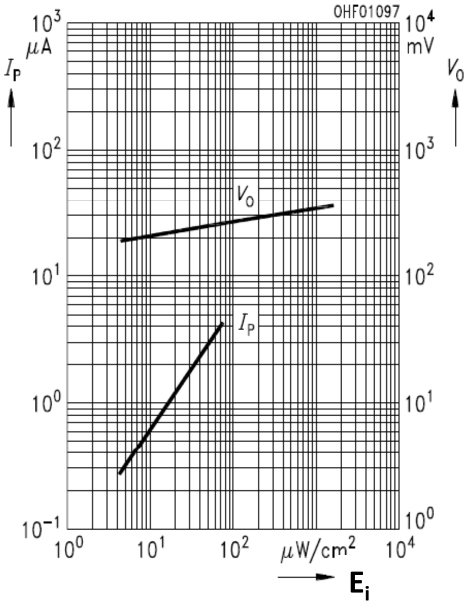


intensity vs angle





NIR Detector



Current $\mathbf{I_p}$ vs incidental optical power $\mathbf{E_i}$

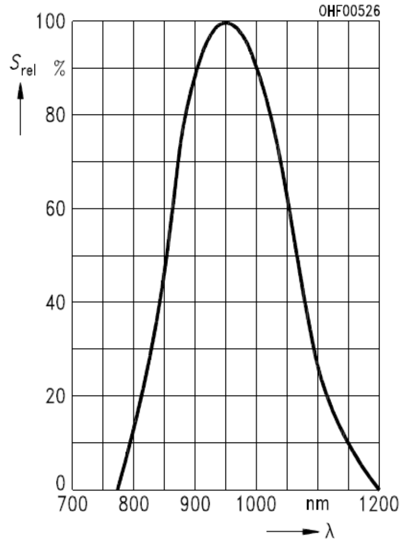
$I_p = E_i G\, R_0(\lambda)$

I_p : current

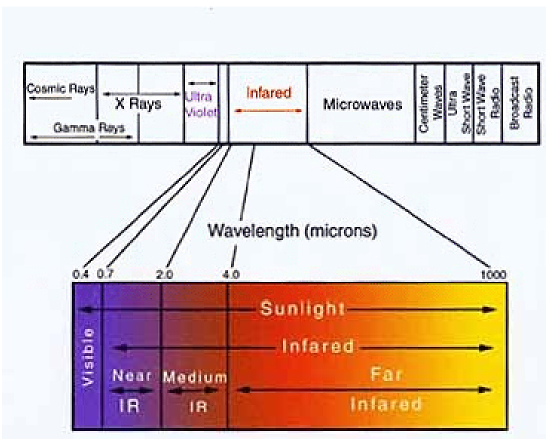
E_i: incidental optical power

G: Internal gain

$R_0(\lambda)$: the spectral responsivity

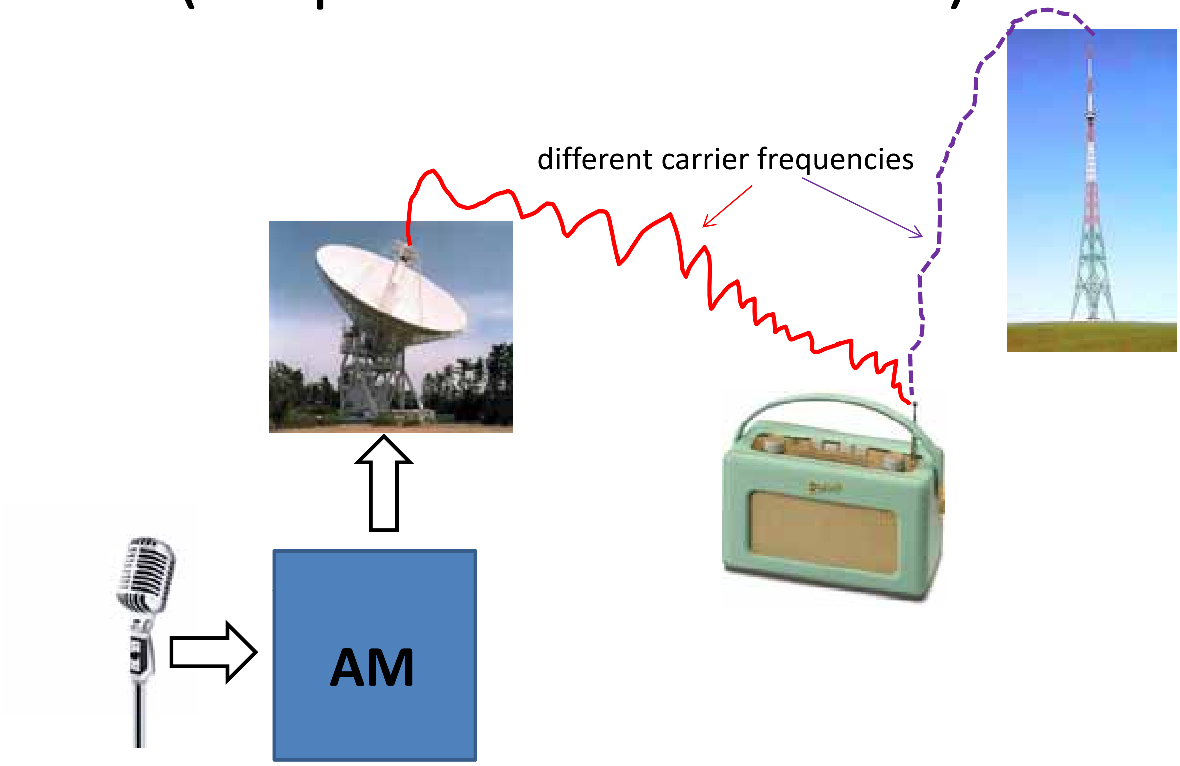


Why modulation?

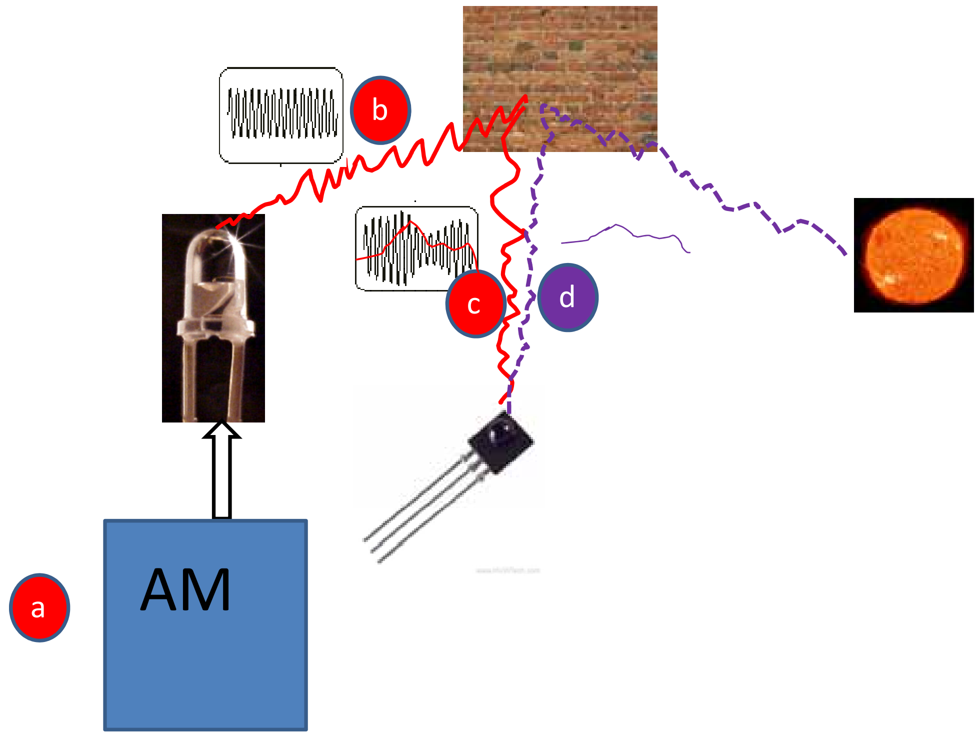


A modulation frequency of 38 kHz is faster than the movement of most mechanical systems, so unintentional modulation of a passive IR source is less likely to cause interference.

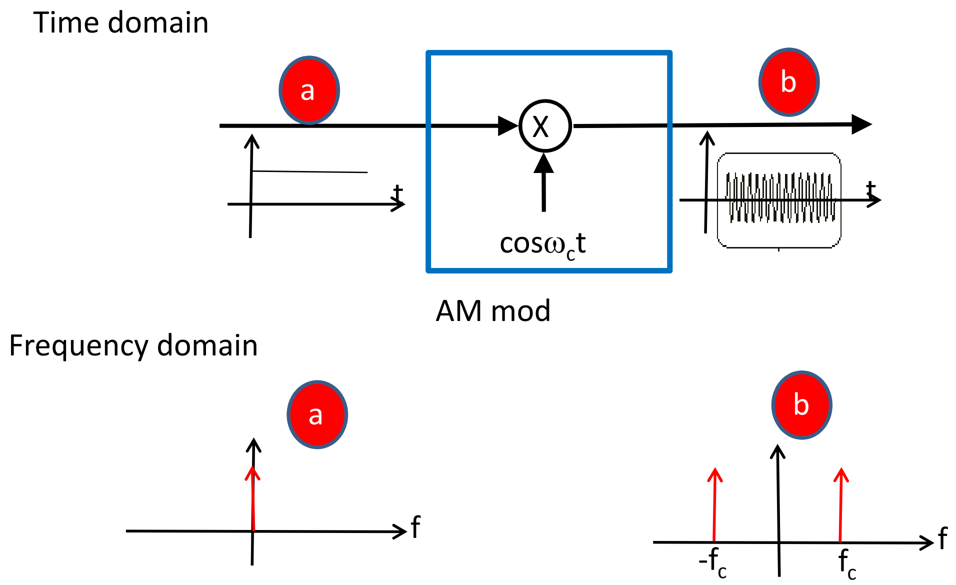
AM (Amplitude Modulation) Radio

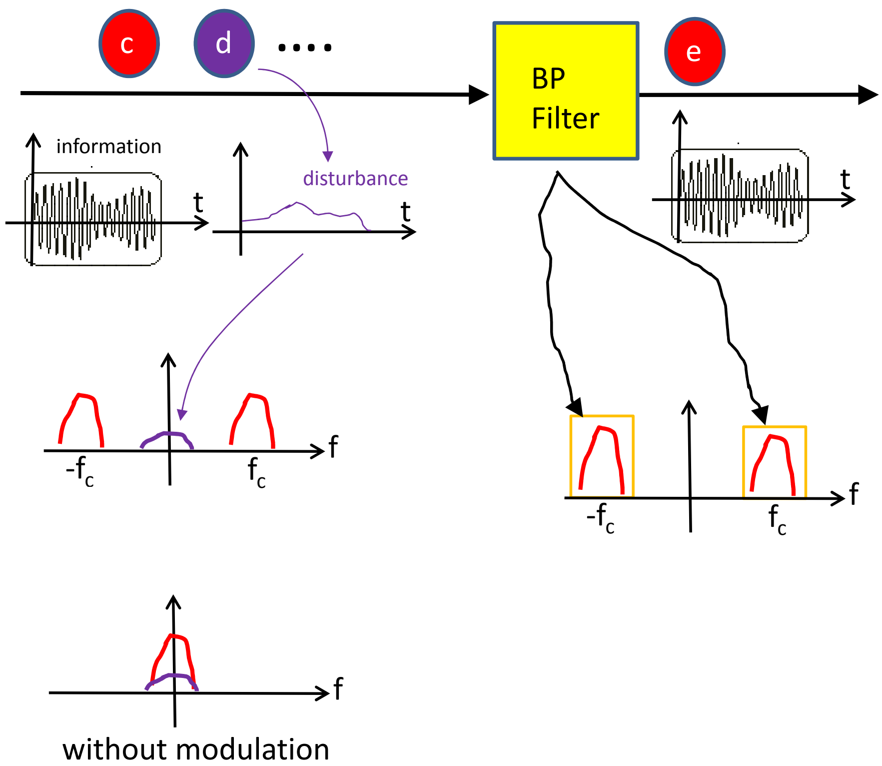


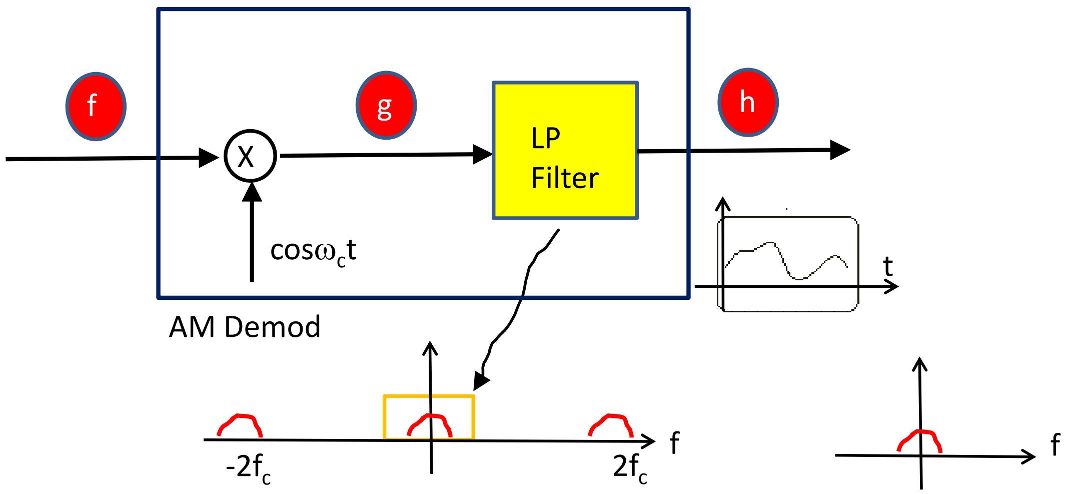
Modulation to reduce ambient light effect



AM Frequency Domain Analysis







This explains why the modulated signals can pertain the intended signals and avoid un-modulated passive IR interference.

Reflectivity

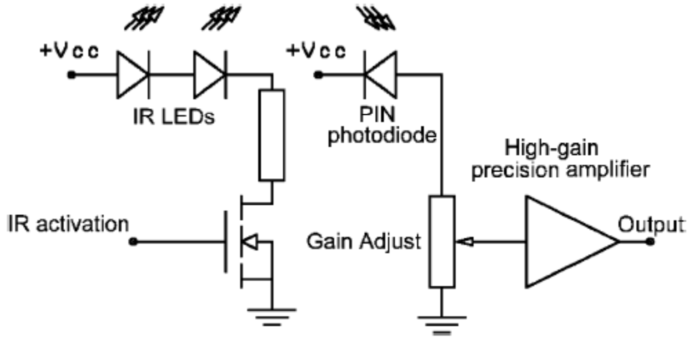
Glass, plexiglass

Material:

Plastic
Paper
Concrete
earth
Water
Mirror
Chemical coating(color)

Metal: gold, aluminum

A Simple Model for a IR sensor



sensor output s

Object

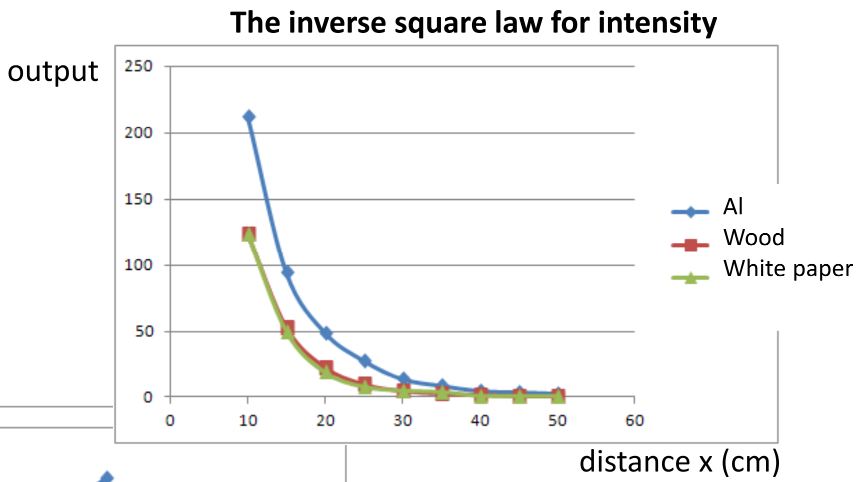
α: *the reflectivity coefficient of the target.*
x: *the distance of the target*

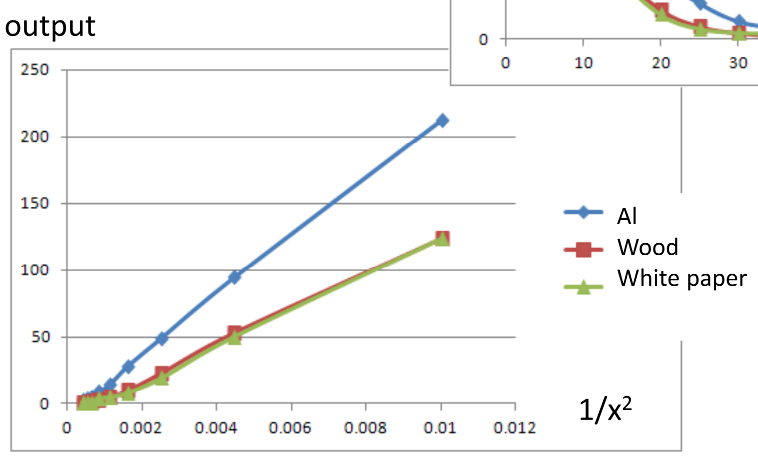
$$s = \frac{\alpha\, \boxed{E_o G\, R_0(\lambda)}}{x^2}$$

E_o: the radiant intensity of the IR emitters,
G: the gain of the amplifier,
$R_0(\lambda)$: the spectral sensitivity of the photodiode,

IR Sensor

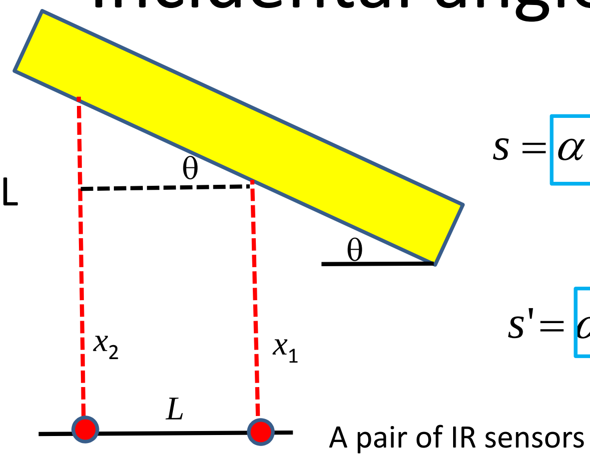
Interpolated equation for distance x





Incidental angle θ

$\tan\theta = (x_2 - x_1)/L$



$$s = \boxed{\alpha\, \mathrm{E_o G\, R_0}(\lambda)} \frac{\cos\theta}{x^2}$$

$$s' = \boxed{\alpha\, \mathrm{E_o G\, R_0}(\lambda)} \frac{\cos 0^o}{x'^2}$$

wrong
distance estimation

$$\begin{cases} x_1' = \dfrac{x_1}{\sqrt{\cos\theta}} \\ x_2' = \dfrac{x_2}{\sqrt{\cos\theta}} \end{cases} \Rightarrow$$

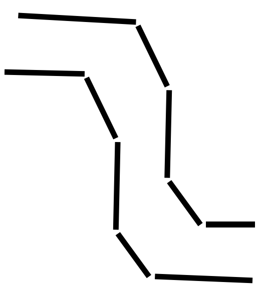
Interpolated equation for θ

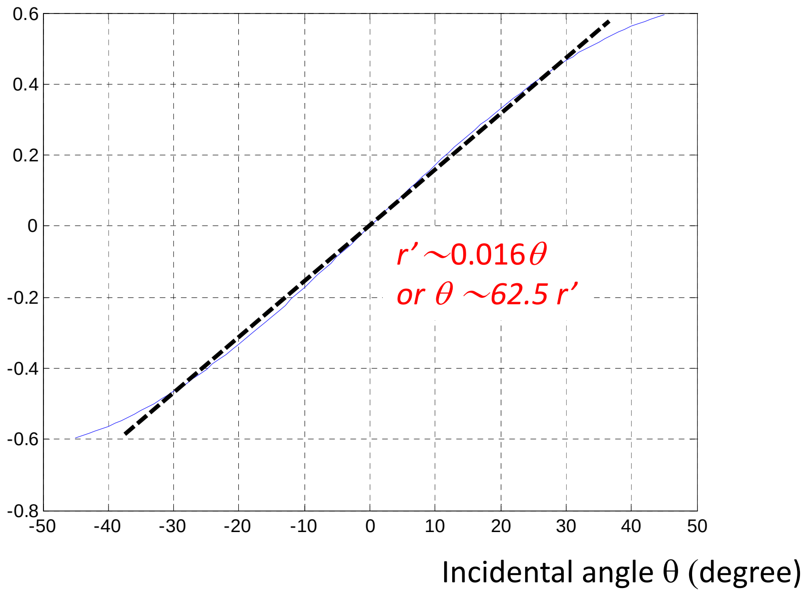
distance ratio r': $\dfrac{x_2' - x_1'}{L} = \dfrac{x_2 - x_1}{L\sqrt{\cos\theta}} = \dfrac{\tan\theta}{\sqrt{\cos\theta}} = \sin\theta\sqrt{\cos\theta}$

$$= \sqrt{\cos\theta(1-\cos^2\theta)}$$

distance ratio

$r' = \dfrac{x_2' - x_1'}{L}$



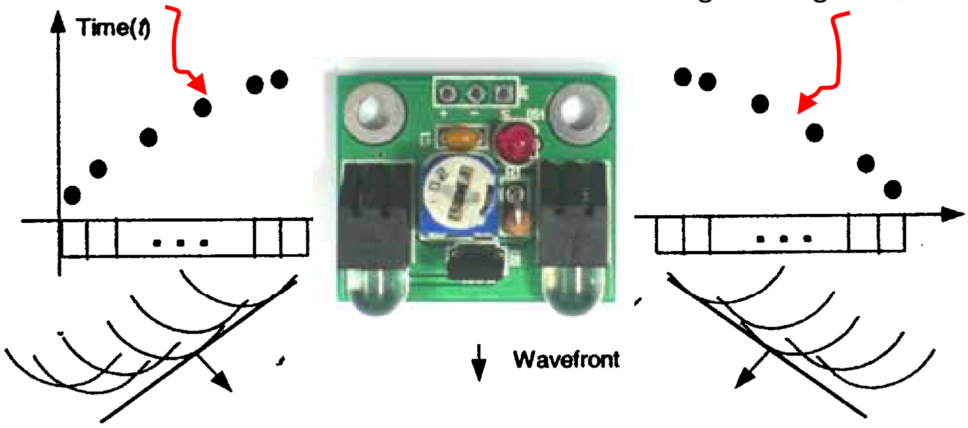


Beamforming

Beamforming implies the directional control of the light beam.

firing from left to right

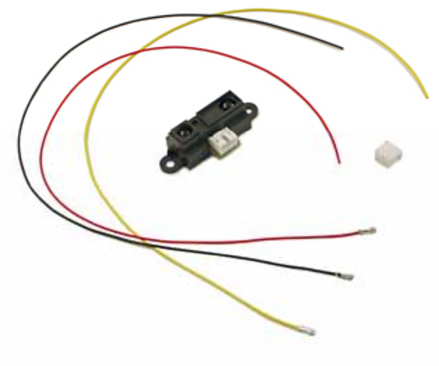
firing from right to left

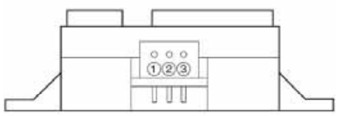


wavefront to the right

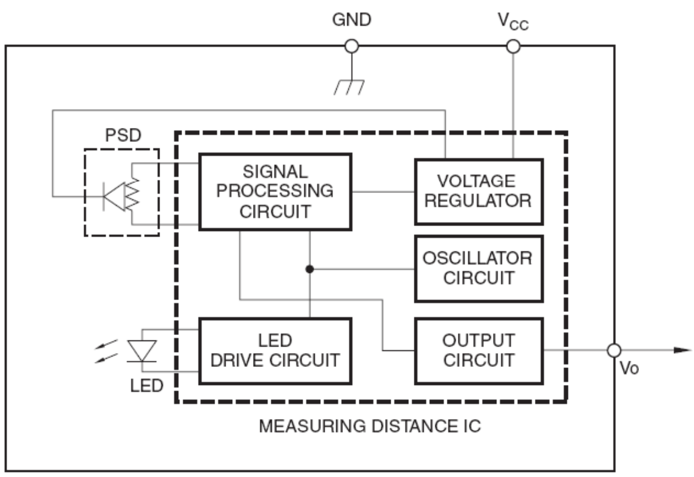
wavefront to the left

DMS (Distance Measurement Sensor)





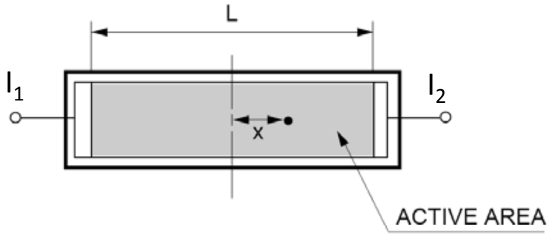
PIN	SIGNAL NAME
1	V_O
2	GND
3	V_{CC}



PSD (Position Sensitive Detector)

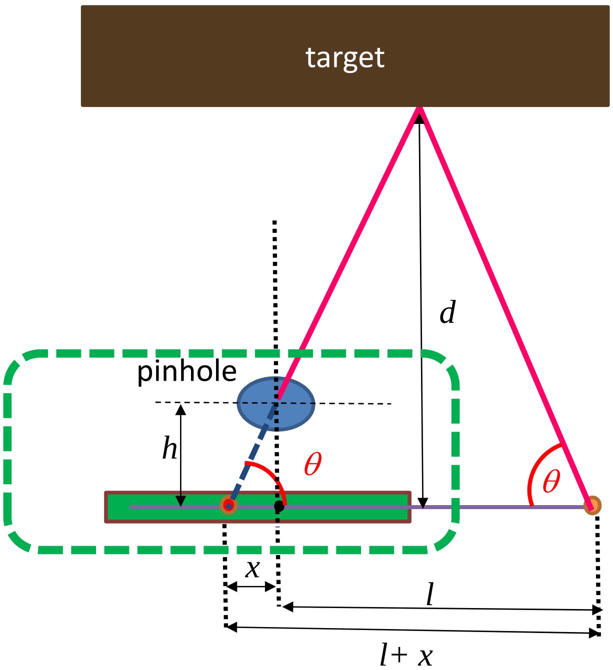
Since the balance of the photocurrents is sensitive to the centroid of the beam spot, the photocurrents collected from its ends will change.

The spatial resolution is much better than the width of the spot.



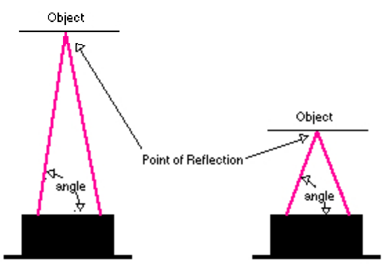
$$\frac{x}{L} = \frac{I_2 - I_1}{I_2 + I_1}$$

Triangulation

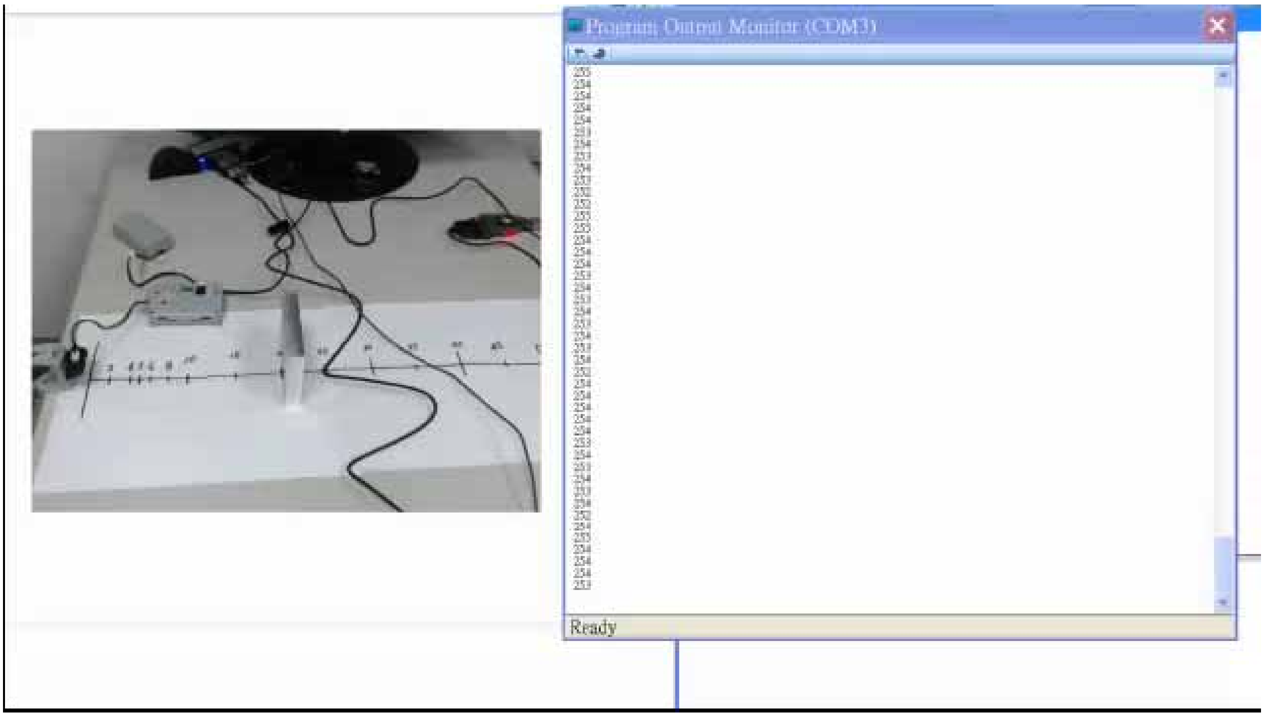


$$\begin{cases} Tan(\theta) = h / x \\ Tan(\theta) = \dfrac{d}{\frac{1}{2}(l + x)} \end{cases}$$

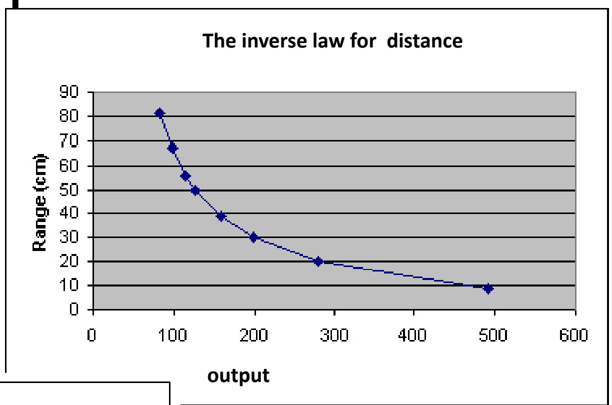
$$\Rightarrow \quad d = \frac{(l + x)h}{2x}$$

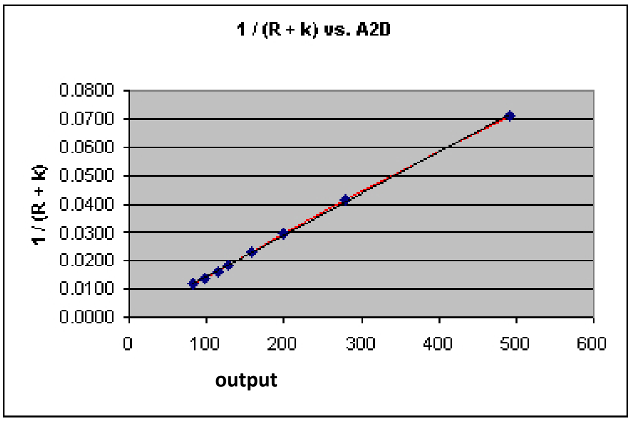


Demo



Interpolated equation for distance x



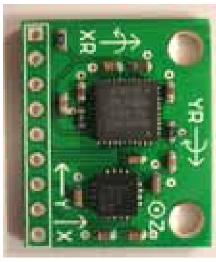


The interpolated equation is demonstrated as: d = 1 / (x + 0.42)

Part II
Odometry

Angle measurement

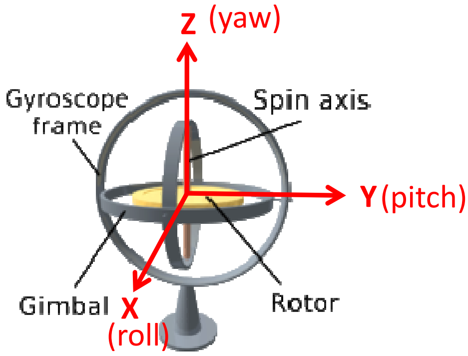
Accelerometer to measure tilt angle

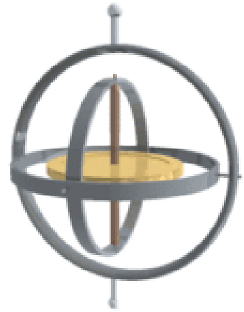


Gyro to measure the angular velocity

IMU: Inertia Measurement Unit

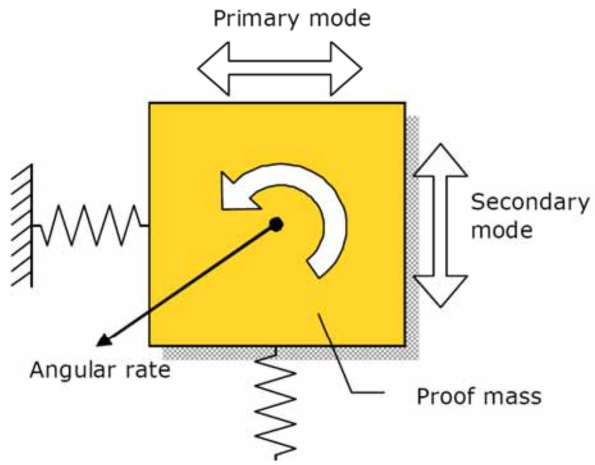
Gyroscope



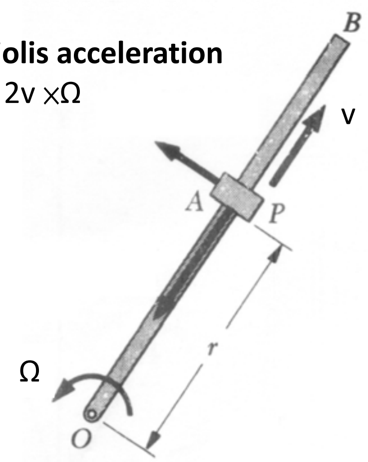


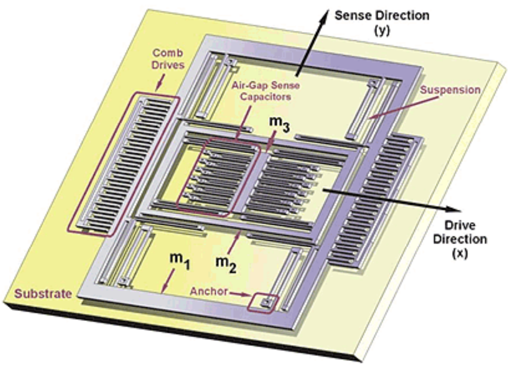
The conservation of angular momentum L = I $\times$ ω

MEMS Gyro

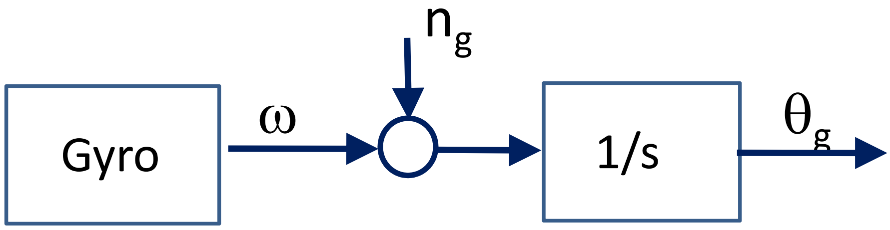


Coriolis acceleration
$a_c = 2v \times \Omega$





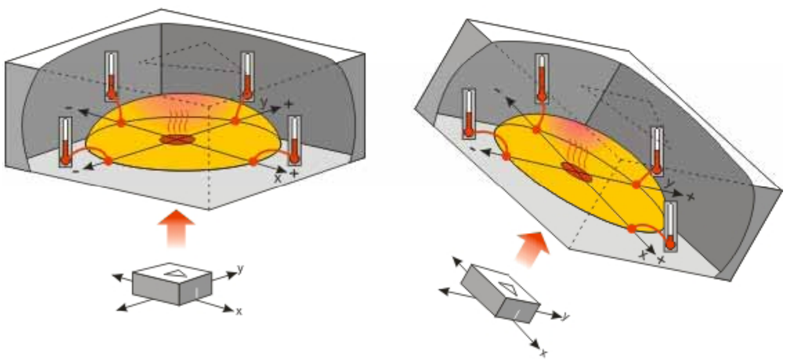
Using Gyro for Measuring Robot's Orientation



The angular information θ can be obtained by Integration of angular velocity ω.

The little bias of angular velocity ω causes a large accumulation errors of θ over time after integration

Accelerometer as a tilt sensor

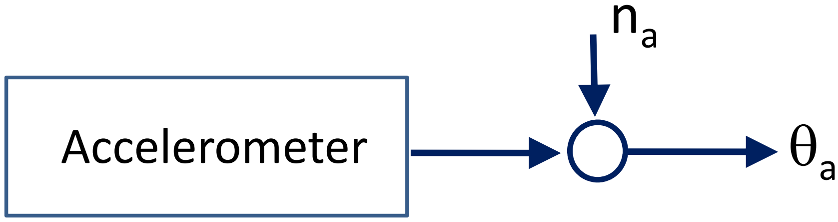


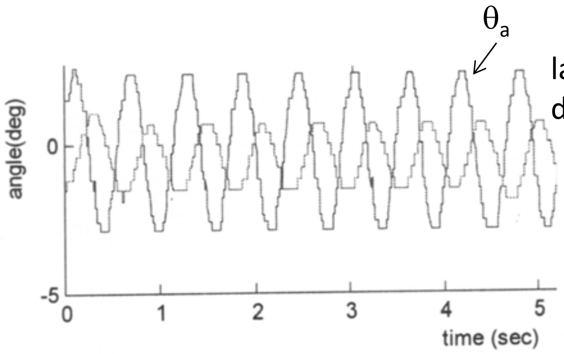
If you place the accelerometer so that both its x axis and y axis are parallel to the earth's surface, it can be used as a 2-axis tilt sensor with a roll axis and a pitch axis.

$$\theta_x = \sin^{-1}(a_X / 1\ g)$$
$$\theta_y = \sin^{-1}(a_y / 1\ g)$$

static acceleration

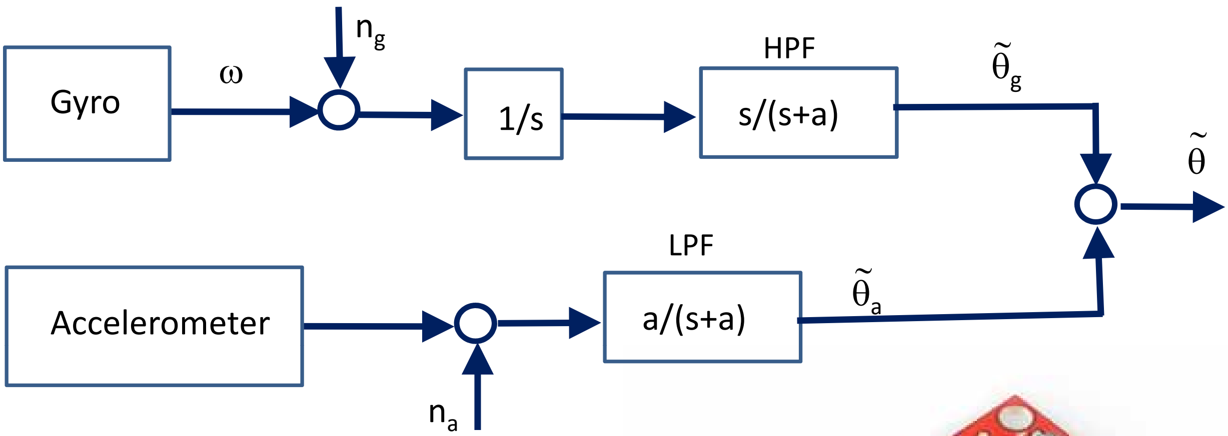
Using Accelerometer as a Tilt Sensor



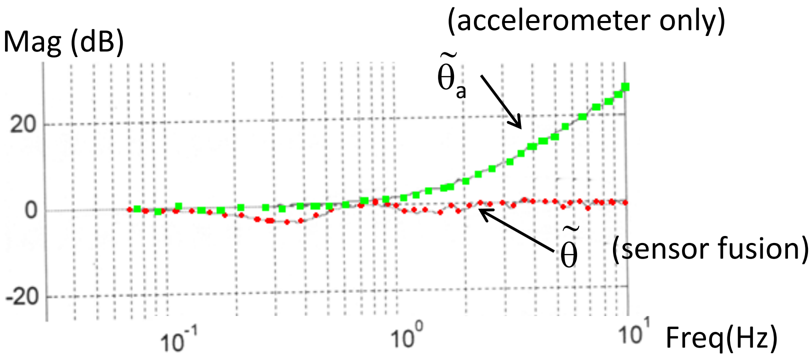


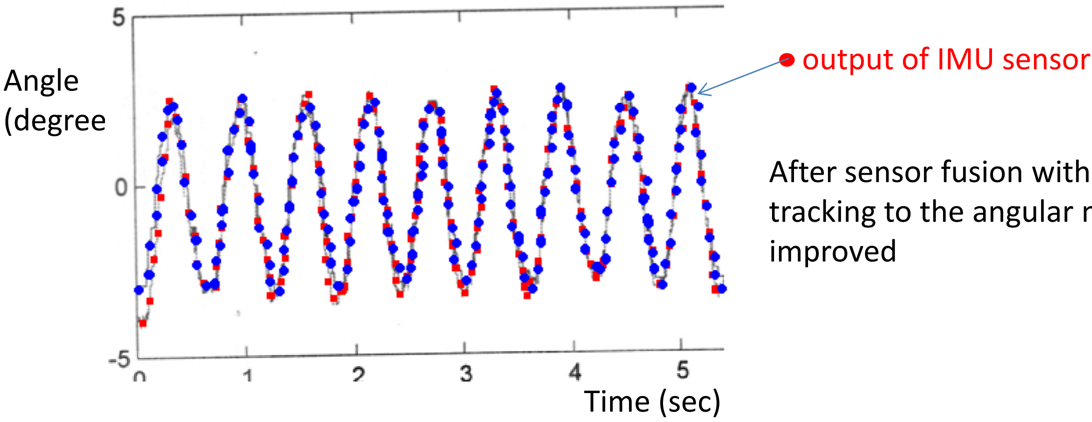
larger angular displacement was estimated due to the effects of other accelerations

Sensor Fusion



$$\tilde{\theta} = \frac{s}{s+a}\tilde{\theta}_g + \frac{a}{s+a}\tilde{\theta}_a$$





After sensor fusion with gyro, tracking to the angular motion is improved

Exercise

For Infrared Sensing

1. Build up a relationship of output v.s. distance and check if there is an inverse square law for intensity
2. Choose at least 5 materials (including one aluminum foil) and define relative reflectivity (to aluminum foil) for each material
3. Measure the output for angles between $\pm 80^{o}$ at a distance (say 10cm). Check the cosine relationship of output vs incidental angle
4. Can you make a non-vertical turn by using more than one infrared sensor? Please calculate the model for two sensors?
5. For DMS, build up a relationship of output v.s. distance and check if there is an inverse law. Check if the DMS is immune to the materials, ambient light and incidental angle?

For Gyro and Accelerometer

1. Integrate the gyro's output and obtain the tilt angle from the gyro sensor. Keep the gyro at a certain angle and observe how the estimated angle goes over time.
2. Rotate the accelerometer by a motor between the angles $\pm 45^{o}$ to and fro with different rotating speeds. Check whether the measured angles can accurately track the motor's rotation angles or not.
3. Construct an angular sensor using sensor fusion technology by integrating a Gyro and an accelerometer together. Repeat #1 and #2, to see the output is more accurate and responsive.