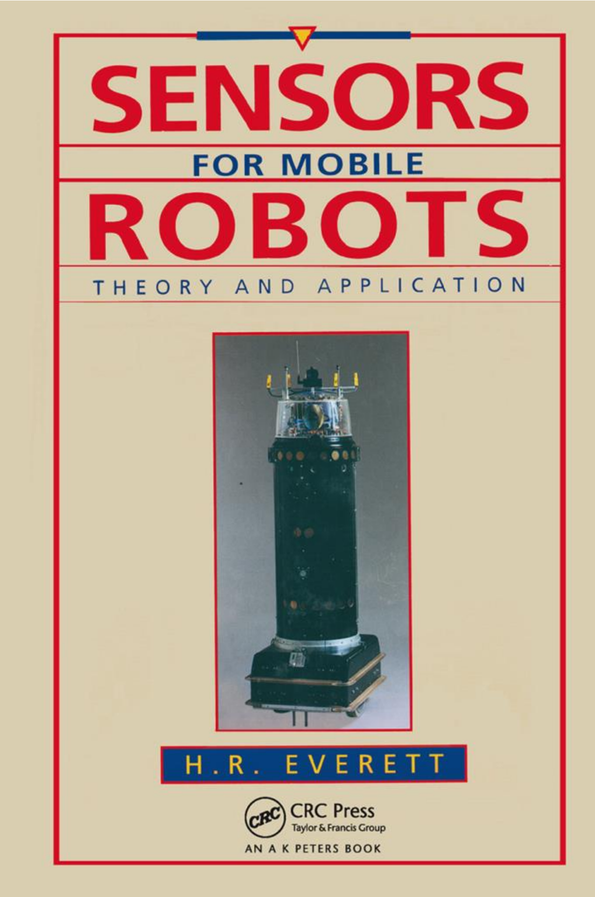
Mobile Robots (EECN30169/535307)

Lec. 5 Sensors & Batteries

2022/10/28



"Sensors for Mobile Robots" by H. R. Everett,

Published December 1, 2019 by A K Peters/CRC Press

544 Pages

Outline

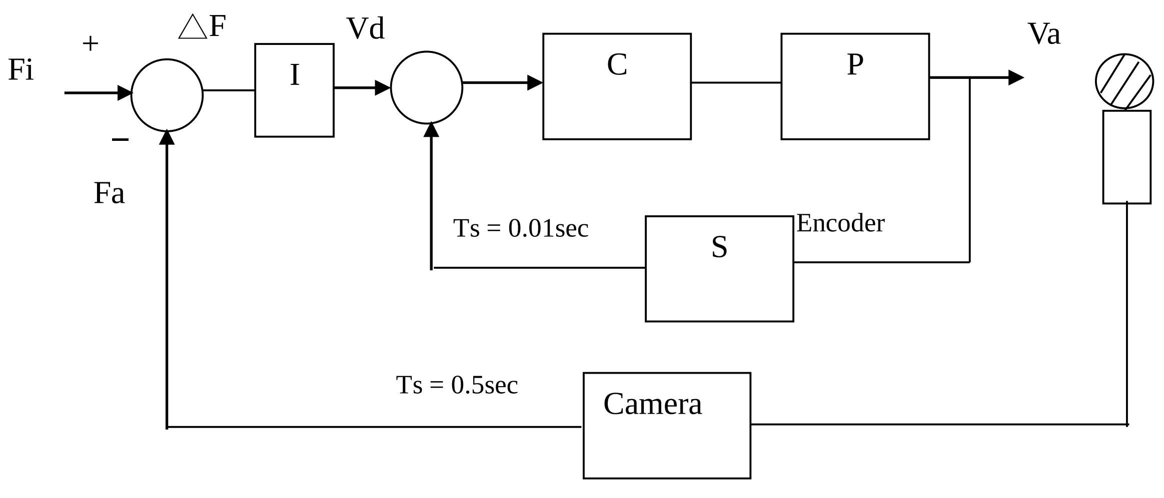
- Importance of sensors
- Interfacing electronics
- Most used sensors for mobile robots
- Batteries

Importance of sensors

- An autonomous mobile robot moving around in an unstructured and dynamically changing environment must use various sensors to obtain information about its surroundings to determine its action and accomplish the assigned task.
- Human-robot interaction relies on sensory information

Sensory data in feedback control loops

- From the viewpoint of control, sensor data are required to feedback the actual state of the system or process, such that the desired state can be achieved.
- Depending on how the feedback loop is closed, the behavior of robot needs various types of sensory information.



Types of robotic sensors

- Internal sensors: sensors used for robots to understand the state of itself.

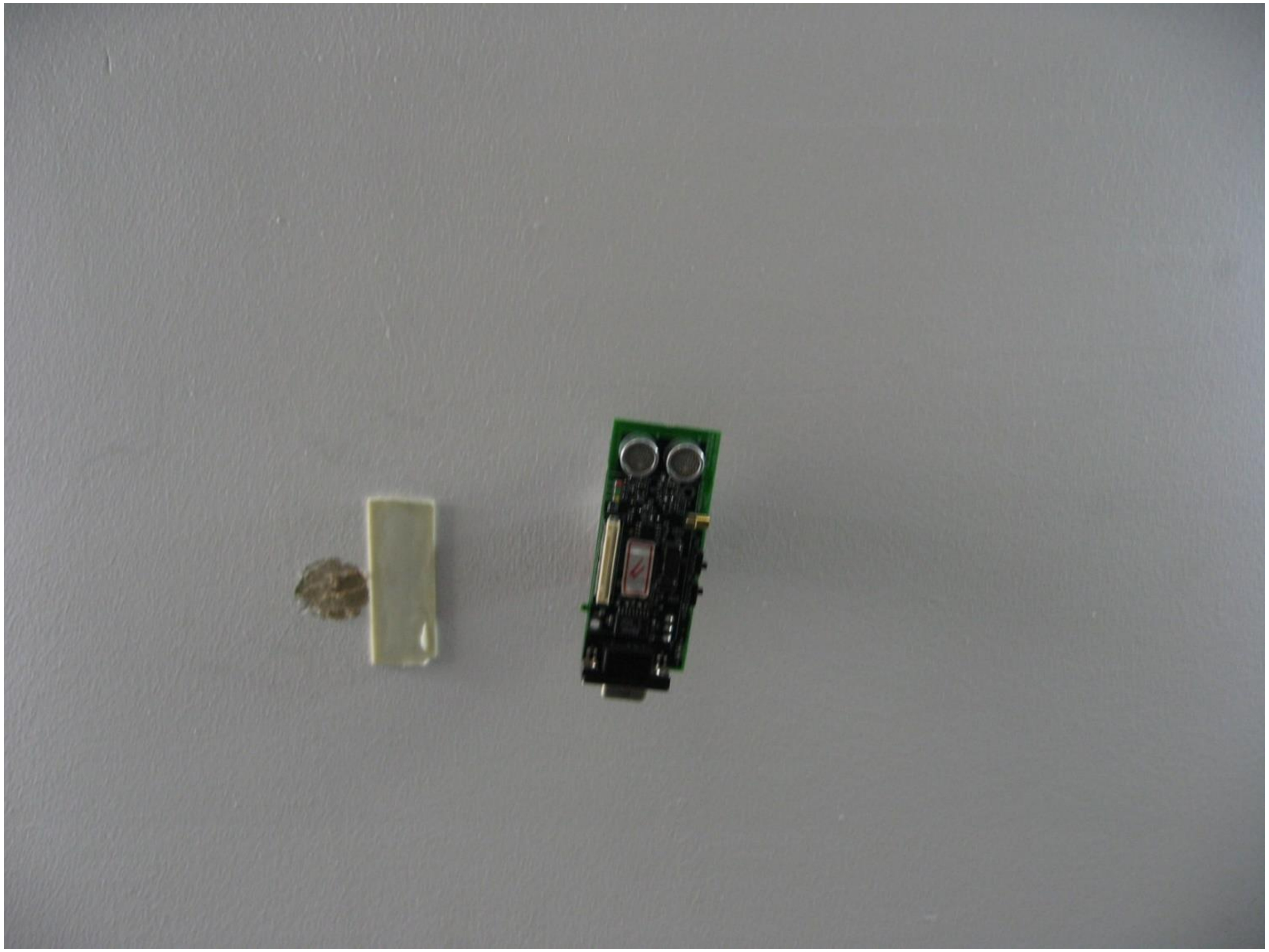
  e.g. sensors for self-localization (pose estimation),

  sensors for motor servo control (shaft encoders), gyros, limit switches, etc
- External sensors: sensors used for robots to understand the external world.

  e.g. ultrasonic range sensors, infrared sensors, laser scanner (range finder), image sensor, microphone, touch sensor, gas sensor, etc
- On-board sensors: sensors that are installed on board the robot.

Human friendly room at KAIST

Ultrasonic sensors



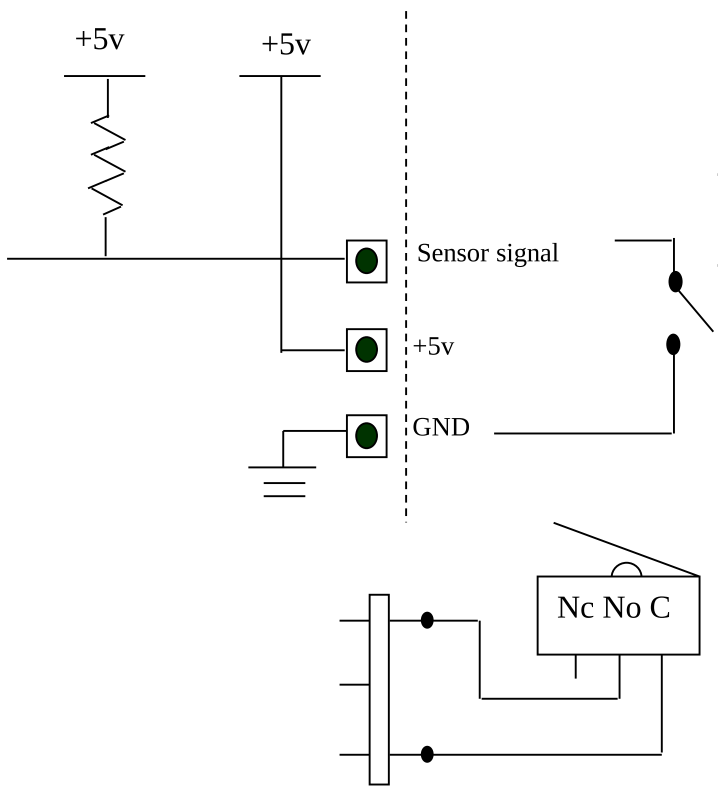
Human-Robot Interface

Command identification

Robotic wheelchair

A general connection for sensor inputs

- Digital inputs



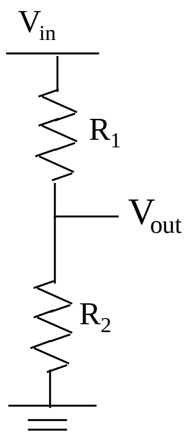
- Switch is released (open)
  +5v logic1
- switch is pressed (closed)
  0v logic 0

Touch sensor:
Logic high = not pressed
Logic low = pressed

Vsens: connects to either digital input circuitry or analog input circuitry.

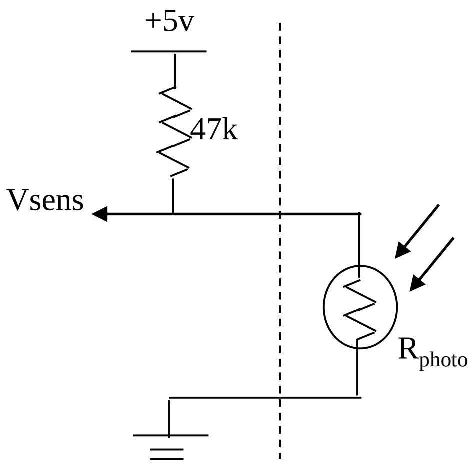
Light sensor (Analog inputs): Photocell CdS

Connecting a resistive sensor



$$V_{out} = \frac{R_2}{R_1 + R_2} V_{in}$$

Connecting a photocell, Analog input, need an A/D converter

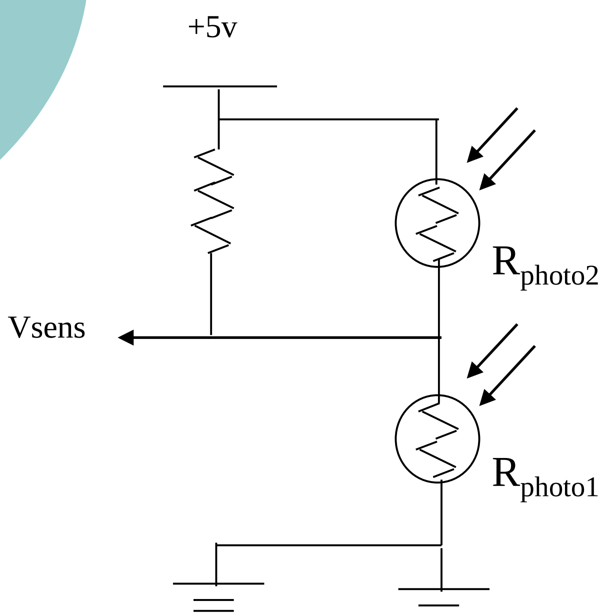


Single photocell circuit

1. Brightly illuminated
   Rphoto : small
   Vsens : close to 0
2. Dark
   Rphoto : large
   Vsens : close to 5V

Differential photocell sensor

Wire a pair of photocells to produce a voltage that represents the difference in value between the two.



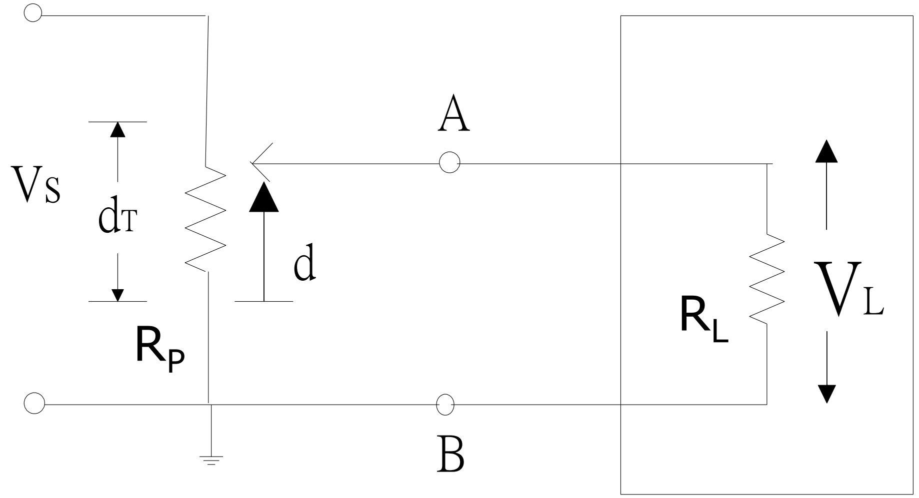
$$V_{SENS} = 5\text{V}\,\frac{R_{photo1}}{R_{photo2} + R_{photo1}}$$

Consider loading effect:

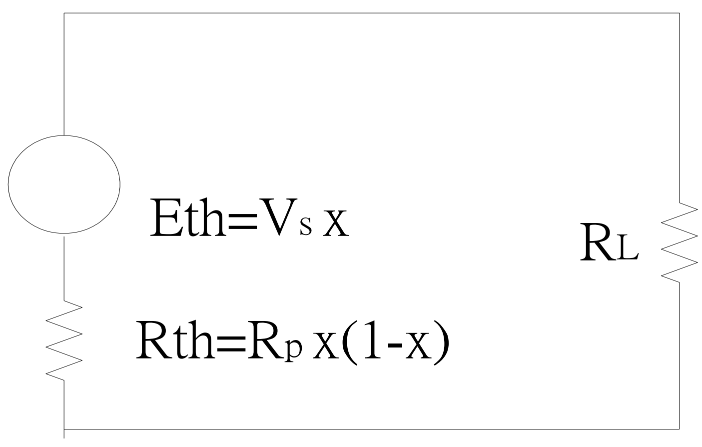
choose photocell that has a relatively small dark resistance (i.e. about 10k)

$$\frac{1}{10k} + \frac{1}{47k} \approx 8.25k\Omega$$

Loading effect in Resistive position sensors



$$\frac{d}{d_T} = x$$



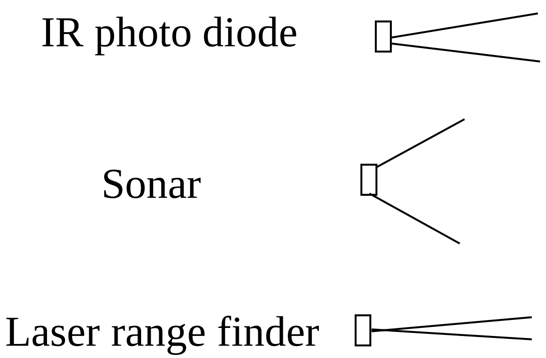
$$V_L = V_s x \frac{R_L}{R_{th} + R_L}$$

Photo Diodes /Photo Transistors

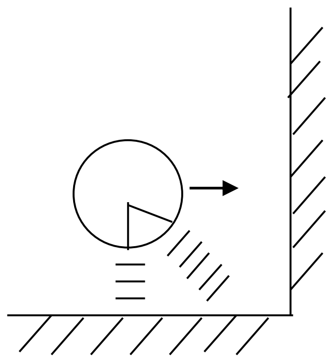
- Photo diode/ photo transistors vs. photocells(CdS) photo resistors
  - rapid response time
  - more sensitive to small level of light (e.g. from LED element)

Near-infrared proximity sensor

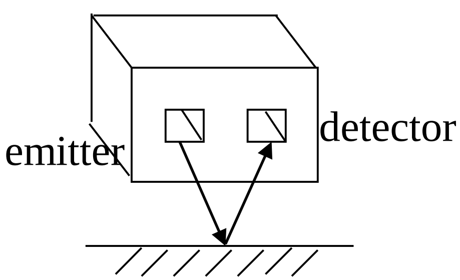
- ~880nm from LED element (Emitter)
  - These sensors typically do not return actual distance to an object, they signify whether or not something is present within the cone of detection.
  - These types of sensors usually have much narrower beam width than sonar range finders.



Reflective optosensors (active sensors)



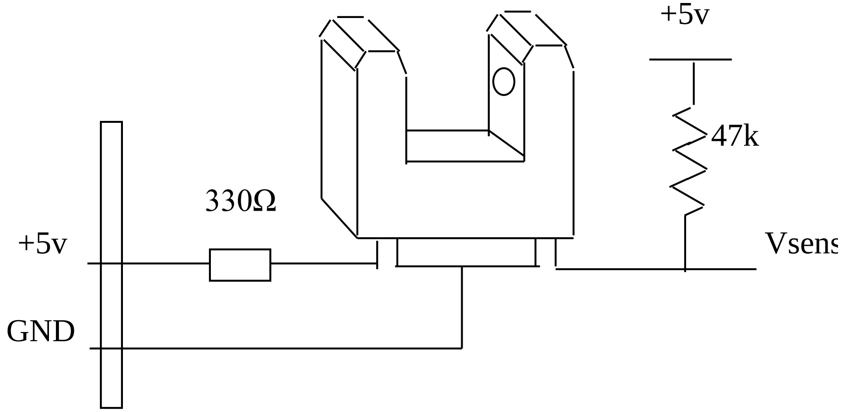
Light is reflective off a surface into a detector element, consisting of an emitter LED and a detector photo diode



Transmitter LED and Receiver photo diode

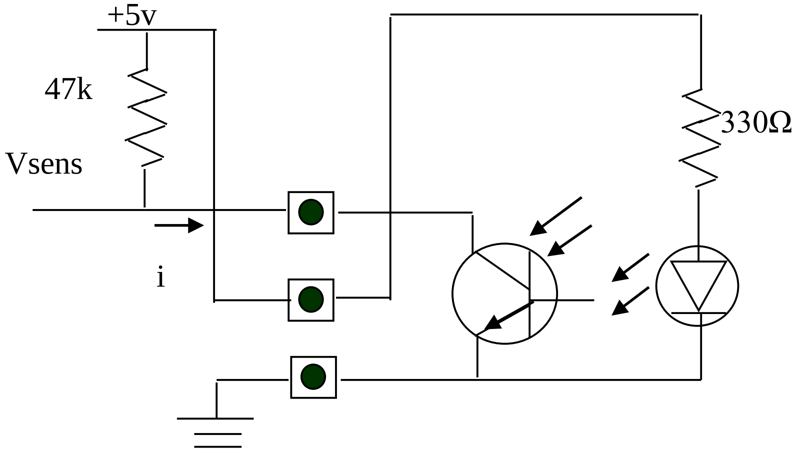
Ambient light is a problem

Break-beam sensors



The break-beam device consists of a light-emitting component aimed at a light-detecting component. When an opaque object comes between the emitter and detector, the beam of light is occluded, and the output of the detector changes

Measurement of light intensity



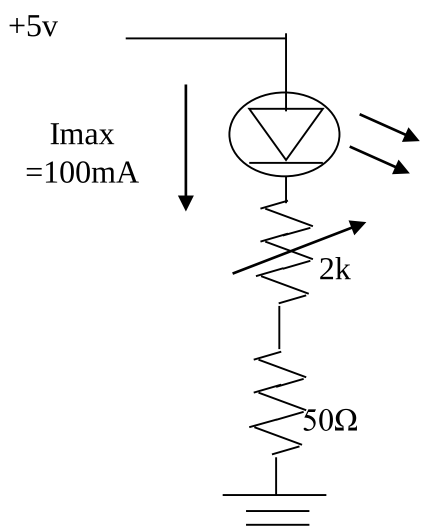
The more light received by the phototransistor, the more current flows. This creates a voltage drop in the 47K pull-up resistor. This voltage drop is reflected in a smaller voltage on the Vsens signal line.

i =0.01mA

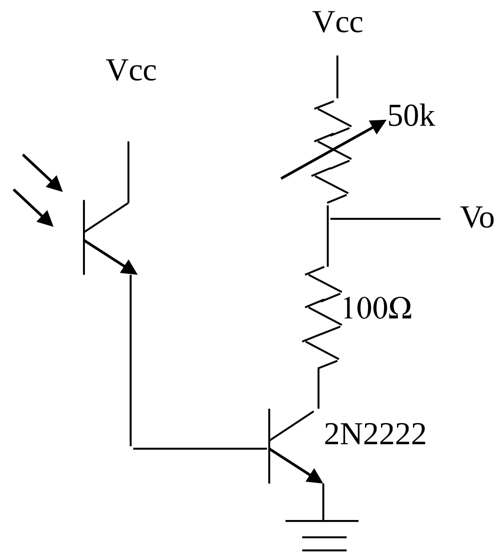
V= i R = $0.01*10^{-3}*47*10^{3}$= 0.47V

Vsens= 5 - 0.47 = 4.53V

Light sensor interface circuitry

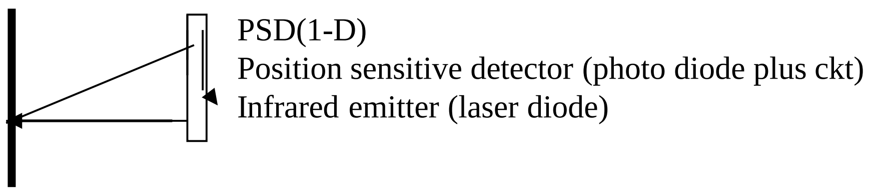


Light emitting LED



Receiving photo transistor

Optical distance sensing detector with Sharp GP2D02



An IR emitter LED projects a spot of modulated light onto the target surface.

The light is focused on a 1D PSD element.

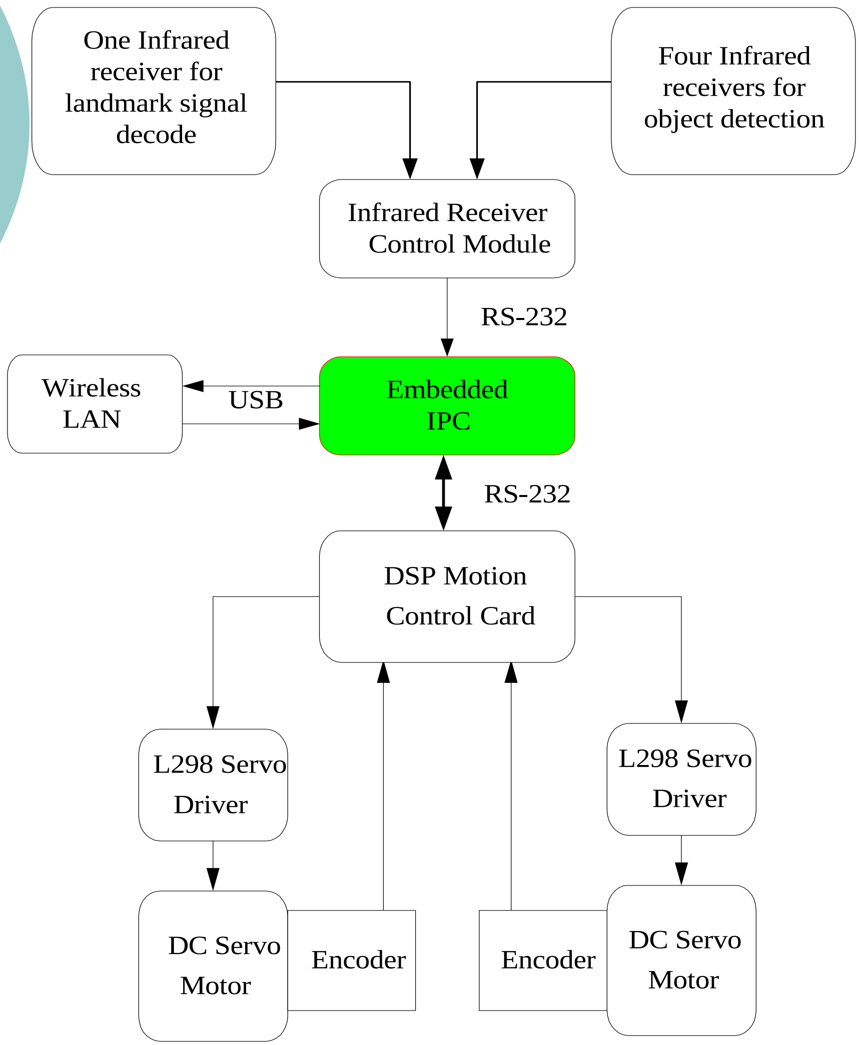
The angle of the incoming light will change depending on the distance between the target surface and the sensor.

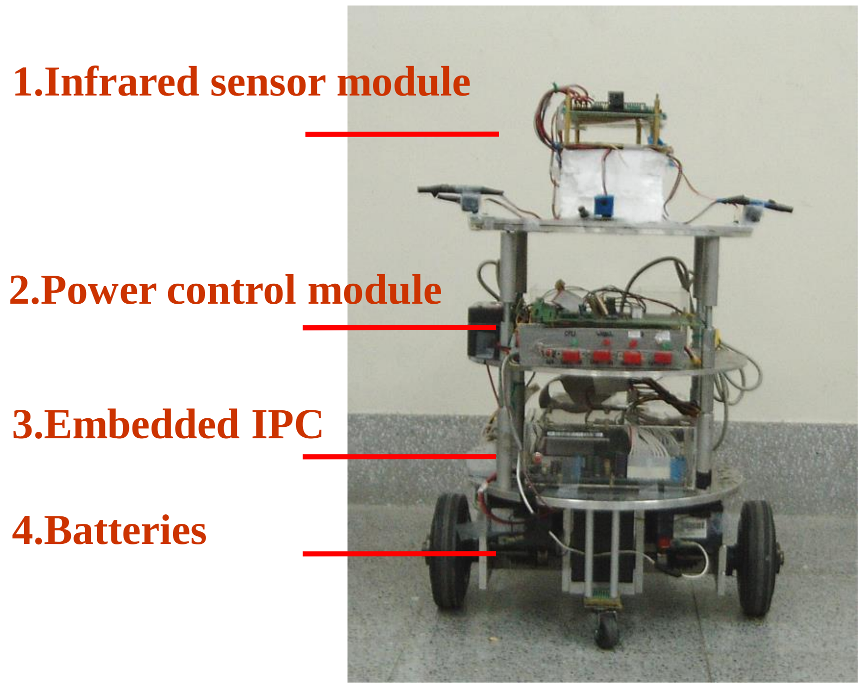
The spot of light will project to different point along the PSD.

The location of the light spot on PSD is a function of distance.

Experimental Results

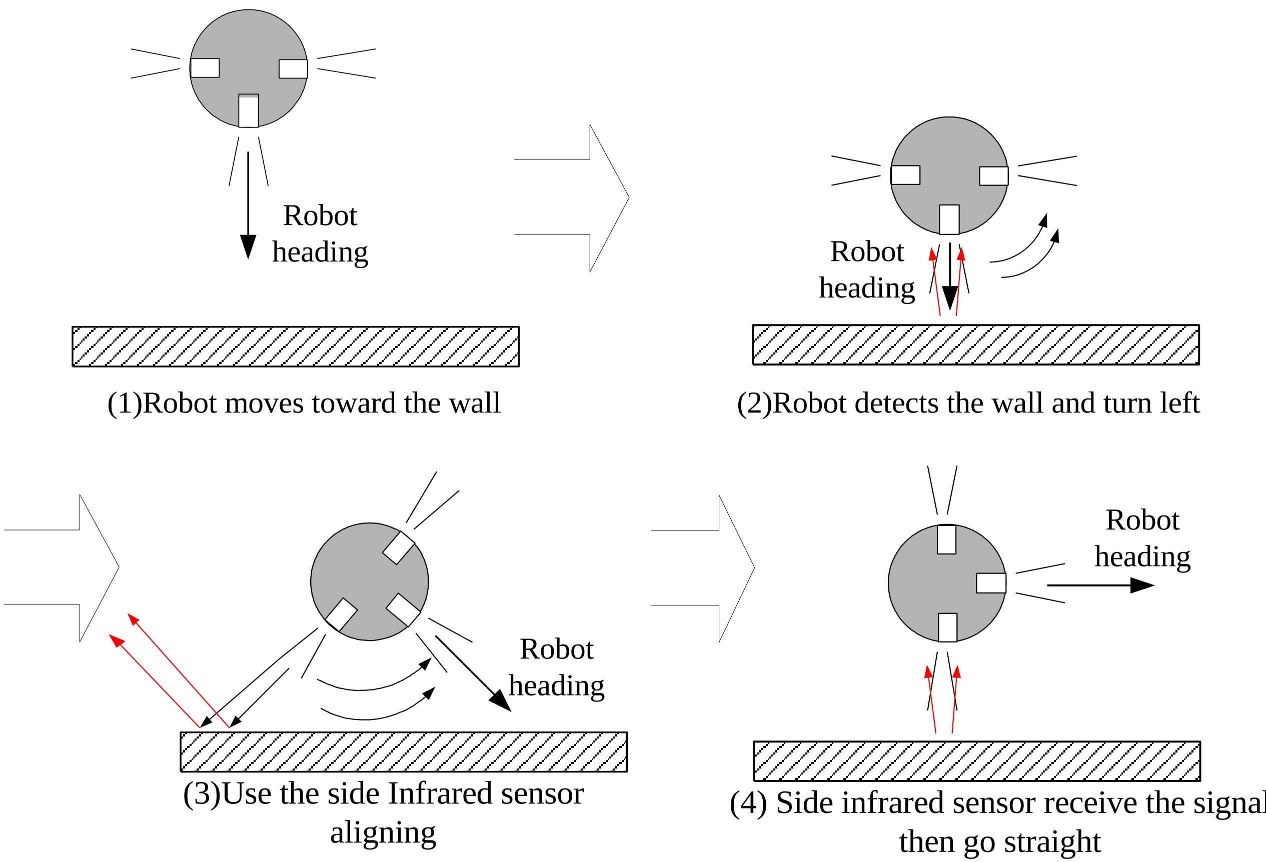
- **The experimental mobile robots**





Design with Infrared Sensors

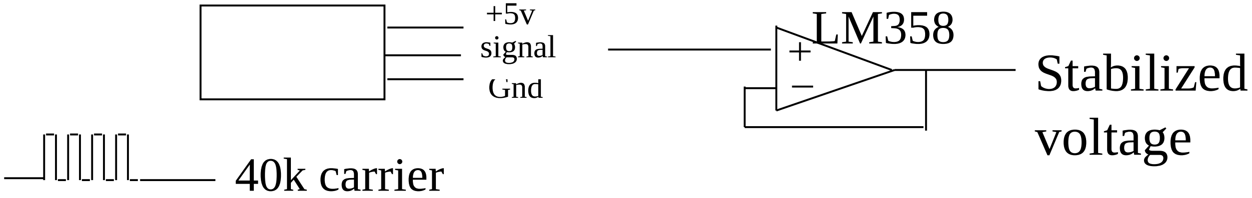
- **Front infrared sensors : detect the wall.**
- **Side infrared sensors : align with the wall.**



Modulated IR Signal @ IR Bbeacon

- IR detectors respond to a modulated carrier sent by the near-infrared LED.
- The programmer is responsible for blinking the LED in certain pattern such that the detector will respond.

Sharp GP1U 52X near-infrared proximity detector



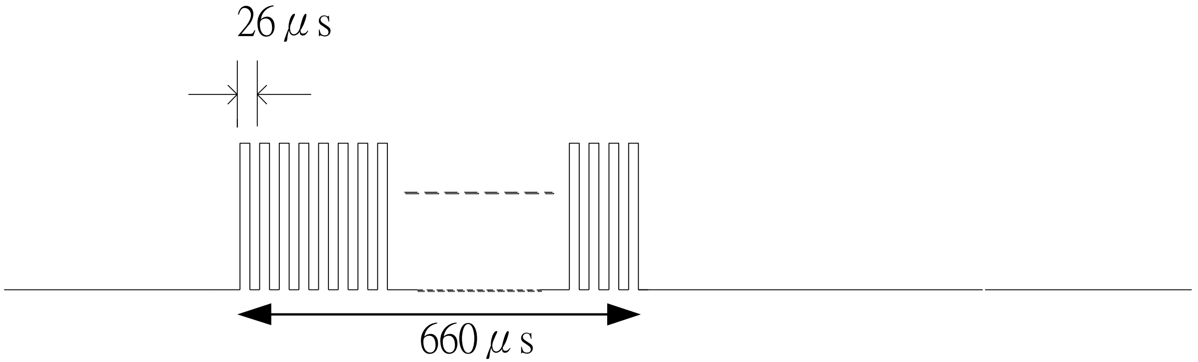
Modulated signal

Liteon IR330

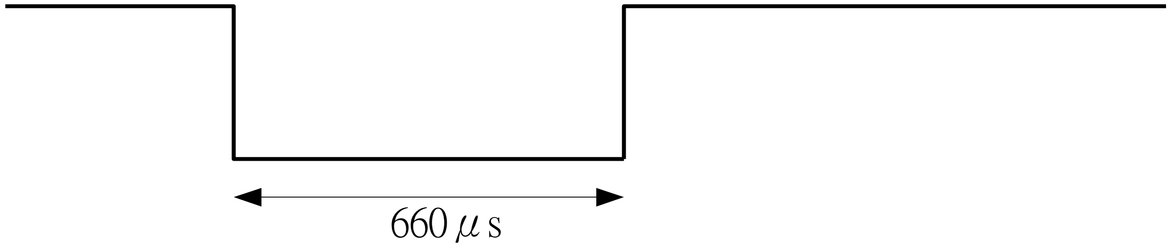
- Light is modulated so that intensity of ambient light will not affect the sensitivity of module.
- Liteon IR330, 38KHz 940nm

Single Infrared Signal

- Transmit single infrared signal

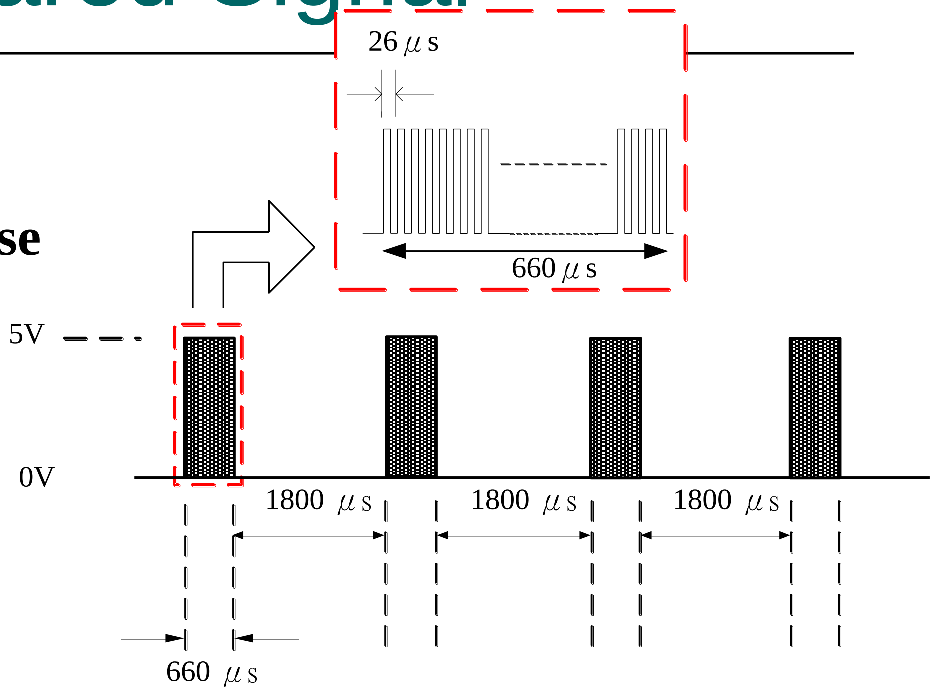


- Receive single infrared signal

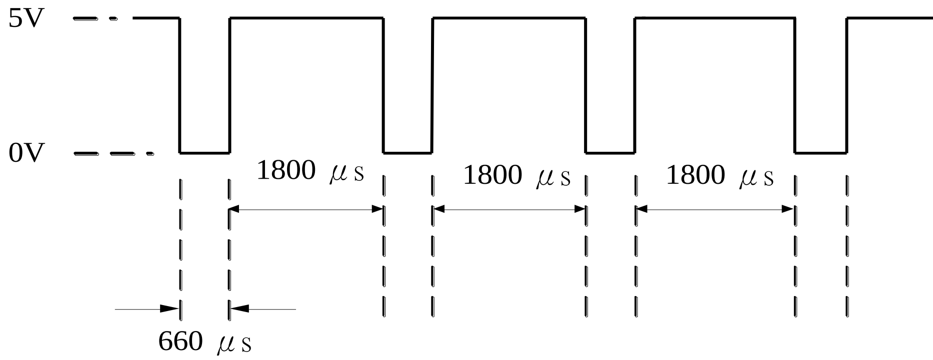


Continuous Infrared Signal

- Transmitted signal
  - 660 μ s continuous pulse and 1800 μ s logic low.

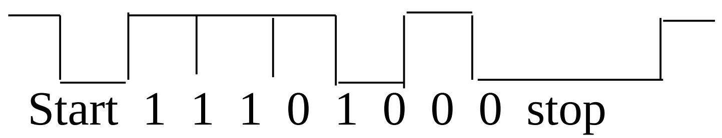


- Received signal
  - 660 μ s logic Low and 1800 μ s logic High.

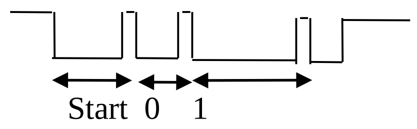


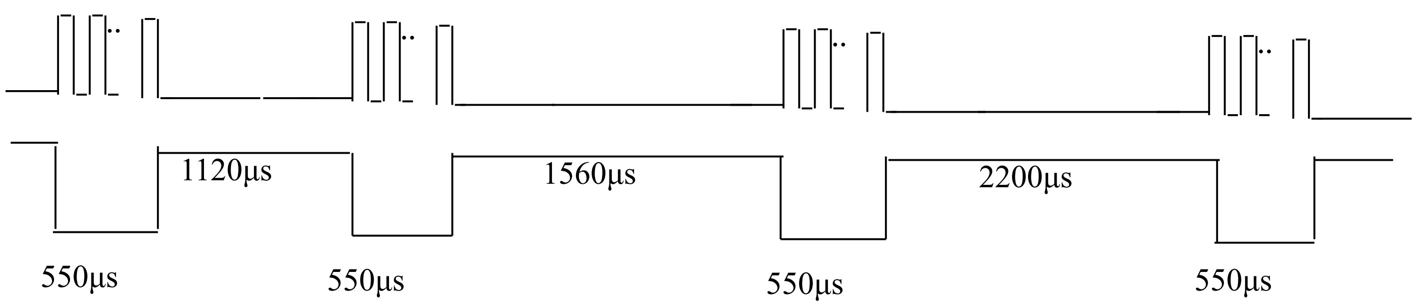
How to read a digital code?

Bit form



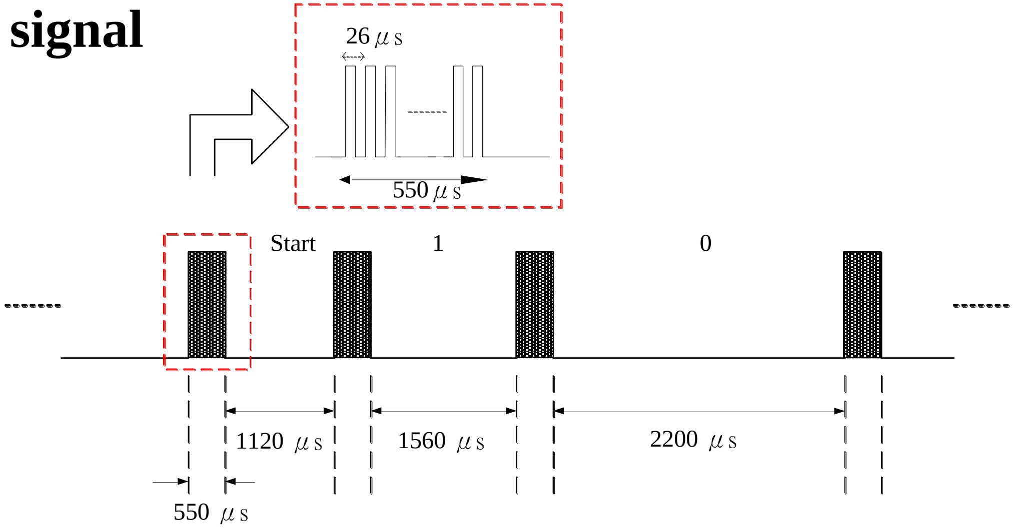
Bit interval



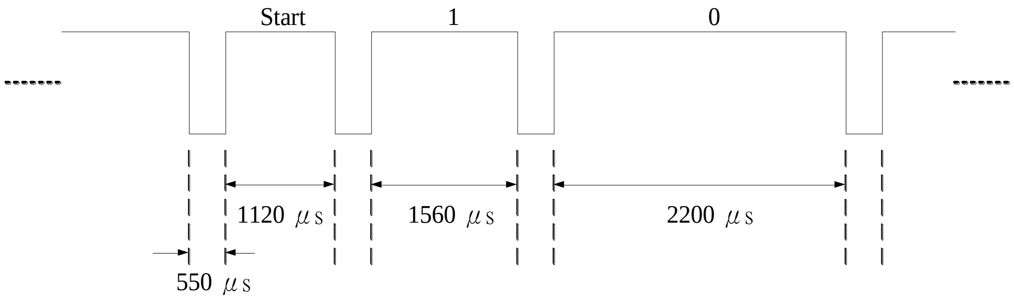


Coded Infrared Signal

- Low interval of transmitted signal
  - Start bit :1120 μs
  - Logic 1 :1560 μs
  - Logic 0 :2200 μs



- Received signal code



Decoding of infrared signal

- Look at elapsed time between falling edges to determine if a bit is "1" or "0".

Ex: 1.67ms --> start

2.11ms --> 1

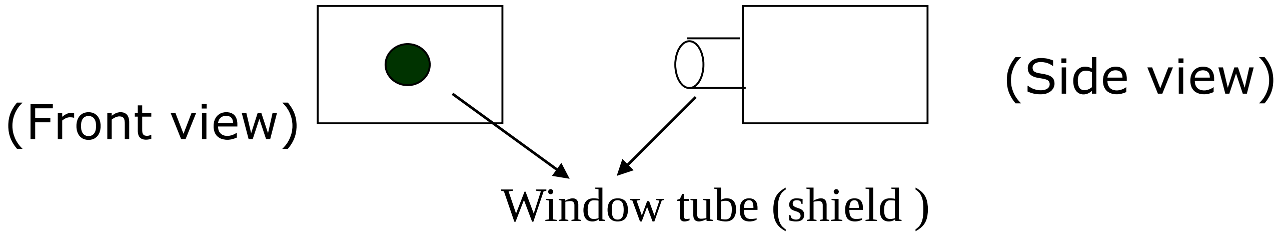
2.75ms --> 0

Sony unit: 1.2ms = 0

1.8ms = 1

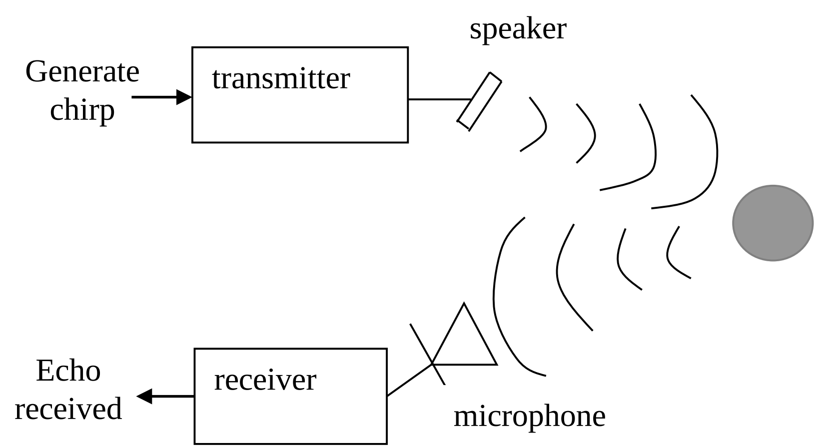
Shield of light

- IR modules receive light(signals) from wide angles need to narrow angle of received signal to leave it on it.

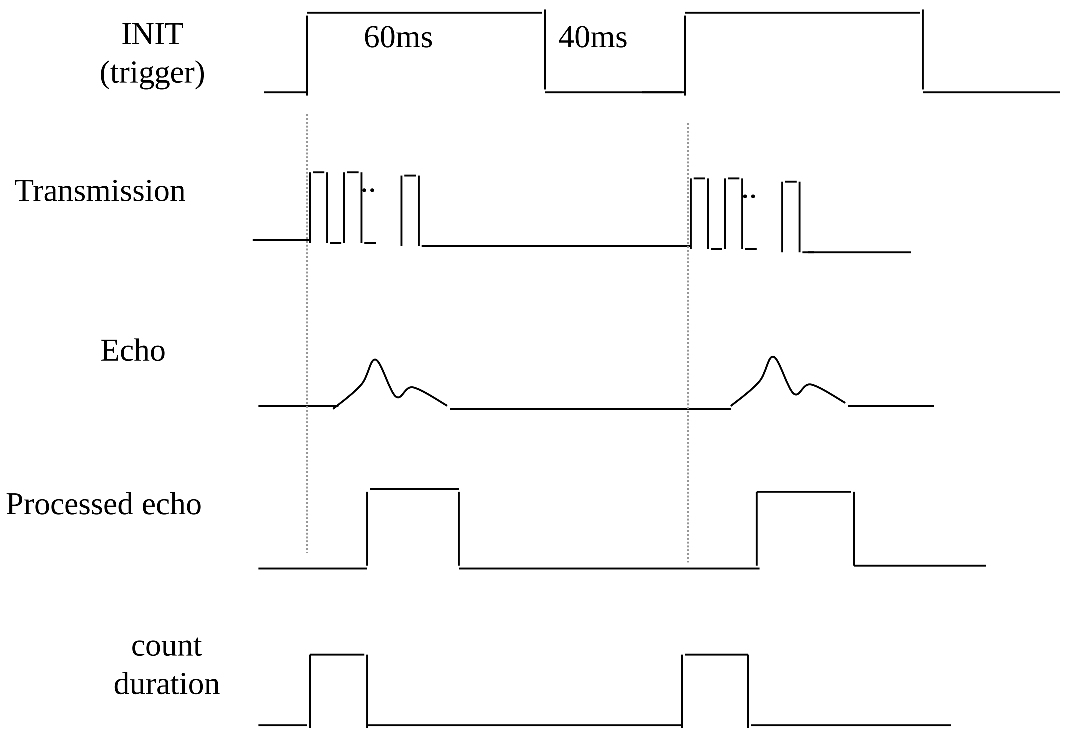


Ultrasonic ranging system

- SONAR (Polaroid 6500)
- Measures the time of flight for a sonar “chirp” to bounce off a target and return to the sonar (Echo).
- More accurate than IR, giving a distance to a direction, possible to make a scanning of the environment.

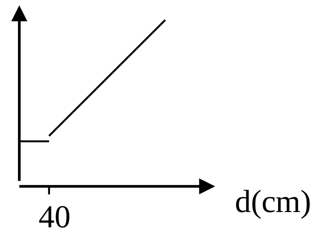


Polaroid 6500 sonar ranging system

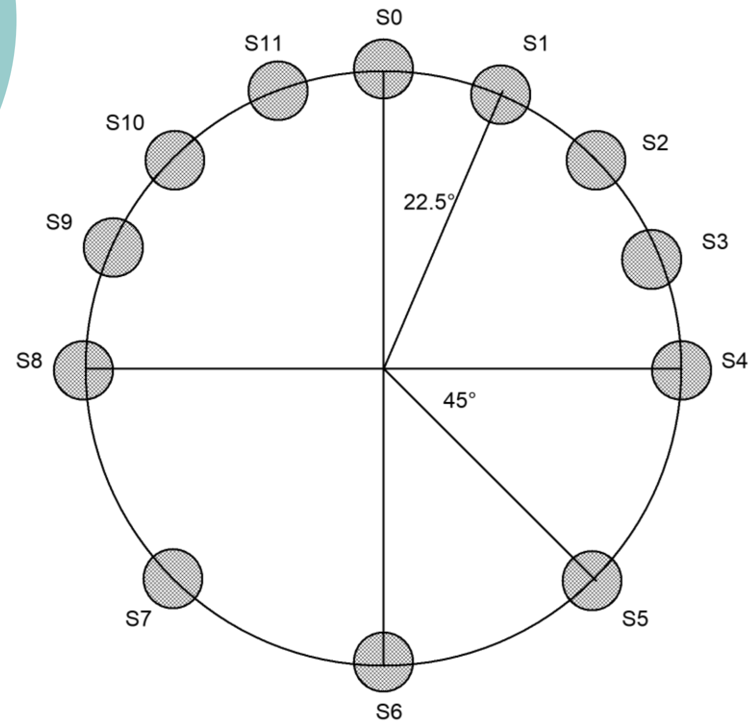


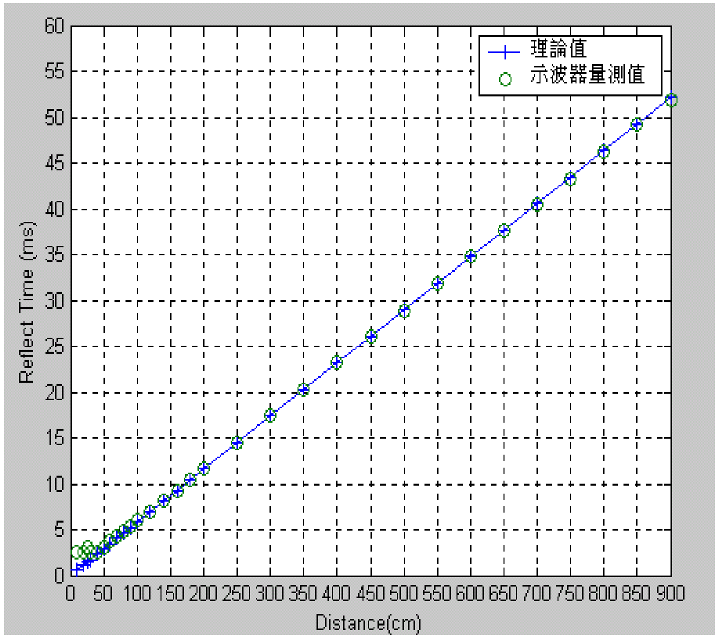
Characteristics of Sonar system

- A transducer which acts as both the speaker and microphone
- A circuit board
- chirp frequency 50kHz (49.4kHz), 16 cycles
- Blanking of signal in the beginning for 2.38ms (40cm)



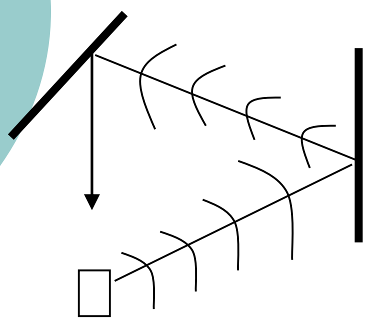
Characteristics of ultrasonic ranging system



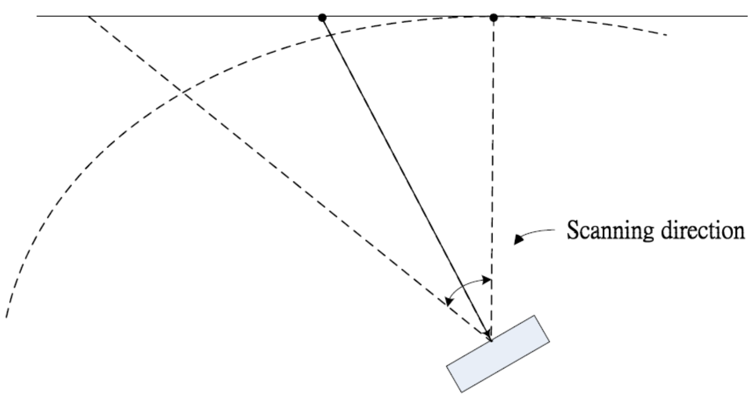


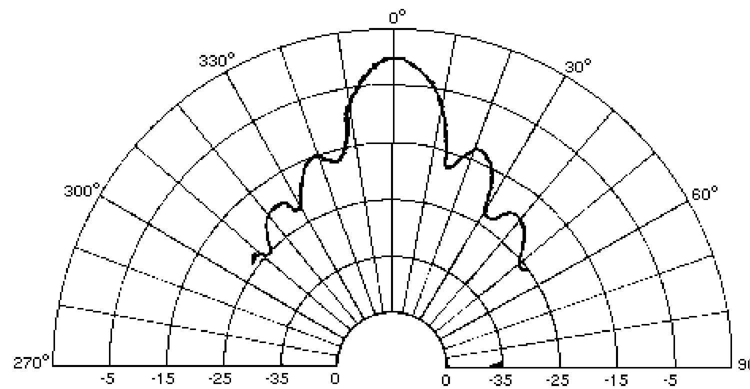
Limitations

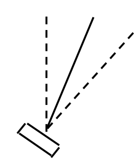
- Specular reflection



- Bean angle of the ultrasonic transducer causes measurement error.







beam angle = 22.5°

Laser Scanner

- Laser scanner

  Can get accurate environment distance, fast scanning, powerful, but expensive.
- SICK LMS 291
- 75Hz, 81m (10mm resolution),

  0~ 180Deg (0.25/0.5/1 Deg resolution)

  RS 232,

  RS 422.

Hokuyo URG-04LX

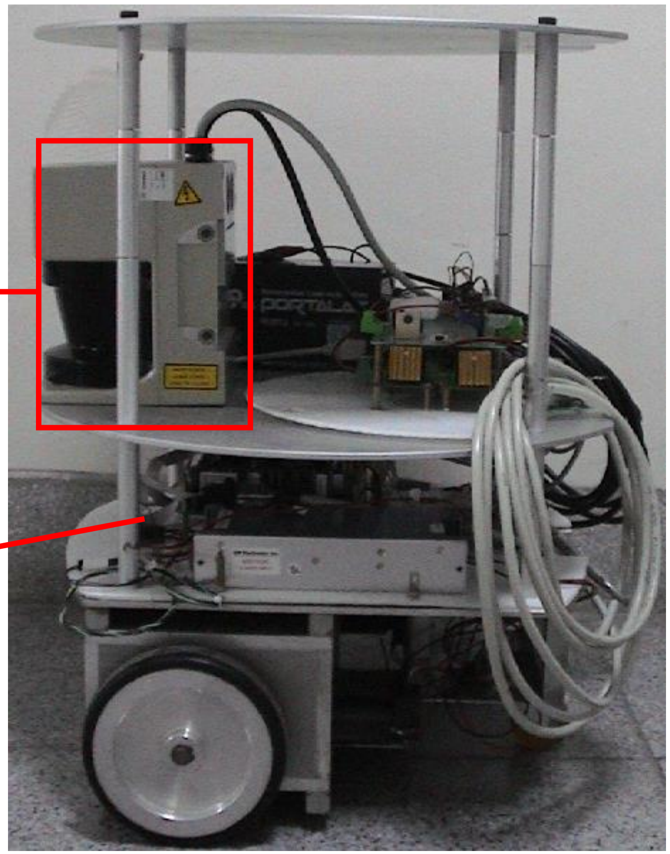
Model No.	URG-04LX-UG01
Power source	5VDC±5%(USB Bus power)
Light source	Semiconductor laser diode(λ =785nm), Laser safety class 1
Measuring area	20 to 5600mm(white paper with 70mm×70mm), 240°
Accuracy	60 to 1,000mm : ±30mm, 1,000 to 4,095mm : ±3% of measurement
Angular resolution	Step angle : approx. 0.36°(360°/1,024 steps)
Scanning time	100ms/scan
Noise	25dB or less
Interface	USB2.0/1.1[Mini B](Full Speed)
Command System	SCIP Ver.2.0
Ambient illuminance[*1]	Halogen/mercury lamp: 10,000Lux or less, Florescent: 6000Lux(Max)

160g

SICK Laser Scanner

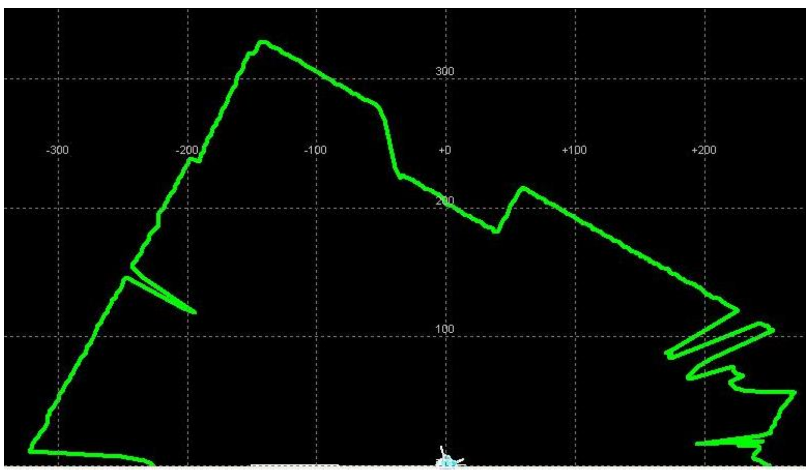
Laser scanner

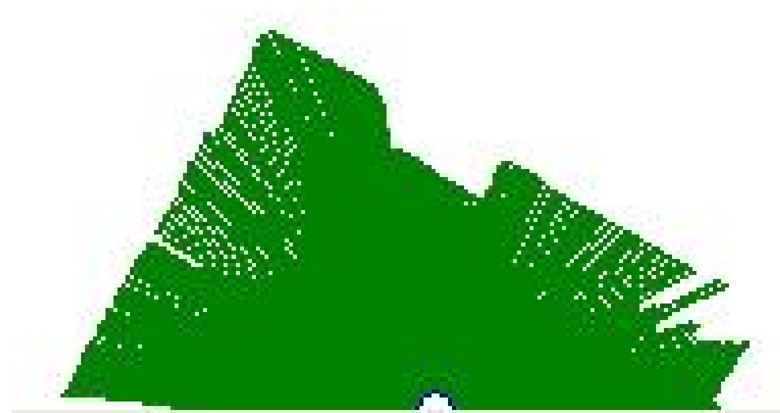
IPC



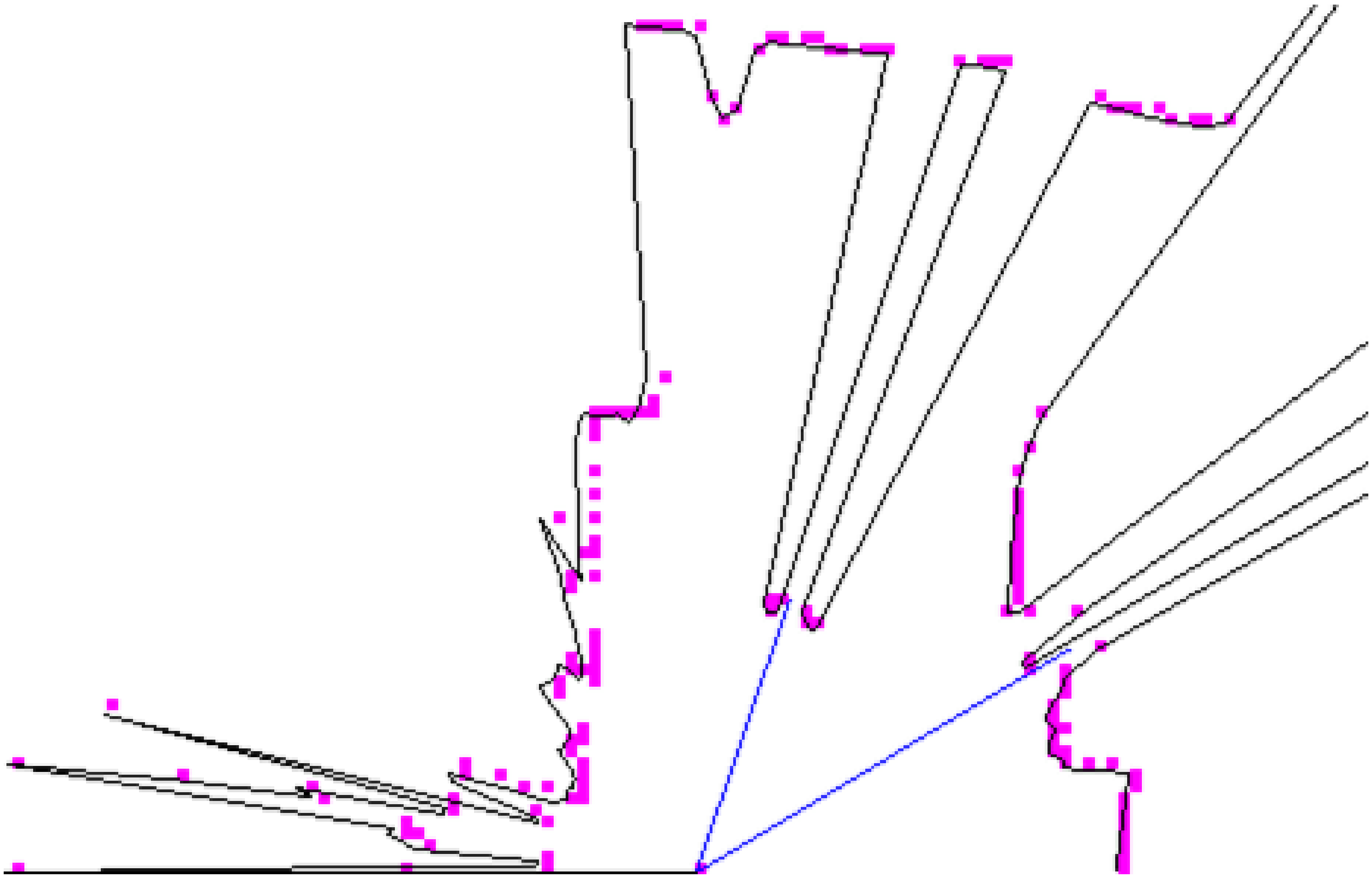
Laser scanner Measurement

- Scanning data

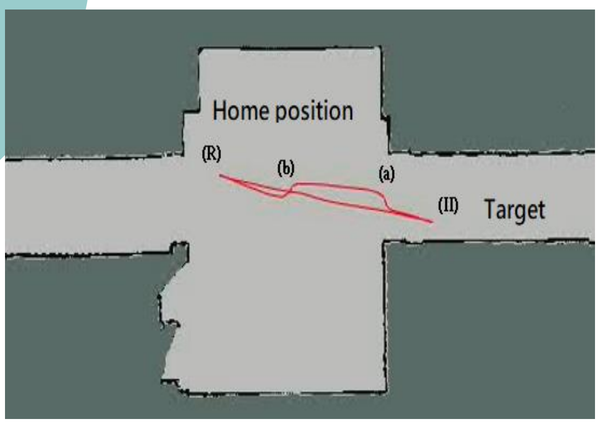




Laser Scanning Data



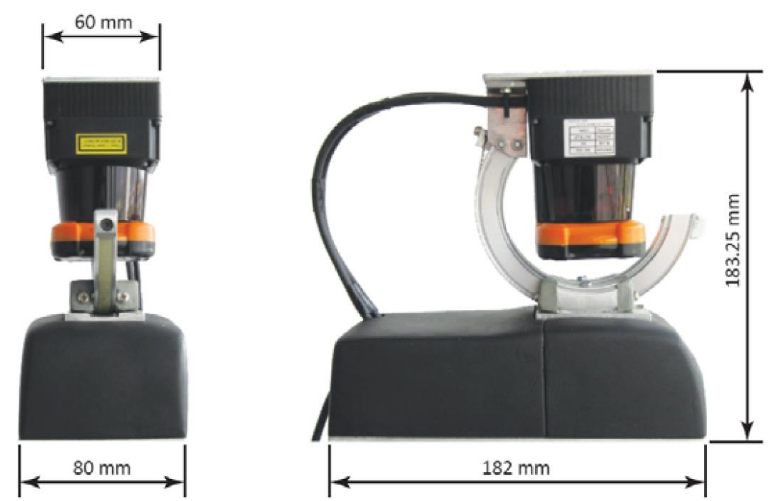
LiDAR SLAM



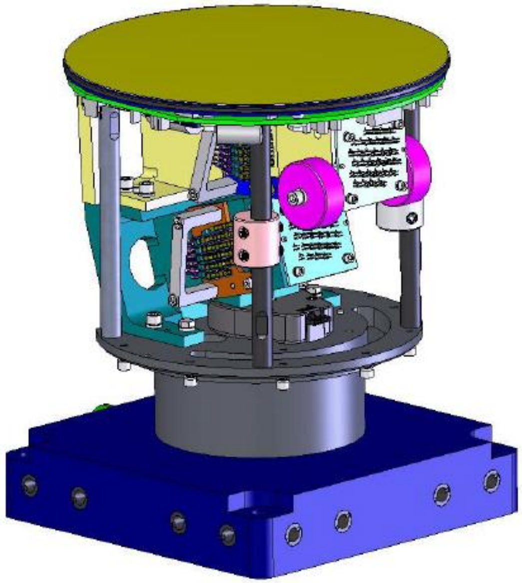
[Demo 2]

3D Laser Scanner

Product Name	3D Laser Sacnner
Supply voltage Supply current	12VDC ±10% 1.2 A (nominal) 2.8 (max)
Host interface Detection	USB 2.0 (Virtual COM) 0.1-30 m
range Measurement	
resolution	1 mm
Field of view	270° x 135°
Max angular resolution	0.25° x 0.067367° 0.25° x 0.001347° 50 ms 1.54s
(continuous mode) Max	(minimum resolution) 182mm x 80 mm x 191 mm
angular resolution (step	
mode) 2D Scaning time 3D	Weight 850g
Scaning time Dimensions	



Velodyne LiDAR Sensor



- 64 lasers, entire unit spins
  - 1.33M points/sec.
- 360° HFOV
- 26.8° VFOV
- Radial accuracy: .1°
- Distance accuracy: 5cm”
- Range: 2-120M
- 5 – 15 Hz frame rate, variable
- Variable power lasers
- Distance, intensity data
- 905 nm laser frequency, pulsed
- Class 1 eye safe
- Ethernet data interface

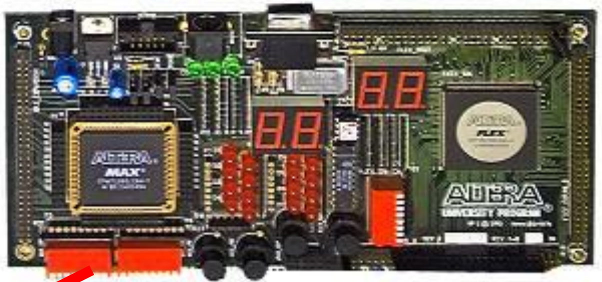
Vision Sensors

- CCD Camera
- CMOS Camera
- PTZ Camera

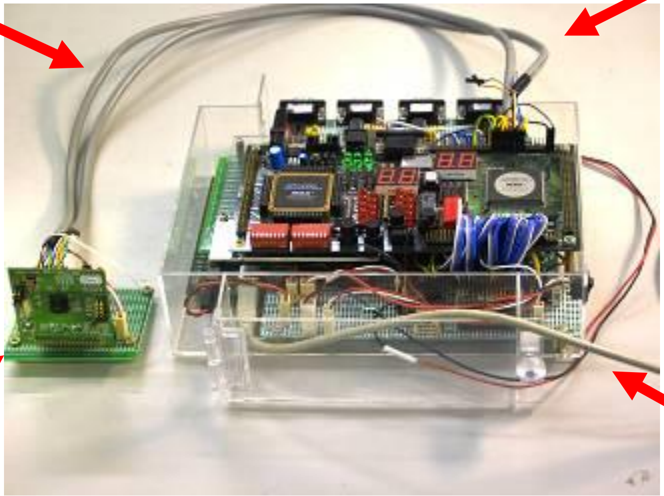
- Image frames contain much information of the immediate environment. It's therefore required to segment useful features and extract information need for task execution.
- →image acquisition + image processing + recognition algorithm (visual servoing ,visual tracking)

Real-Time Imaging System

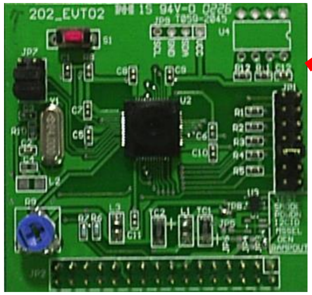
TI TMS320C6416 DSK



FLEX10K70RC240



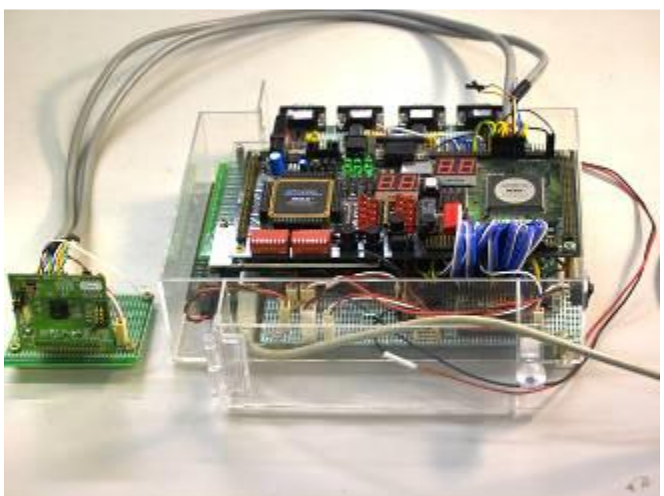
CMOS Sensor
ICM205B

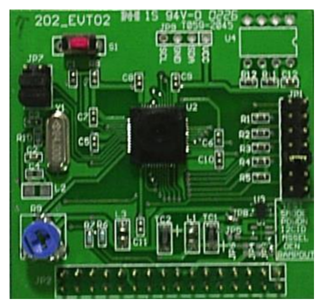


Frame Buffer
AL422B

Eye-in-Hand Configuration

- Eye-in-hand configuration for camera mounting.
- Real-time robotic vision system for image processing.






Real-time Robotic Vision
ISCI Lab, NCTU, Tainwan

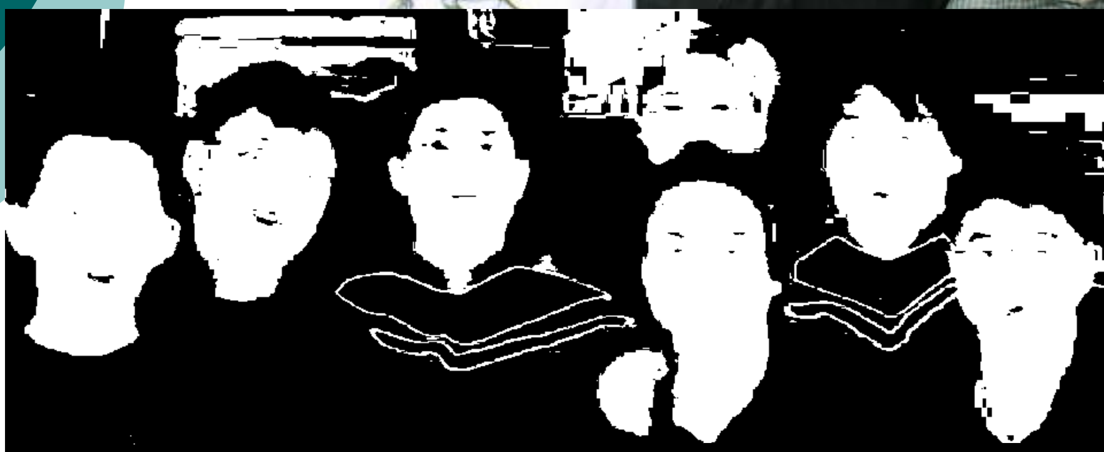


Image Segmentation by Using Color Information

Edge Detection

Without low-pass filter

With a low-pass filter

Target Searching and Tracking

Color segmentation

RAW image

Sobel edge detection

Oval searching

Image tracking

Face Tracking by Using Adaptive Threshold

Power and Battery

Battery converts chemical energy to electrical energy

- Factors considered
  - -Energy density
  - -Voltage
  - -Capacity
  - -Internal resistance
- Power regulation
- Isolation and grounding

Battery Chemistry	Recharge	Energy Density (Whr/kg)	Cell Voltage	Typical Capacity (mAh)		Internal Resistance (ohms)	Comments
Alkaline	No	130	1.5	AA	1400		Most common primary battery
				C	4500	0.1	
				D	10000		
Lead-Acid	Yes	40	2.0	1.2 - 120 Ah		C-size 0.006	Available in a wide variety of sizes
Lithium	No	300	3.0	A	1800		Execellent energy density, high unit cost
				C	5000	0.3	
				D	14000		
Mercury	No	120	1.35	Coin	190	10	
NiCd	Yes	38	1.2	AA	500		Low internal resistance, available from many sources
				C	1800	0.009	
				D	4000		
NiMH	Yes	57	1.3	AA	1100		Better energy density than NiCd, expensive
				4/3A	2300		
Silver	No	130	1.6	Coin	180	10	
Zinc-Air	No	310	1.4				High energy density but not widly available, limited range of sizes
Carbon-Zinc	No	75	1.5	D	6000		Inexpensive but obsolete

All numbers listed here are approximate. Precise values depend on the details of the particular battery.
Some values depend on the battery's state of charge, temperature, and discharge history.

Battery Properties

1) Rechargeability

2) Energy Density

The maximum energy per unit mass : Watt-hours/kg (Wh/kg).

3) Capacity

Energy stored in cell, usually in mA-hrs. (some in A-hrs).

Capacity (with rated voltage) = energy density x mass of battery.

Properties(Continued)

4) Voltage

Voltage of a single cell depends on type of battery, voltage also depends on the state of charging of the cell.

5) Internal resistance

Determines maximum current a battery can supply. The internal resistance increases as the battery discharges.

6) Shelf life

How quickly a battery discharge without external load.

Energy density

- Gasoline has > 400 x energy density of NiCds (~80 x if gasoline converted to electricity)
- Batteries can be cost effective despite the high absolute costs of the energy they supply.
- Fuel cell, or other type of power supply will become more important in the future.

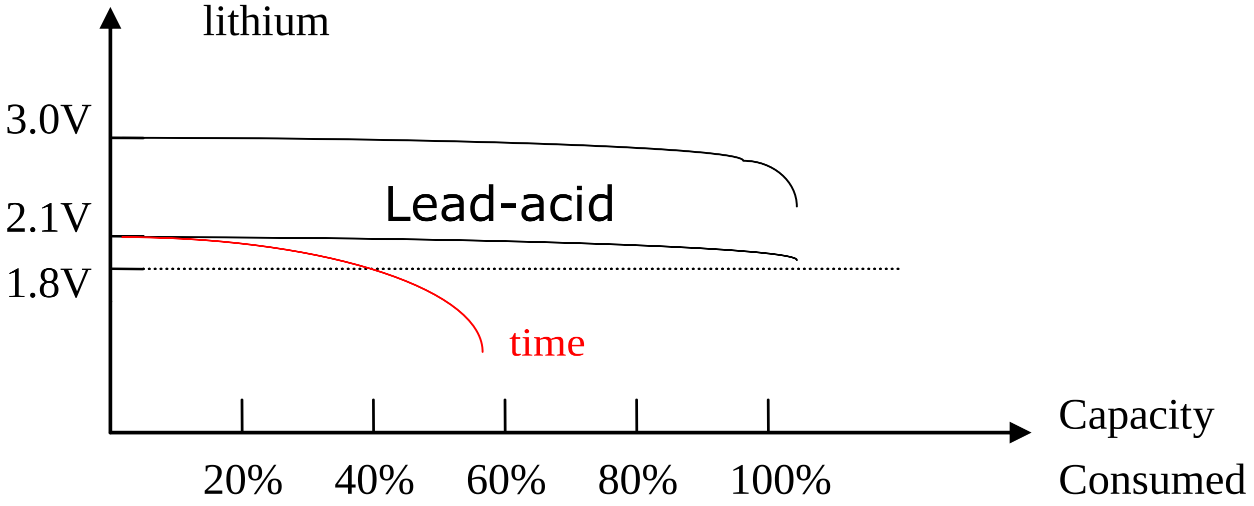
Voltage : depends on state of charge

NiCd : ~1.2V when fully charged.

1.1V when at 10-20% of capacity.

Lead-acid : 2.1V when fully charged.

1.8V when at low capacity.



Capacity :

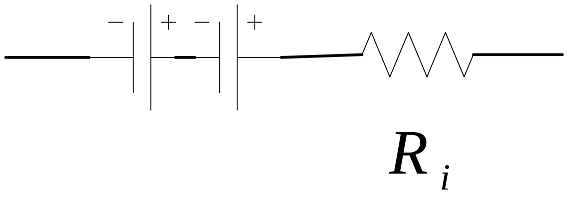
- Amp-hours (?), mA-hrs,

  mA-hrs x voltage = energy (mW-hrs).
- Rated capacity: under favorable conditions.
- Only about 60%-80% is available under rapid discharge conditions.

Internal resistance :

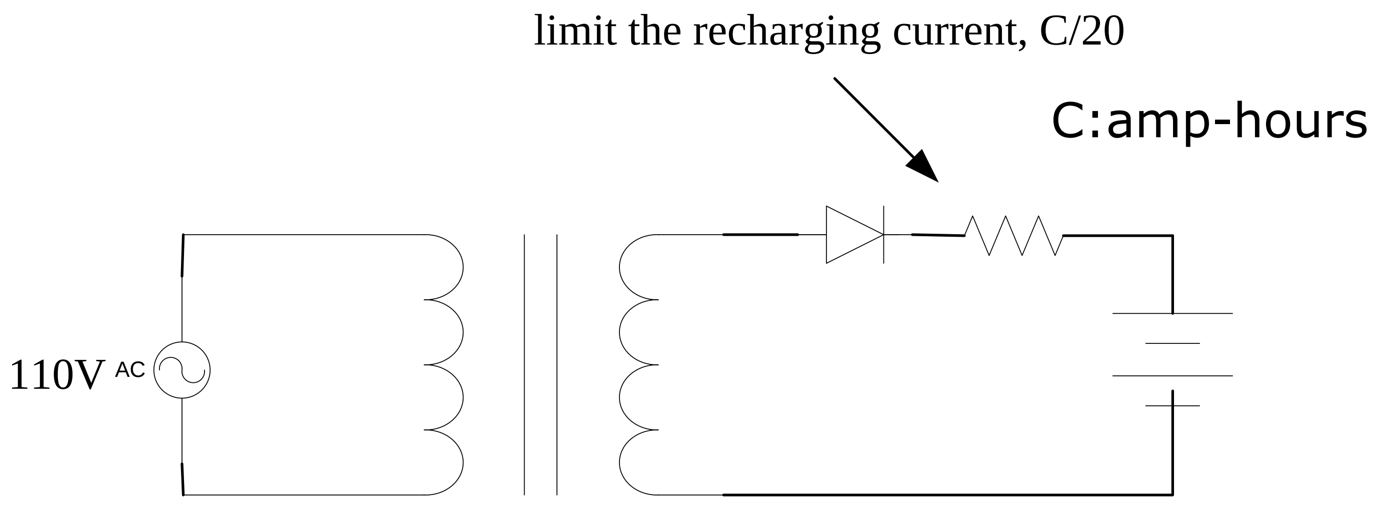
- If the positive and negative terminals of a battery are shorted together, the current is limited by the internal resistance of the battery.

the battery cell model



NiCd cells have small internal resistance, despite its lower energy density. NiCd is more suitable for application of high surge current. But more dangerous to use.

Recharging of the battery



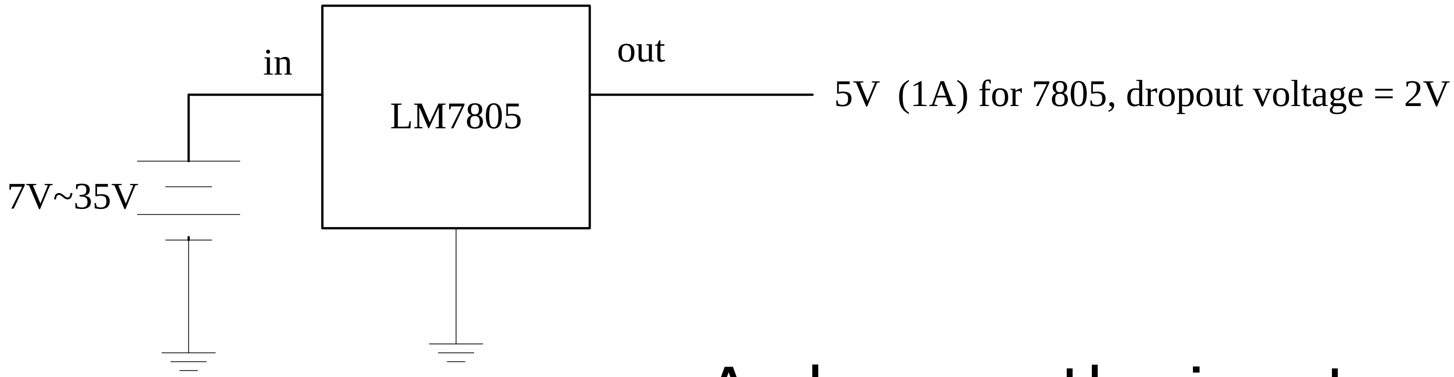
Charging circuit (IC chips)

Power regulation

- Battery voltage changes as the battery discharges.
  - -Want constant voltage for IC power supply.
  - -Want constant voltage as load changes (or current demand changes).
  - -May want several voltages from a single battery pack.

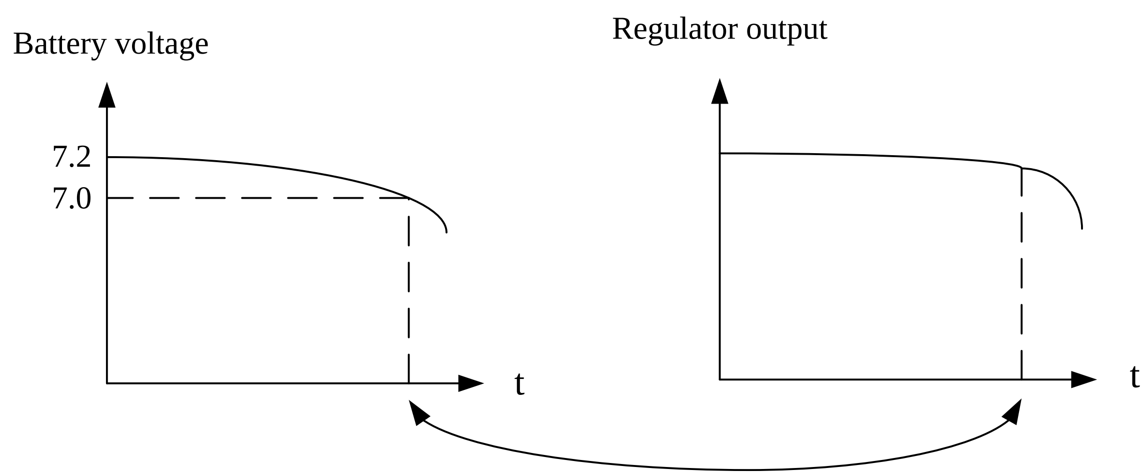
Linear regulators

LM7805 -5V regulator (1.0 A current supply)



As long as the input voltage is higher than the required output voltage by a certain amount (dropout voltage), the output voltage will be constant.

Can have 0.2V drop in battery voltage before regulator output change!
(Basic stamp will work to ~4.5V)



This may correspond to a cell that has only used up a small portion of battery capacity. (1.2V cell x 6 = 7.2V, each battery cell will still have 1 volt when used up.)

How many battery cells?

- Can use 8.4V battery, but this will increase power loss.

Power loss : $P = I(V_{in} - V_{out})$

V_{in} : supply voltage

V_{out} : output voltage

I : current output

P : power dissipated by the linear regulator

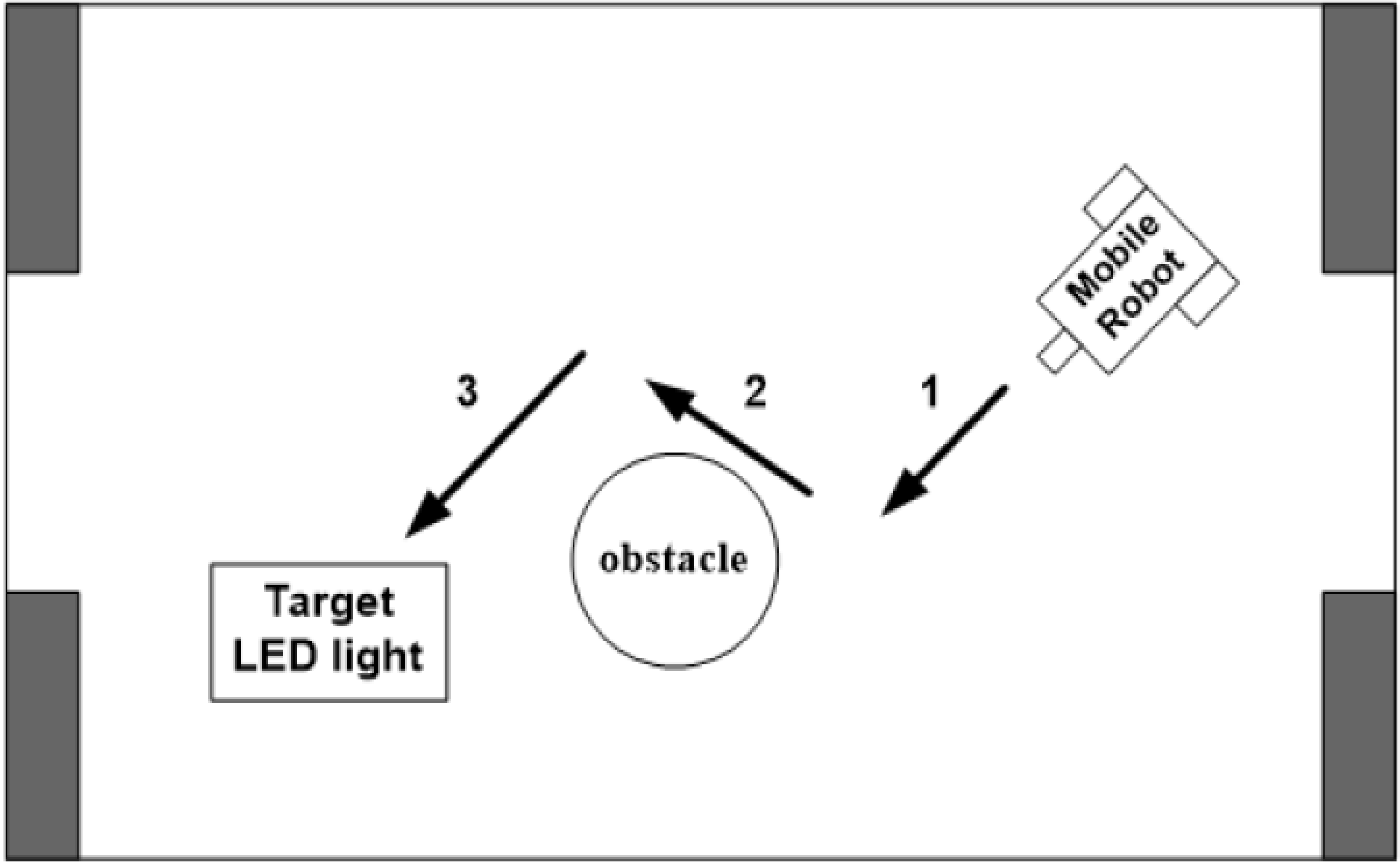
Circuit uses: 5.0I

Regulator consumes : 3.4I

→Linear regulator with a smaller dropout

LM2940CT-5.0 (more expensive)

Checkpoint #3 Arena



Checkpoint #3 Assignment

- The purpose of this checkpoint is to make sure you can control your robot to move in the arena. The mobile robot needs to detect an obstacle in front of it and take action to avoid the obstacle in order to continue its motion.
- Further, your robot can find the puck. In this checkpoint, the puck is a ring of LED lights.

Checkpoint #3 Grading Policy

1. Please start to arrange the space configuration of your robot, make sure every and each component such as circuit boards and sensors is settled firmly and stable on the chassis and all the robot functions will not be affected by wires. **(15%)**
2. Make sure that your robot can move freely. It means that you do not need to use keyboard to control it anymore. **(20%)**
3. Integrate a light sensor and two touch sensors to the robot and program your robot to find and move toward the puck (LED light). **(30%)**
4. The time to find the puck (in 90 sec). **(35%)**