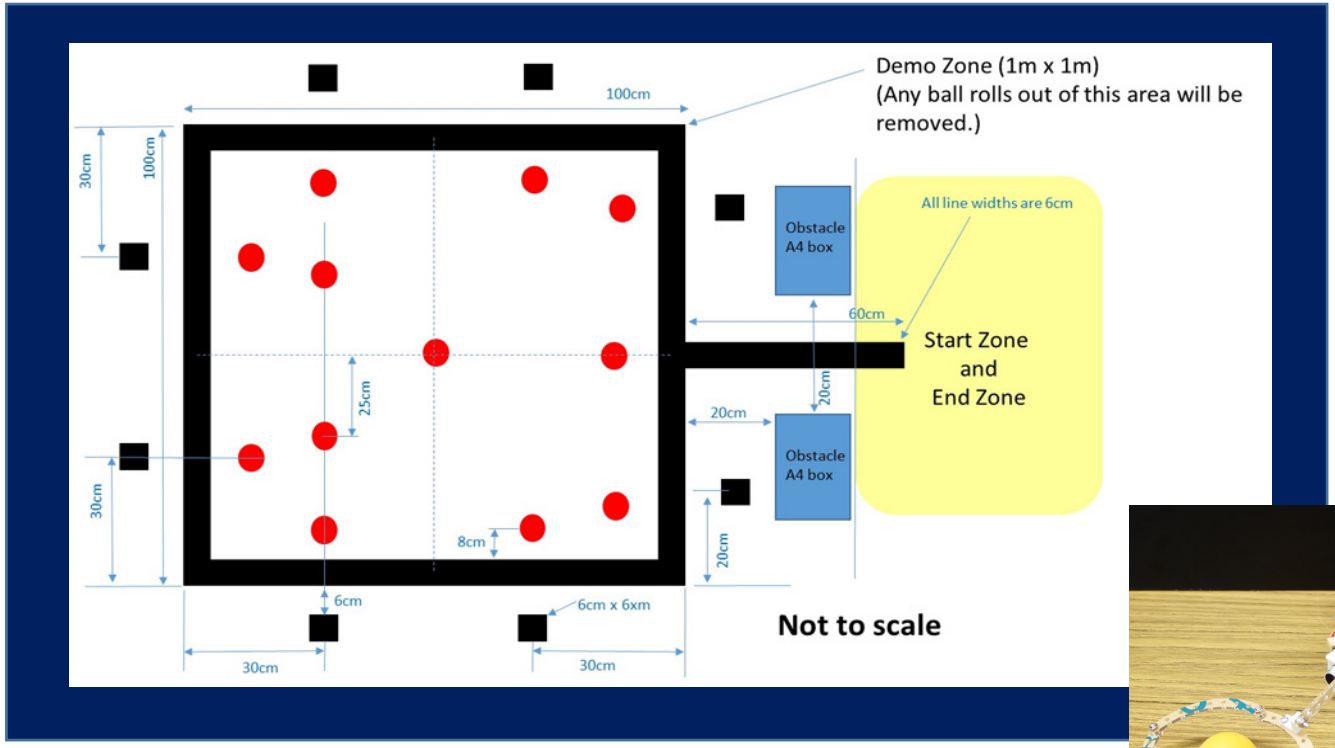
Lecture 6
Sensors & Actuators

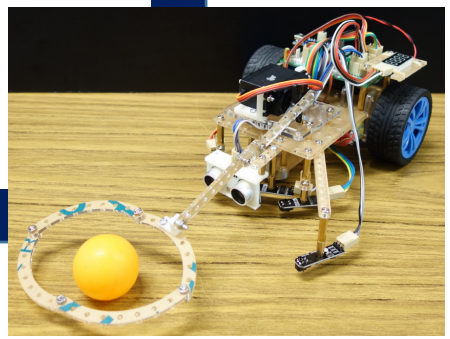
Prof. Xiankai Sun

Department of Electronic Engineering

Acknowledgment: The lecture slides were prepared by
Prof. Lian-Kuan Chen, Department of Information Engineering

Final project of this year





- *Task:*

  Using a robot car to find and pick up as many balls as possible and drop them off at a specific location within a given time limit.

Outline

- Sensors
  - Types of sensors
  - IR sensors
  - Ultrasonic sensors
  - Sensitivity and dynamic range of sensors
- Actuators
  - DC motors
  - Servo motors

Sensors

- *A sensor is a device that converts changes in a particular physical property (e.g., temperature, power, motion, …) to a signal (e.g., resistance) that is more suitable for measurement or other actions.*

Examples:

- Motion sensor: to detect intruders or to turn light on when people pass by.

http://en.wikipedia.org/wiki/Motion_detector

- Thermometer

http://en.wikipedia.org/wiki/Medical_thermometer

- Accerometer: to detect motion and gravity

http://www.iphone-gear.org

Examples of sensors

Physical Property	Sensor	
Temperature	Thermocouple Thermistor Thermostat Resistive temperature detectors (RTD)	
Light	Light Dependant Resistor (LDR) Photodiode Photo-transistor Solar Cell	
Distance	Ultrasonic Laser	
Wind speed	Anemometer	
Pressure	Strain Gauge Pressure Switch Load Cells	
Radiation	Geiger Counter	

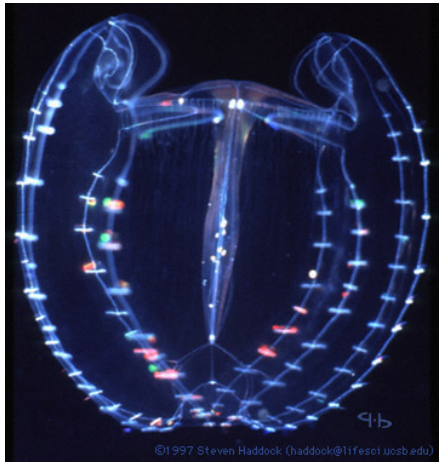
Two types of sensors used this year:
IR sensor & Ultrasonic sensor

http://www.electronics-tutorials.ws/io/io_1.html

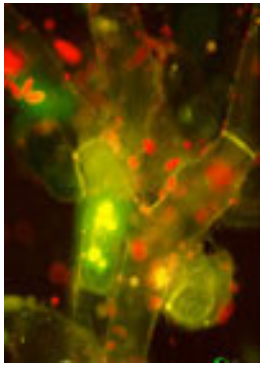
Light sensing

-- need light sources and optical detectors

Light source in nature - *Bioluminescence*



http://e-info.org.tw



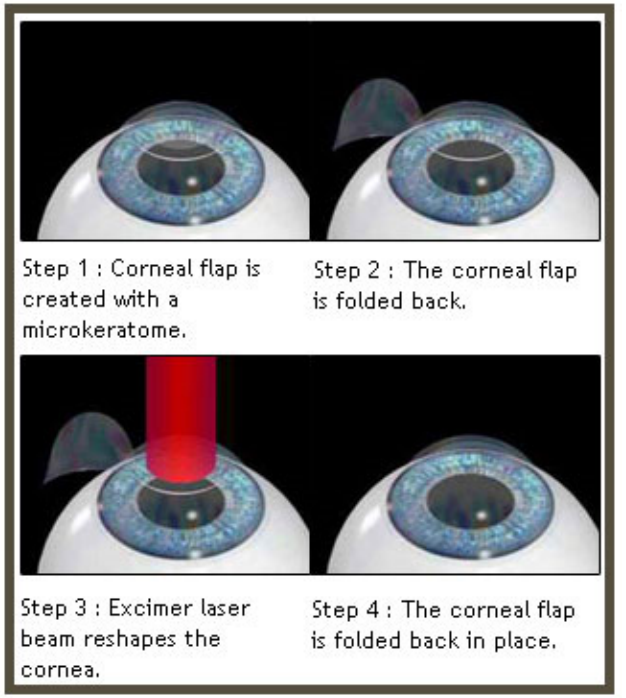
http://www.lifesci.ucsb.edu/~biolum/organism/photo.html

Light sources for different Applications

- Different light sources can be used for
  - Illumination
  - Beacon
  - Communications
  - Surgery
  - Sensing
  - …

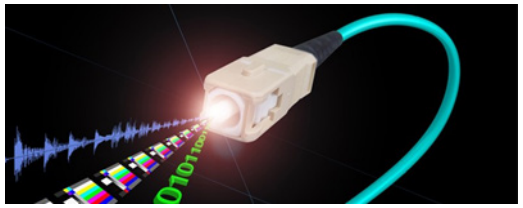
http://globe-views.com/dreams/torch.html

http://www.photo-dictionary.com/phrase/3081/beacon.html



http://www.theorganicprepper.ca/lasik-surgery-have-you-considered-permanent-vision-correction-as-a-prep-01072015

https://9to5mac.com/2015/10/02/opinion-apple-watch-double-down-health-sensors-battery-life-waterproofing/

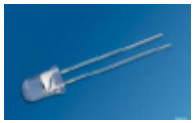


Different light sources

- Light bulb

- Fluoresce light

- LED light

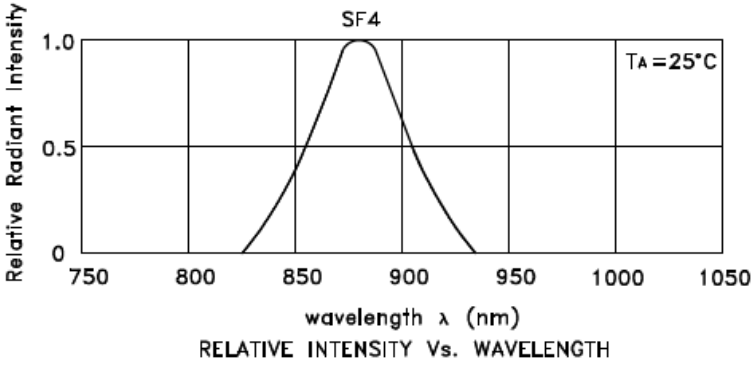


- Laser
  -
  -
  -

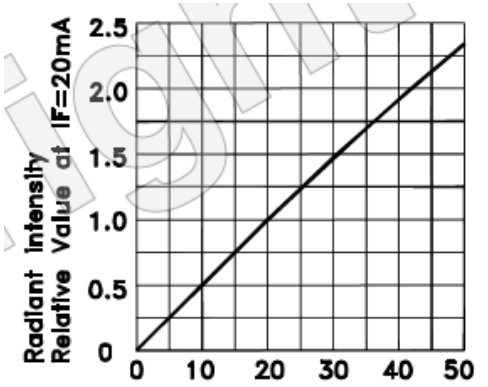
Some characteristics of a light source

- wavelength;
- output optical power (intensity) vs. input current;
- beam profile and direction;
- absolute maximum ratings.

Example specifications of an IR LED

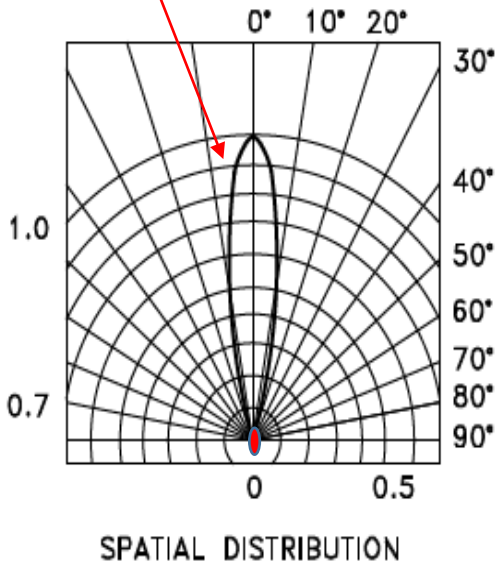


RELATIVE INTENSITY Vs. WAVELENGTH



RADIANT INTENSITY Vs. FORWARD CURRENT

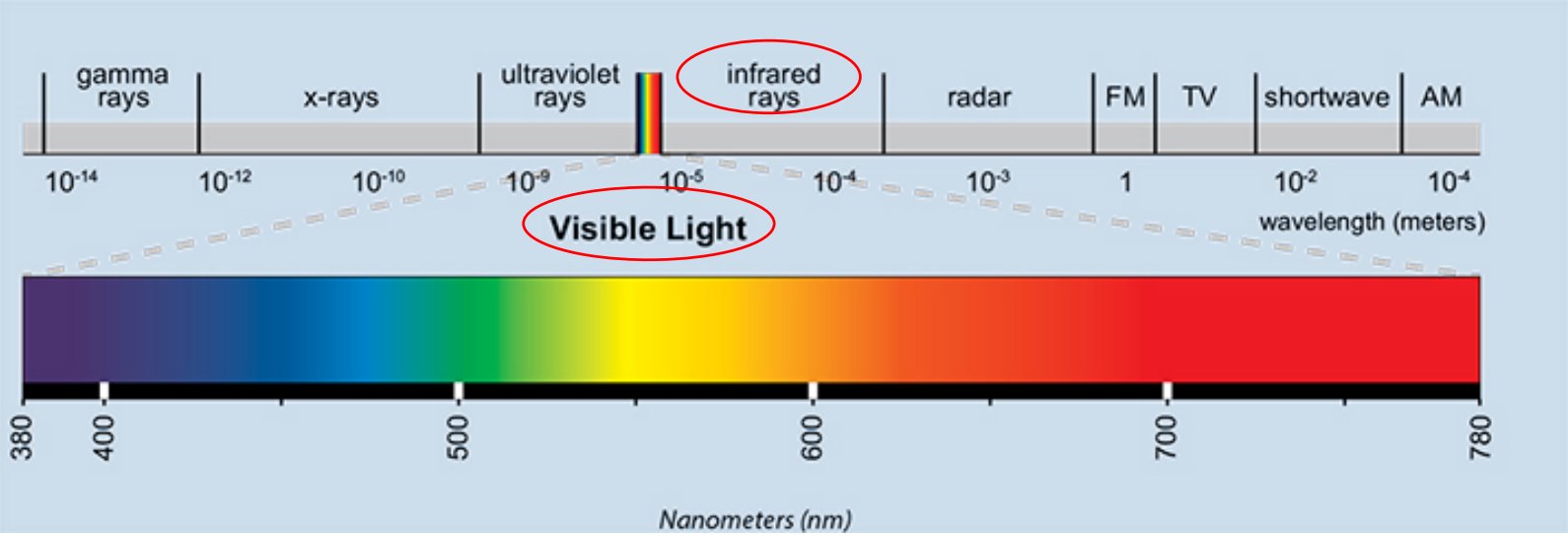
The line represents the position for a constant light power



SPATIAL DISTRIBUTION

Wavelength selection

- All light source and sensors do not cover the entire wavelength range.
- Matching source's wavelength to sensor's is necessary.
- Due to the interference from sun light, visible light is not suitable for outdoors high-speed communication and sensing.
- Ultraviolet rays causes health hazard; because short wavelength = high energy.



http://www.eyelighting.com/resources/lighting-technology-education/general-lighting-basics/light-spectrum/

Laser safety issue

- Don't look directly into the laser or high power LED, as it may seriously damage your eyes.

  (https://en.wikipedia.org/wiki/Laser_safety)

- **Safety Guidelines (for your reference only)**

  (http://www.emsd.gov.hk/en/other_regulatory_services/laser_safety/publications/safety_guidelines_for_laser_products/index.html)

  - For Classes 1, 1M, 2, 2M, 3R, 3B & 4 laser products
    - Never look directly into a laser beam.
    - Never aim a laser beam at a person's eyes (*or play it as a lightsaber*!).
  - Additional precautions for Classes 3R, 3B & 4 laser products
    - Follow the guidelines listed in the operation manuals of laser products.
    - Employ qualified or trained personnel for the maintenance or repair of laser products.
    - Wear suitable protective goggles and clothing when operating or servicing medium or high power laser products.

Photodiode

- On the receiver side, a photodiode (PD) can be used to convert photons to free-running electrons (current).

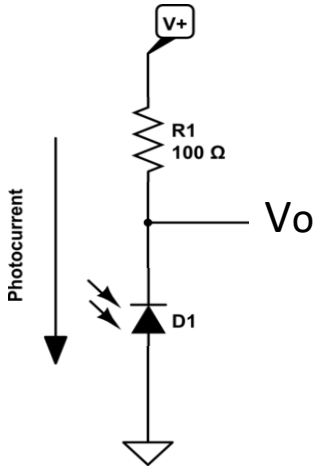
  optical signal → *electrical signal*

- PD is typically reverse-biased to enhance sensitivity.

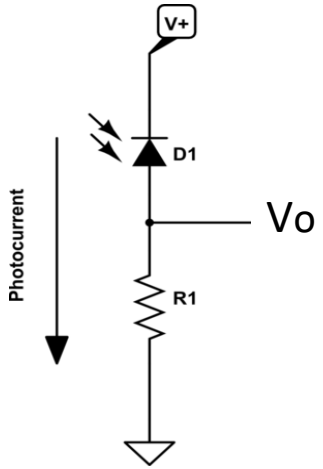
photodiode symbol

SFH 213 FA

Two possible driving circuit for PD



(a) larger light→ lower Vo



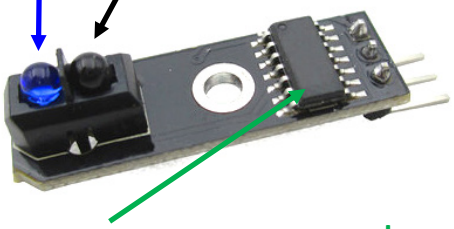
(b) larger light → larger Vo

Infrared sensor module

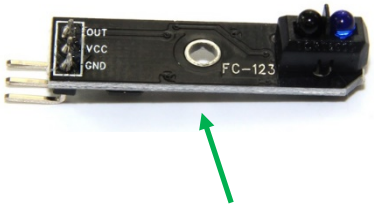
- This year, we use an IR sensor module that comes with a light source transmitter and an IR-photodiode to detect “black” or “white”.
- IR is good for indoor short-distance communication (e.g. TV remote controller).
  - Low IR energy in indoor visible lighting.
  - Not good for outdoor environment, as high IR energy in sunlight.
- Environment interference can be neglected for reflection-type module.

Transmitter (Infrared light emitter diode, LED)

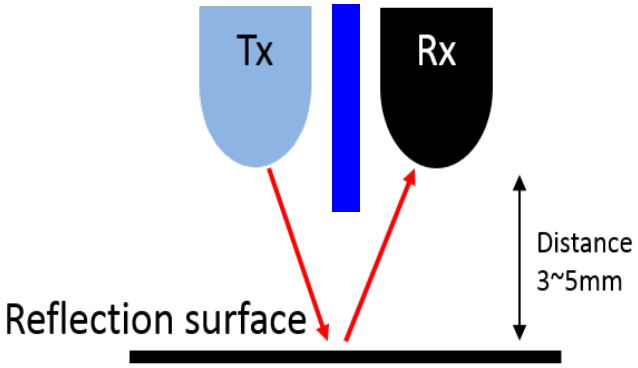
Receiver (Infrared photodiode, PD)



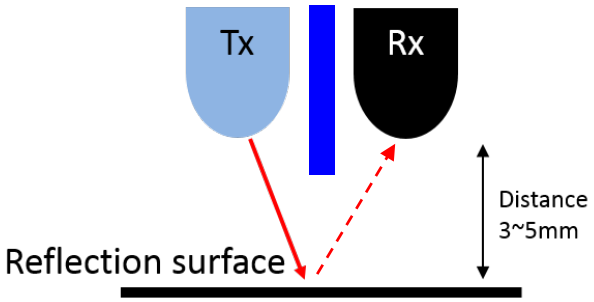
Amplifier



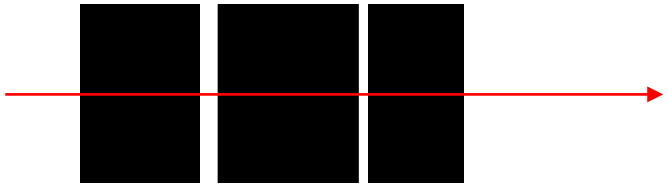
Lower-cost model uses logic IC to determine the logic low and high.



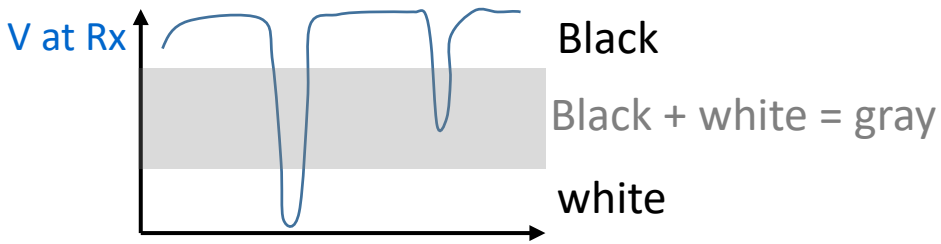
How does the IR sensor module work?



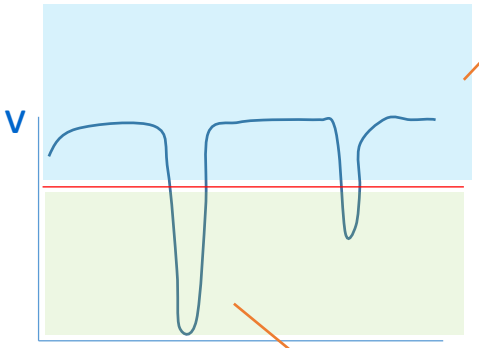
- The reflected light intensity depends on the reflectivity of the surface and the distance.
- "white" reflects more light than "black" or empty space.



Move the module along this direction.



How does the IR sensor module work?



Grater than the “threshold” -> it is defined as **HIGH**.

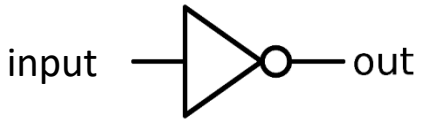
Threshold voltage, preset by the LOGIC IC.

(This threshold voltage model is simplified. There are two threshold voltages for High-to-Low and Low-to-High of 74HC14 Schmitt trigger NOT gate).

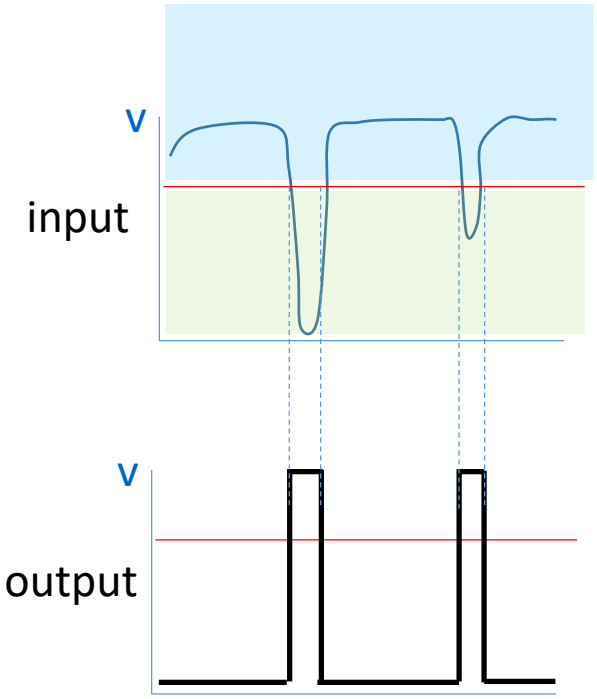
Less than the “threshold voltage” -> it is defined as **LOW**.

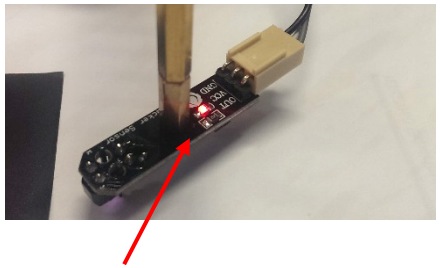
How does the IR module work?

In our project, a logic IC 74HC14 (NOT gate) is used as an amplifier to determine the input signal and output a logic signal (HIGH/LOW).



NOT gate



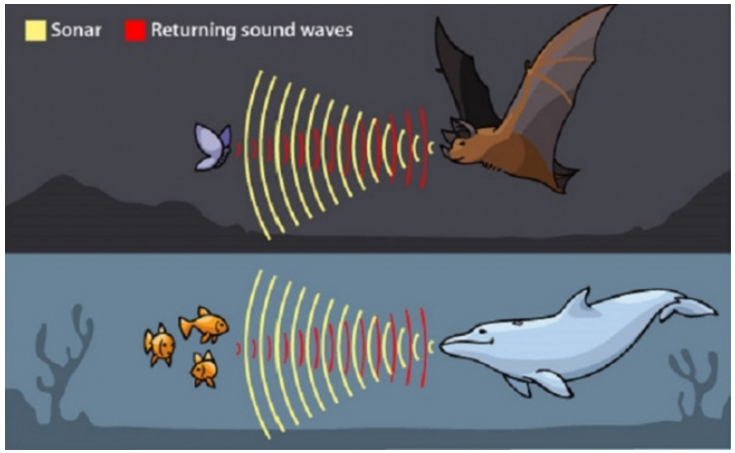


- There is an LED on the IR module to indicate the output logic.
- Check the meaning (detected WHITE/BLACK) when the LED is ON. Important for your project.

Ultrasonic Sensors

Ultrasonic sensor

- This year, an ultrasonic sensor is used in the project for distance detection.
- Principle: similar to *animal echolocation*

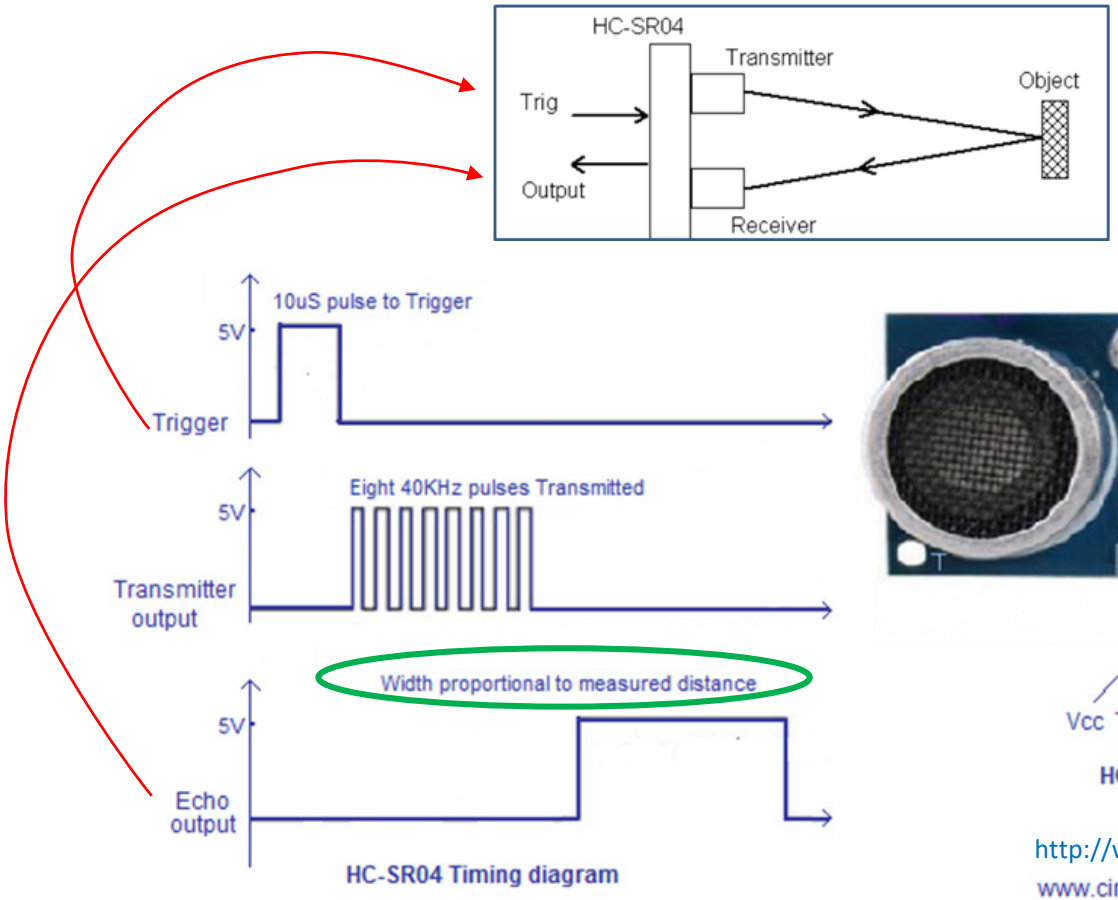


Ref:
http://images.hngn.com/data/images/full/10968/scientists-found-bats-and-dolphins-developed-echolocation-the-same-way.jpg?w=650

An ultrasonic pulse is sent and then its echo is detected. The distance can be derived from the time delay of the echo arrival and the speed of the ultrasound.

Ultrasonic sensor (HC-SR04)

- HC-SR04 sensor will be used in this project.



http://www.speakelectronics.com/

www.circuitstoday.com

Distance calculation

The distance of the object can be calculated as:

$$\text{Object Distance (D)} = \text{V} * \text{T/2}$$

where V (velocity of sound in air) ≈ 345 meter/s at 21 °C

Example: Assume the echo pulse delay (T) is 5 ms.

Object Distance (D) x 2 = V * T = 1.725 meter, therefore D=862.5mm.

Speed of sound

- The speed of sound in dry air (0% humidity) at temperatures near 0 °C can be calculated from

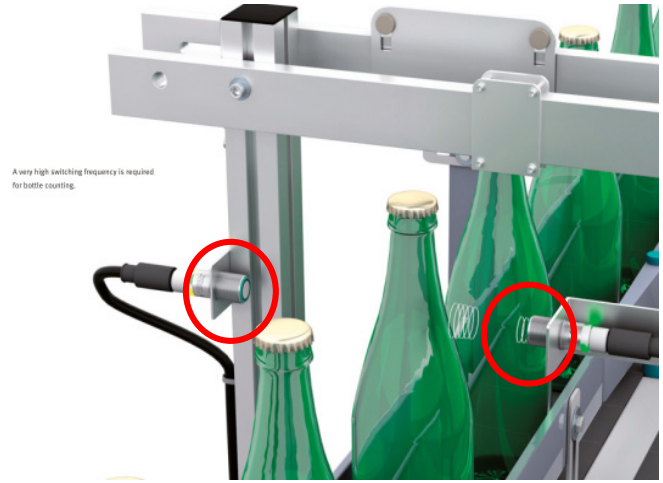
$$c_{air} \approx 331.3 + 0.66 \cdot \vartheta \quad \text{(meter/s)}$$

where ϑ : temperature in °C

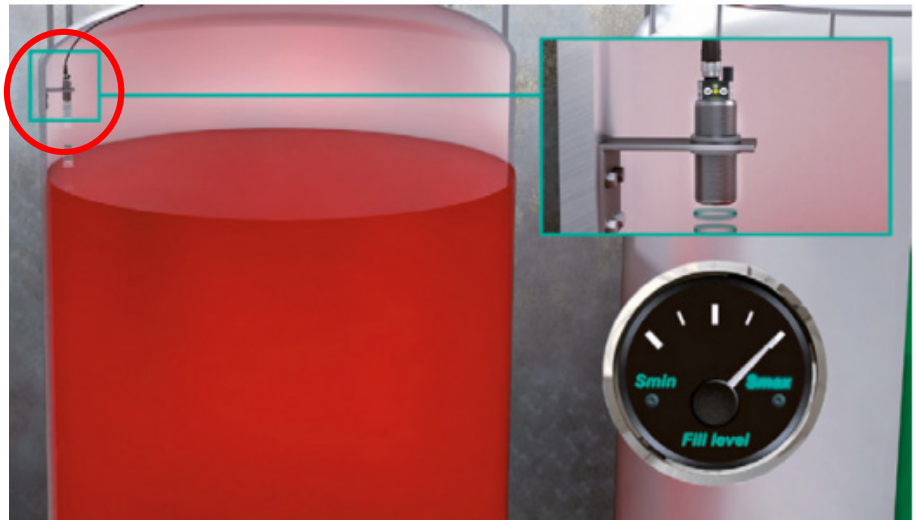
https://en.wikipedia.org/wiki/Speed_of_sound

- Question: What will affect sound speed?
  - temperature
  - humidity
- Question: What will affect the accuracy of distance measurement?

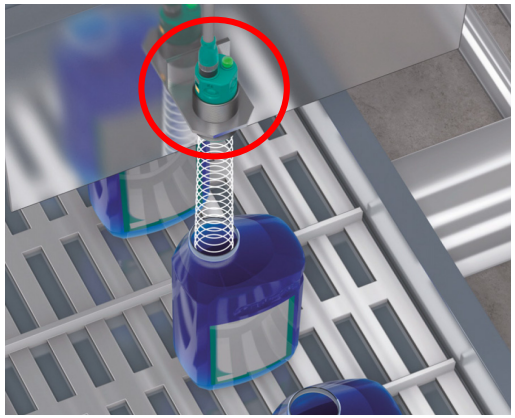
Applications of ultrasonic sensors



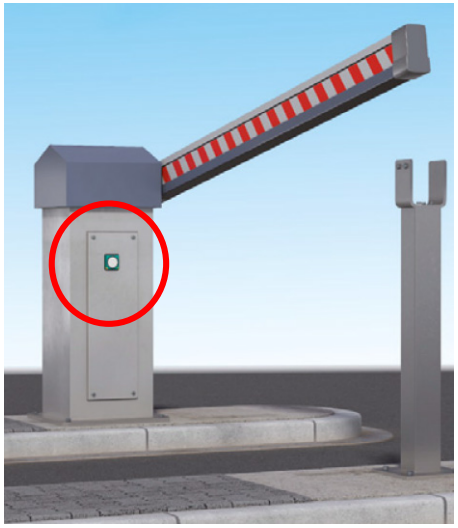
Object counting



Level measurement



Applications of ultrasonic sensors



object detection

Sensitivity and Dynamic Range

Sensitivity and dynamic range

- Two important performance indexes for sensors: *sensitivity* & *dynamic range*.

- E.g. :
  - *Which is the dimmest star that you can see with naked-eye?*
  - *What is the ratio of the loudest and smallest sound that you can hear, without damaging your ears?*

Ref: http://hubblesite.org

Sensitivity of a sensor

- Sensitivity: the smallest detectable signal value for a required *signal-to-noise ratio (SNR)*.
- Why is SNR involved?
- Think about the previous question --
  - *Which is the dimmest star that you can see with naked-eye?*
- The answer depends on:
  - visibility of the sky
  - your eye-sight
  - ambient light

http://www.cuastro.net/rev.html

cloud, pollution, humidity: attenuating/ distorting signals

vision impairments: affecting signal

光害: noise, interference

Signal-to-noise ratio (SNR)

- SNR is an important concept for signal detection and communications.

$$\text{SNR} = \frac{Signal\ Power}{Noise\ Power}$$

- It is the "SNR" (not the "signal" level alone) that really matters.
- Q: How to increase SNR?

  ↑signal or ↓noise

- In other words, if you can reduce the noise, you can detect an extremely small signal (e.g. pin-drop or your own heartbeat).
- Note: Increasing signal level is not always beneficial. (Why?)

  Think about having a conversation in a crowded restaurant. (Your "signal" is "noise" to the people dining at other tables)

Noise reduction

- How to reduce noise?
- Key information to know:
  - sources of the noises (e.g. amplifier noise, 50Hz powerline noise, hairdryer, microwave, ...) and the
  - characteristics of noises (e.g. frequency).
- Common practice:
  - Noise usually occupies wider frequency band, so it can be reduced by using a frequency filter to extract the signal (like a TV or radio tuner) or suppress noise (low-pass filter to suppress high frequency noise or notch filer for powerline noise)

    - The IR sensor module has an optical filter to remove unwanted signal.

Dynamic range of a sensor

- *Dynamic range*: the ratio between the smallest and the largest possible values of a parameter to be measured.
  - E.g. audio signal: The dynamic range of human hearing is better than approximately 120 dB!.

Q: What is dB?

$20 \log_{10}(A_{max}/A_{min})$ or

$10 \log_{10}(P_{max}/P_{min})$

A: current; P: power

http://en.wikipedia.org/wiki/Decibel

Factor (power)	Decibels
1	0
2	3.01
4	6.02
10	10
100	20
1 000	30
1 000 000	60
100 000 000	80
10 000 000 000	100

Ref: http://en.wikipedia.org/wiki/Dynamic_range

Considerations when choosing a sensor

Environmental Factors	Economic Factors	Sensor Characteristics
Temperature range	Cost	Sensitivity
Humidity effects	Availability	Range
Corrosion	Lifetime	Stability
Size		Repeatability
Overrange protection		Linearity
Susceptibility to EM interferences		Error
Ruggedness		Response time
Power Consumption		Frequency response
Self-test capability		

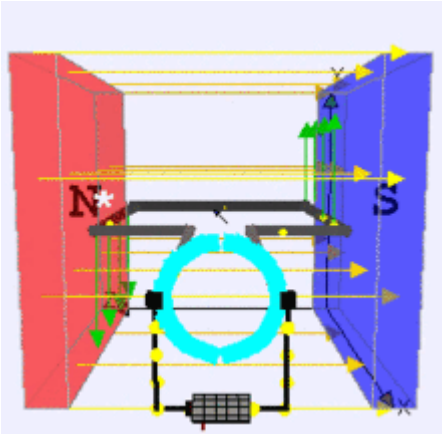
Motors and Motor Driving Circuits

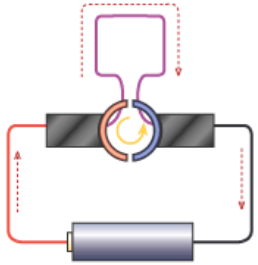
DC motor, H-bridge, and motor driver IC

DC motor

- ***Motor:*** *A machine, especially one powered by electricity or internal combustion, that supplies motive power for a vehicle or for another device with moving parts* – Oxford Dictionary

- ***DC motor:***
  - Stationary permanent magnets form the *stator* field.
  - Generating torque from DC power supply by using a *coil* and an internal mechanical *commutator*.
  - Torque is produced by the principle that any current-carrying conductor placed within an external magnetic field experiences a force, known as Lorentz force (a vector represented by the green arrow).



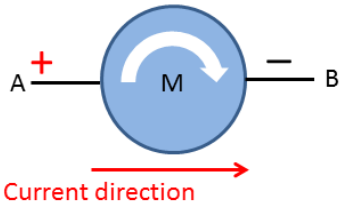


http://en.wikipedia.org/wiki/Commutator_(electric)

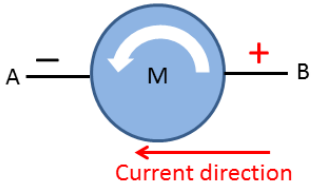
Ref: http://en.wikipedia.org/wiki/DC_motor

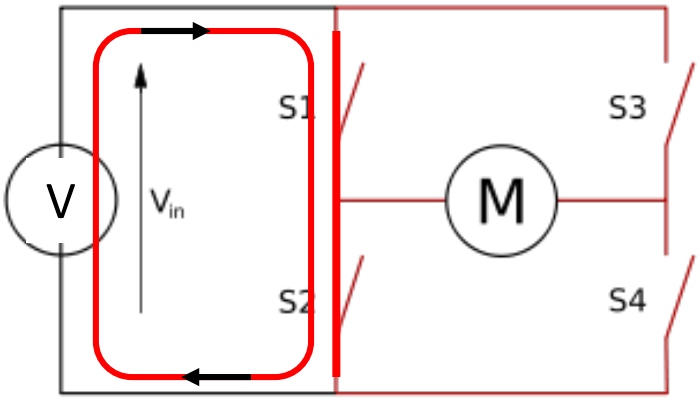
Using H-bridge circuit for rotation direction control

close S1 & S4 → *clockwise (CW) rotation*



close S2 & S3 → *counter-clockwise (CCW) rotation*





Problem of using H-bridge:

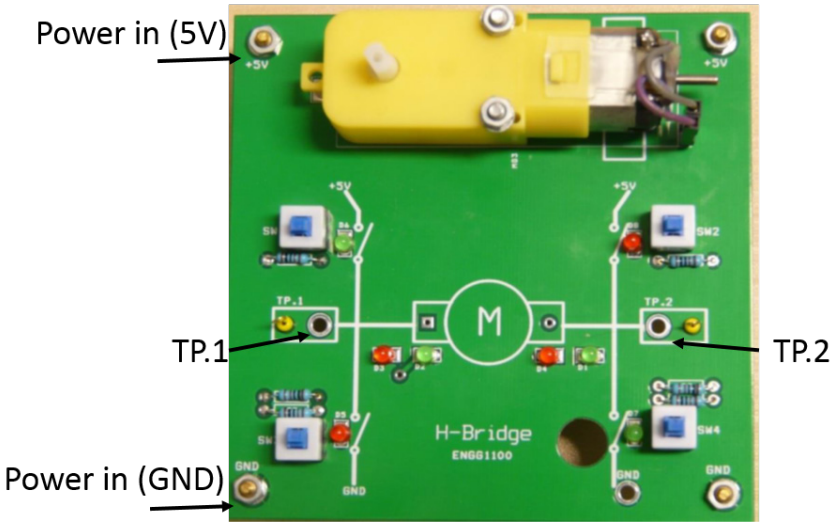
Q: What if you close S1 & S2 or S3 & S4 simultaneously?

→ Short the power supply

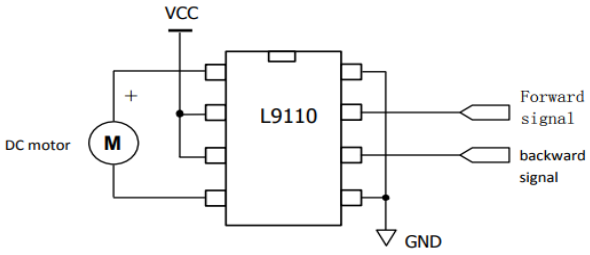
solution? (exp. 7-2)

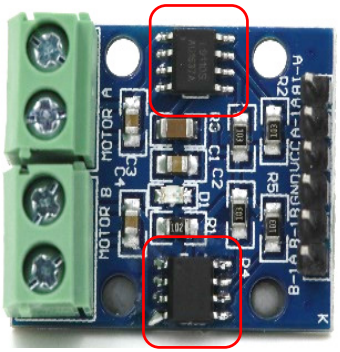
H-bridge board in Exp. 7-1

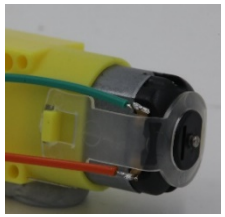
- You will study the effects of the open/close of the four switches on motor rotation direction and detect short-circuit condition.



DC motor driver in Exp. 7-2

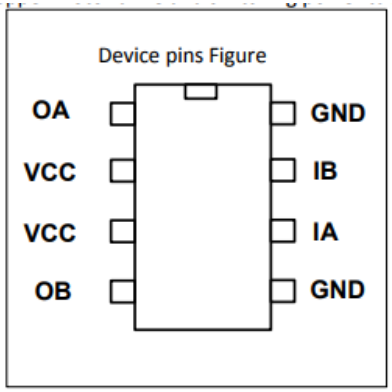






Pin definitions:

No.	Symbol	Function
1	OA	A road output pin
2	VCC	Supply Voltage
3	VCC	Supply Voltage
4	OB	B output pin
5	GND	Ground
6	IA	A road input pin
7	IB	B input pin
8	GND	Ground



- Motor driver IC (L9110 used in our project) is designed to avoid incorrect combination of switches and provide enough current to the motors.
- Two Driver ICs (L9110) are on our driver board for the two DC motors.
- Pin ‘IA’ and ‘IB’ are inputs for backward and forward control
- Pin ‘OA’ and ‘OB’ are outputs to DC motor.

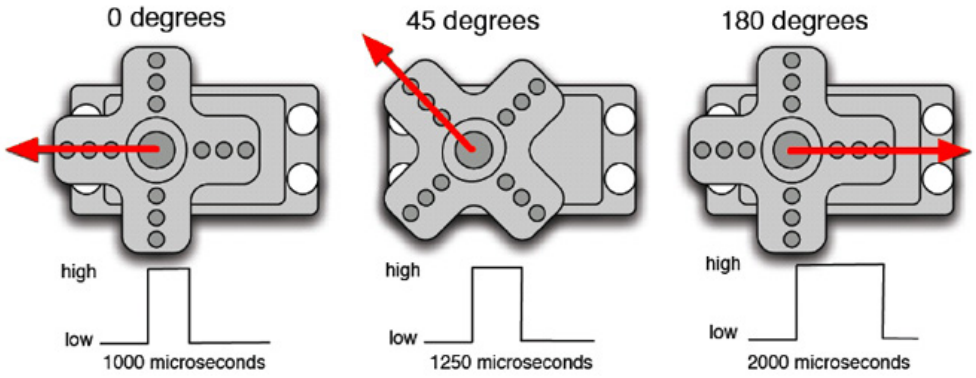
Servo Motors

*A **servomotor** is a rotary actuator or linear actuator that allows for precise control of angular or linear position, velocity and acceleration.*

https://en.wikipedia.org/wiki/Servomotor

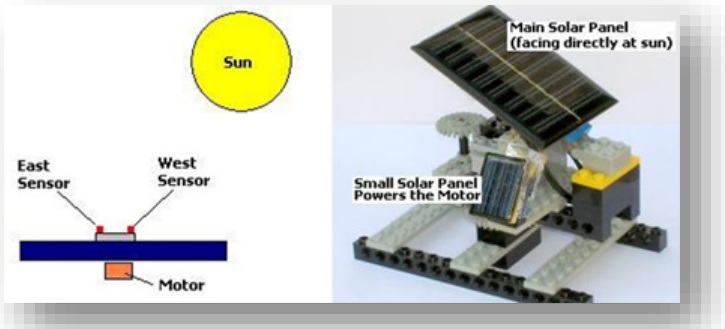
What are the differences between DC motors and Servo motors?

- DC motor: *rotation speed* (rpm: revolution per minute); rotate freely.
- Servo motor: *rotation angle*.
- Both can be controlled by a pulse-width modulation (PWM) signal, which will determine the speed, for DC motor, and the angle, for servo motor.



http://lizarum.com/assignments/physical_computing/2008/servo.html

Servo motor applications: e.g. a solar panel tracking the sun

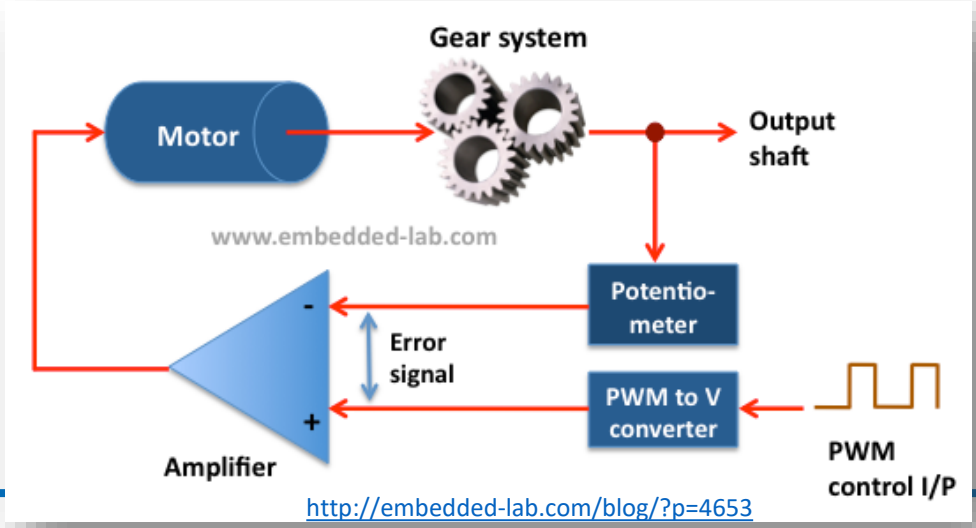


http://www.electrical4u.com/servo-motor-applications-in-robotics-solar-tracking-system-etc/

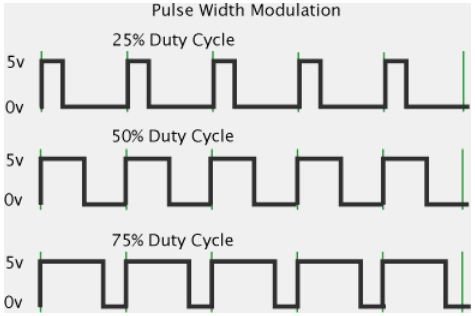
Controlling the servo

- In Lab 7, you will learn
  - using H-bridge to control DC Motor (exp. 7-2);
  - using PWM to control DC motor's speed with FSM environment (exp. 7-3); and
  - Using PWM to control servo motor with FSM to change the ball catcher arm's angle (exp. 7-4).

http://lizarum.com/assignments/physical_computing/2008/servo.html



http://embedded-lab.com/blog/?p=4653



PWM

How are the sensors and motors used in our project?