

E11 Lecture 11: Sensors & Actuators

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Fall 2011

Outline

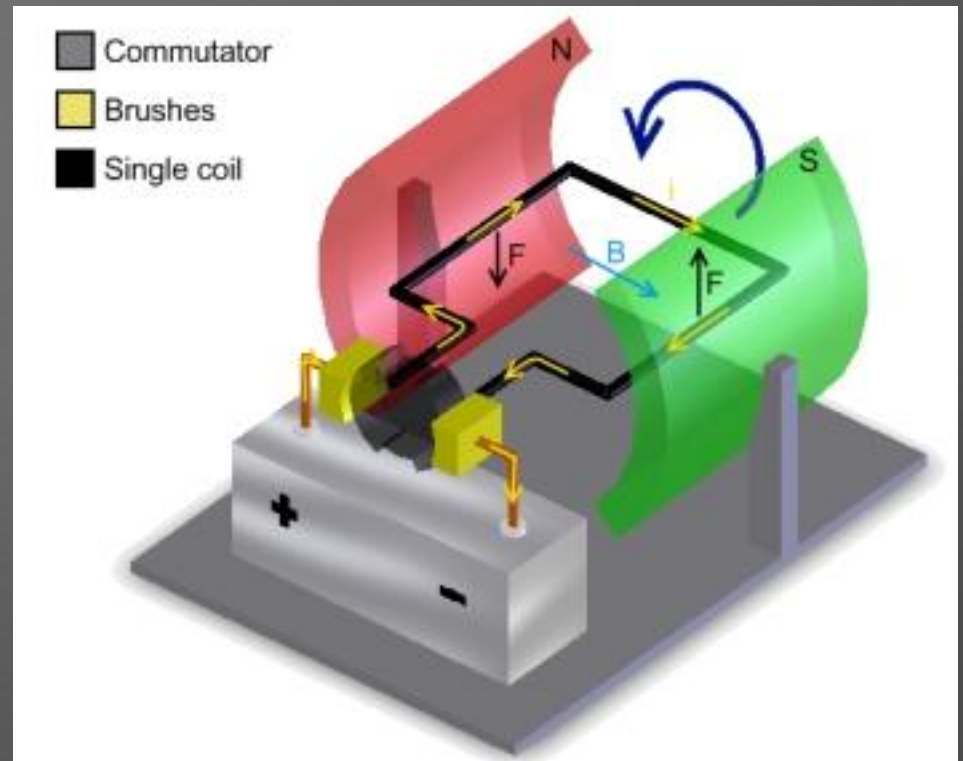
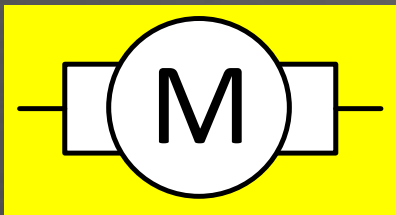
- Actuators
 - DC Motor
 - Servo Motor
 - Stepper Motor
- Sensors
 - Phototransistor
 - Reflectance Sensor
 - IR Distance Sensor
 - Contact Switch
 - Bend Sensor
 - Other Sensors

Logistics

- Bring your laptop, robot, programming cable to the rest of the lab sessions this fall
- Pick your partner for Lab 6 & Final Project
 - Must be in your lab section

DC Motor

- DC motors spin when a steady voltage is applied
 - Can draw significant current (~ 1A or more)
- Fixed permanent magnet
- Rotating coil
- Brushes

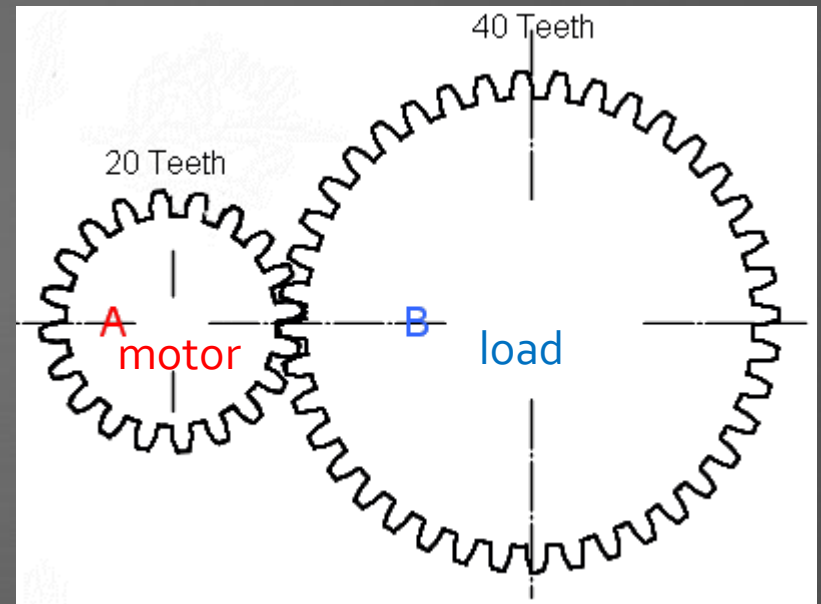


E11 Motors

- Operating Voltage: 3-12 V
- At 6 V operation:
 - Free run speed: 11,500 RPM
 - Unloaded current: 70 mA
 - Stall current: 800 mA
 - ~0.5 oz-in torque

Gearing

- DC motors spin too fast
 - And too little torque
- Gears slow the load rotation
 - Also increase torque
- In this example, load spins at half the speed of the driver

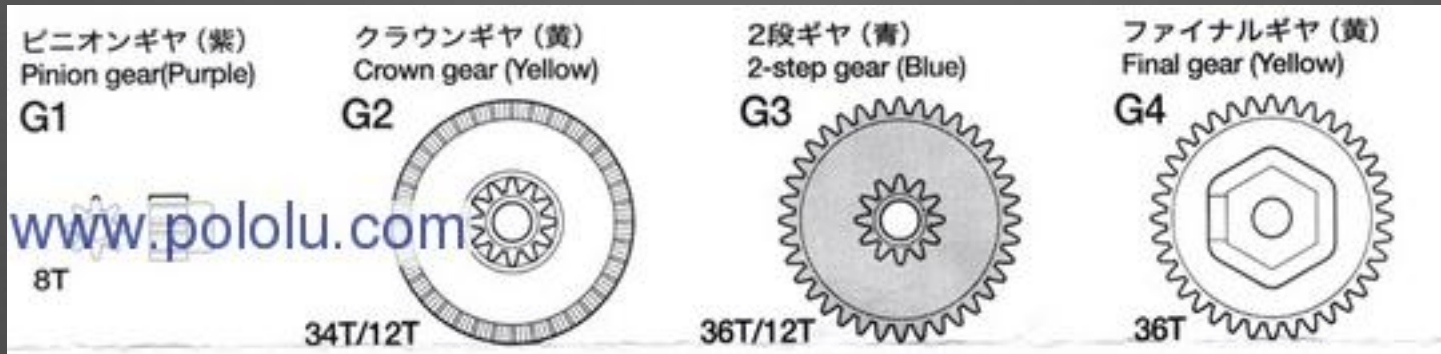
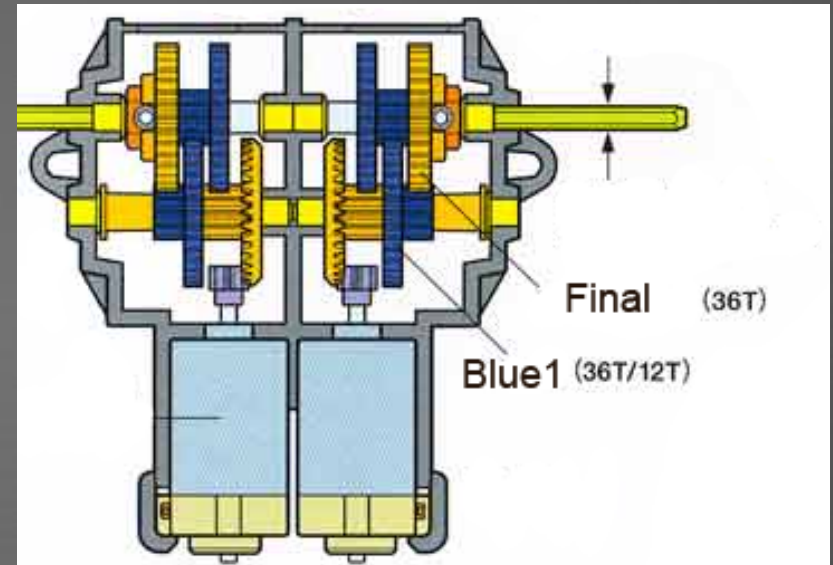


- Gear ratio: $\frac{\omega_B}{\omega_A} = \frac{N_A}{N_B}$

Example: Tamiya Gear Box

● Gear Ratio:

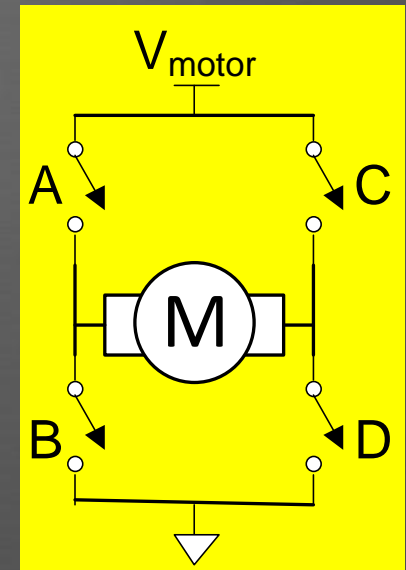
- Final to Blue1
- Blue1 to Blue2
- Blue2 to Crown
- Crown to Pinion
- Total:



H-Bridge

- Motors require large current to operate
 - But Arduino outputs only offer 40 mA
- H-Bridges are used to drive the large current

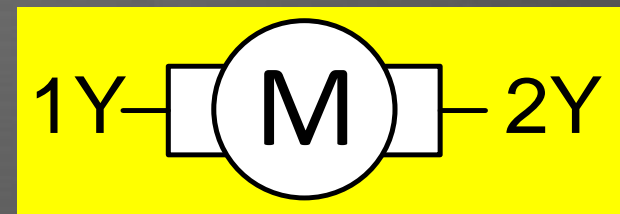
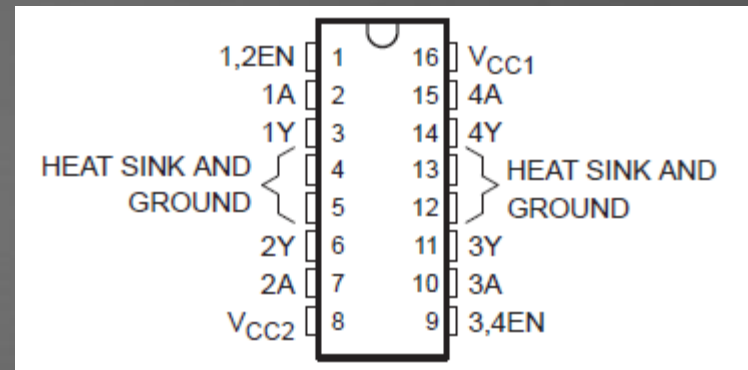
A	B	C	D	Motor
ON	OFF	OFF	ON	
OFF	ON	ON	OFF	
ON	OFF	ON	OFF	
OFF	OFF	OFF	OFF	
ON	ON	OFF	OFF	



SN754410 H-Bridge

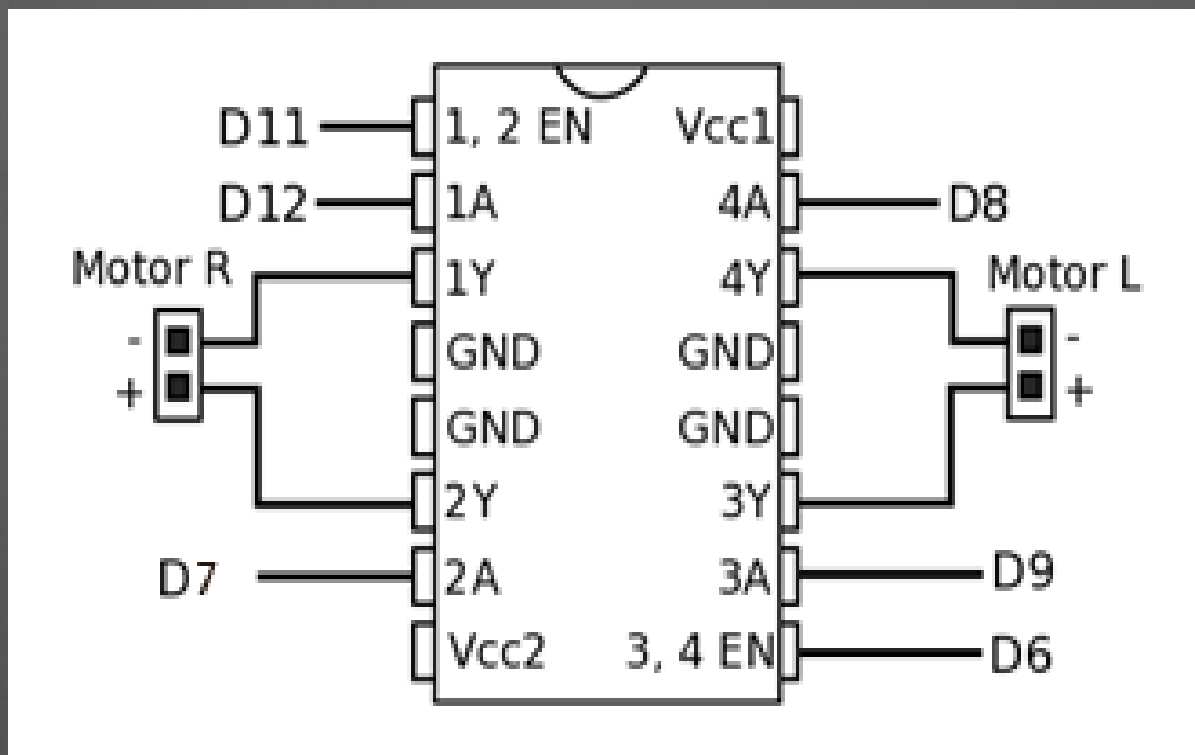
- 754410 Dual H-Bridge is easy to control with digital logic
 - V_{CC1} = Logic Supply (5V)
 - V_{CC2} = Motor Supply (4.5-36 V)

12En	1A	2A	Motor
0	X	X	
1	0	0	
1	0	1	
1	1	0	
1	1	1	



- Contains two H-Bridges to drive two motors

Mudduino H-Bridge Interface



Motor Driver Software

```
#define LEN 6
#define LPLUS 9
#define LMINUS 8

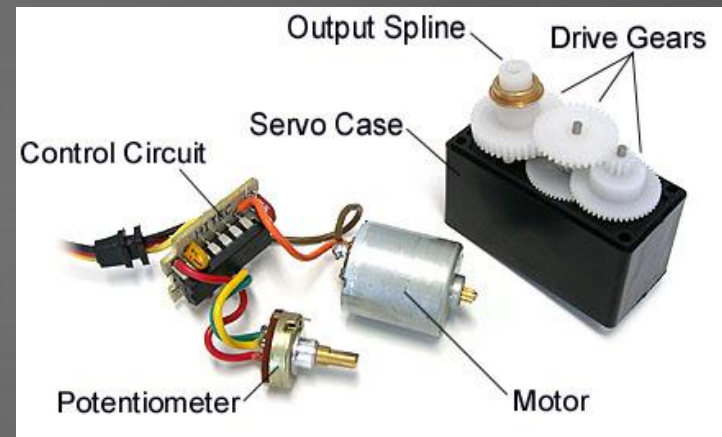
void forward(void)
{
    digitalWrite(LEN, 1);
    digitalWrite(LPLUS, 1);
    digitalWrite(LMINUS, 0);
    // similar for right motor...
}
```

Shaft Encoding

- Sometimes it helps to know the position of the motor
- Optical shaft encoder
 - Disk with slits attached to motor shaft
 - Light and optical sensor on opposite sides of disk
 - Count light pulses as the disk rotates
- Analog shaft encoder
 - Connect potentiometer (variable resistor) to shaft
 - Resistance varies as shaft turns
- Our DC motors don't have shaft encoders built in

Servo Motor

- Servo motors are designed to be easy to use
 - DC motor
 - Gearing
 - Analog shaft encoder
 - Control circuitry
 - High-current driver
- Three wires: 5V, GND, Control
- Turn from 0 to 180 degrees
 - Position determined by pulses on control wire



servocity.com

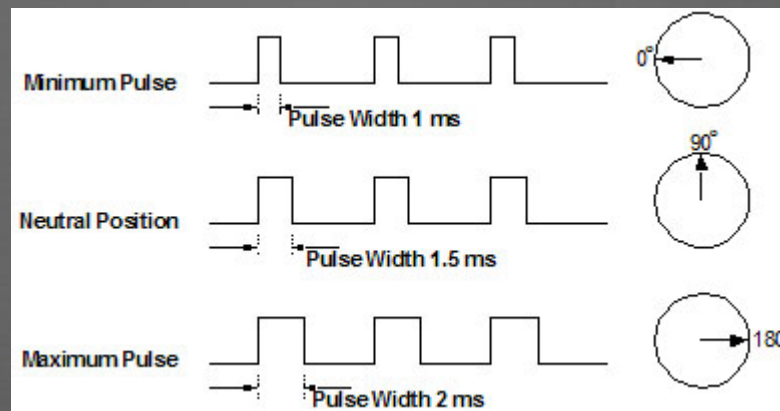
Servo Pulse Width Modulation

- Control position with 50 Hz (20 ms) pulses
- Pulse width modulation (PWM)

- 1 ms = 0°

- 1.5 ms = 90°

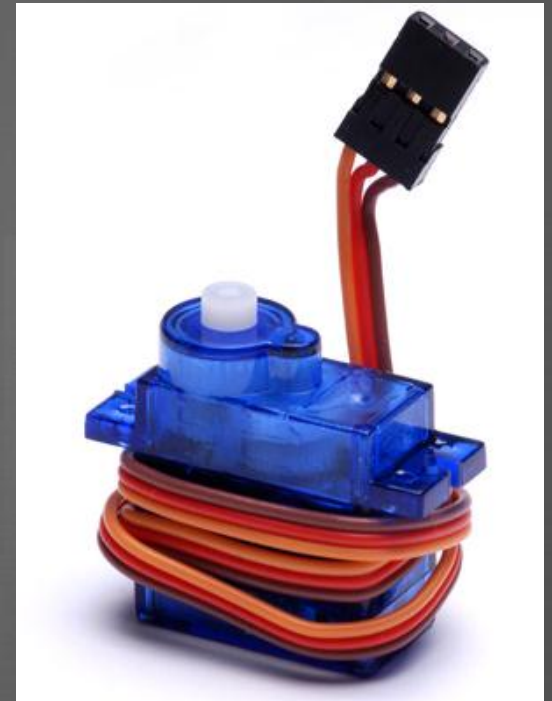
- 2 ms = 180°



servocity.com

SG90 Servo

- 4.0 – 7.2 V Operation
- At 4.8 V
 - Speed: 0.12 sec / 60 degrees (83 RPM)
 - Stall Torque: 16.7 oz-in



hobbypartz.com

Arduino Servo Library

- Arduino offers a servo library for controlling servos

```
// servotest.pde
// David_Harris@hmc.edu 1 October 2011

#include <Servo.h>

// pins
#define SERVOPIN 10

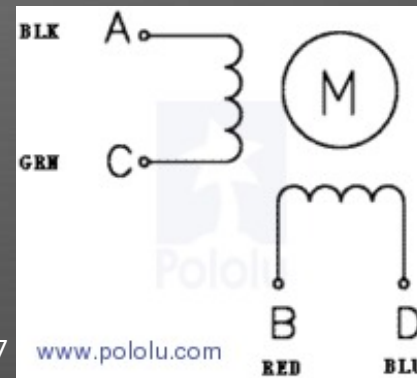
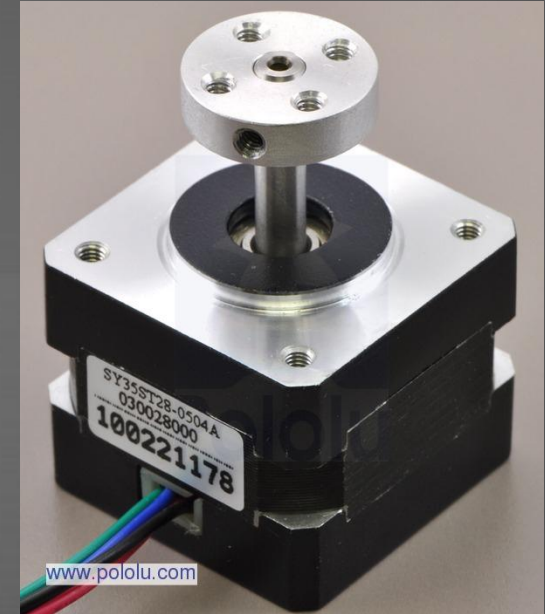
// Global variable for the servo information
Servo servo;

void testServo()
{
  initServo();
  servo.write(90); // set angle between 0 and 180 degrees
}

void initServo()
{
  pinMode(SERVOPIN, OUTPUT);
  servo.attach(SERVOPIN);
}
```

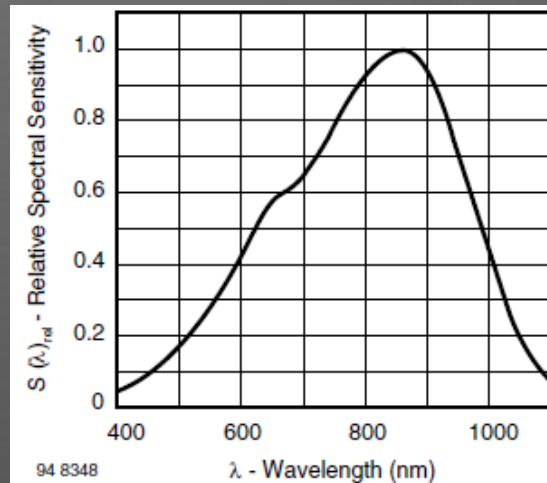
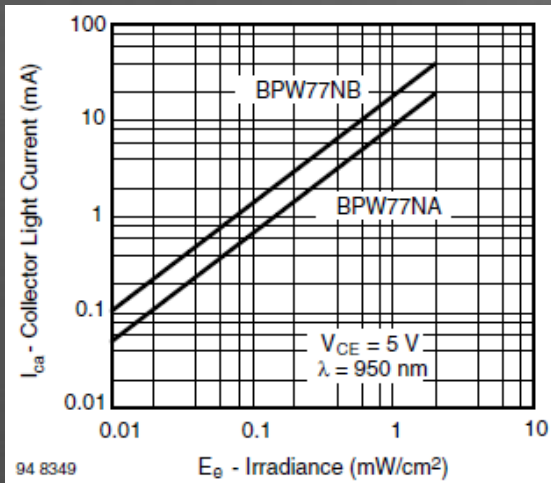

Stepper Motor

- Stepper motors are also popular
 - Motor advances in discrete steps
 - Input pulses indicate when to advance
- Example: Pololu 1207 Stepper Motor
 - 1.8° steps (200 steps/revolution)
 - 280 mA @ 7.4 V
 - 9 oz-in holding torque
 - Needs H-Bridge driver
 - Ground C and D
 - Alternate pulses to A and B



Phototransistor

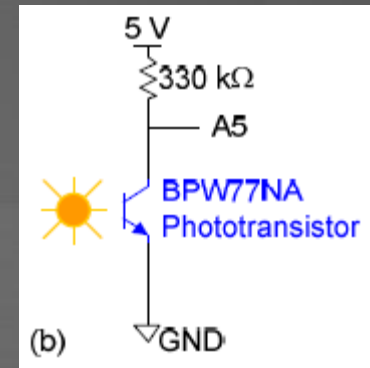
- Converts light to electrical current
- Vishay BPW77NA NPN Phototransistor
 - Dark current: 1 – 100 nA
 - Angle of half sensitivity: $\pm 10^\circ$



jameco.com

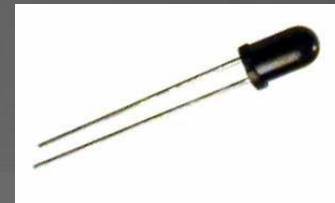
Phototransistor Circuit

- Leave base terminal unconnected
- $V_{\text{out}} = 5 - I_{\text{photo}} \times 330 \text{ k}\Omega$
 - In dark, $V_{\text{out}} \approx 5 \text{ V}$
 - For $I_{\text{photo}} > 15 \mu\text{A}$, V_{out} drops to ~ 0
- Large resistor gives sensitivity to weak light



Other Light Sensors

- Photodiodes
 - Similar to phototransistors
 - Lower sensitivity
- Cadmium Sulfide (CDS) Cell
 - Resistance changes with light
 - From $> 1 \text{ M}\Omega$ in dark to 200Ω in full light
 - Slow response time



goldmine-elec-products.com

Sensor Read Code

```
#define PHOTO_TRANS 19

void setup()
{
  Serial.begin(9600);

  // configure sensors
  pinMode(PHOTO_TRANS, INPUT);
}

void loop()
{
  int sensor;

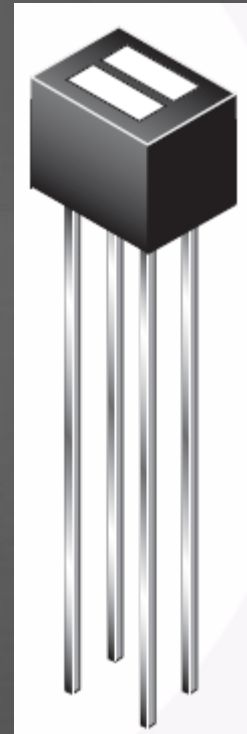
  // test sensors
  sensor = analogRead(PHOTO_TRANS-14); // analogRead uses analog port #
  Serial.print("Reflectance sensor: "); Serial.println(sensor);
  delay(500);
}
```

Sensor Averaging

- Sensors are subject to noise
- Average multiple readings for more stable results

Reflectance Sensor

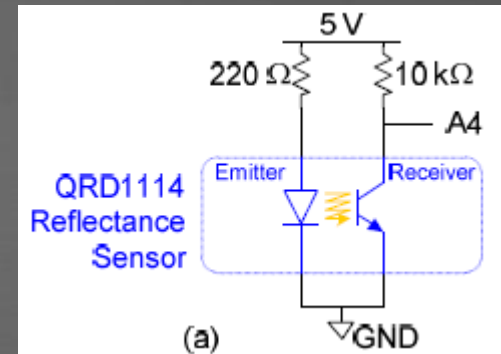
- Infrared LED and phototransistor pair
 - LED illuminates surface
 - Phototransistor receives reflected light
 - Daylight filter on sensor reduces interference
 - Sensitive to distance, color, reflectivity
- Fairchild QRD1114 Reflectance Sensor
 - ~20 mA LED current
 - 1.7 V LED ON voltage
 - 940 nm wavelength (near infrared)



fairchild.com

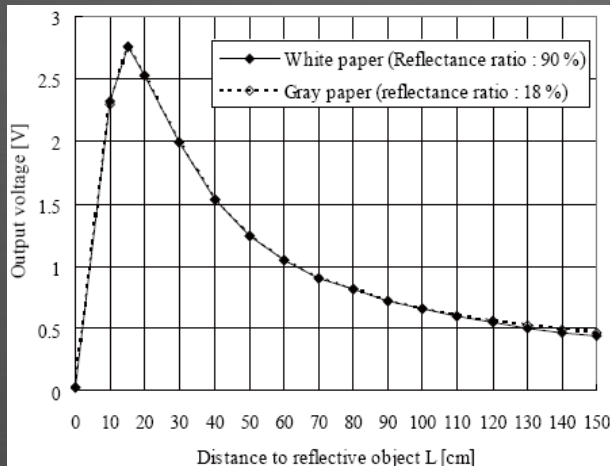
Reflectance Sensor Circuit

- $I_{LED} = (5 - 1.7 \text{ V}) / 220 \Omega = 15 \text{ mA}$
- $V_{out} = 5 - I_{photo} \times 10 \text{ k}\Omega$
- Resistor was selected to give a good range of response



IR Distance Sensor

- Sharp GP2Y0A21YKoF
- Range of 8 to 60"
- Triangulates with linear CCD array
- Three terminals: 5V, GND, Signal



Ultrasonic Distance Sensor

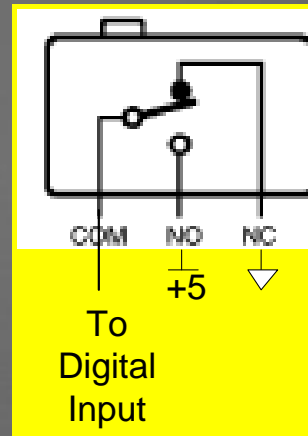
- Measure flight time of ultrasonic pulse
 - Less sensitive to ambient light
 - More precise
 - More expensive
- Example: LV-MaxSonar-EZ
 - 42 KHz ultrasonic beam
 - Range of 254" with resolution of 1"
 - 2.5 – 5.5 V operation
 - Analog voltage output



maxbotix.com

Switches

- Switches are useful for proximity detection
- Three terminals
 - COM: Common
 - NO: Normally Open
 - NC: Normally Closed
- Mounting issues
 - Good supporting surface
 - Gang 2 or more with plate between



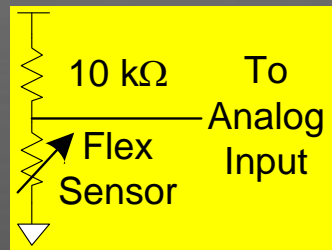
sparkfun.com

Flex Sensors

- Resistance changes with flex
- Example: Spectra Symbol Flex
 - 4.5" length
 - $10\text{ K}\Omega \pm 30\%$ when flat
 - 60-110 $\text{K}\Omega$ when bent

- Sample Circuit

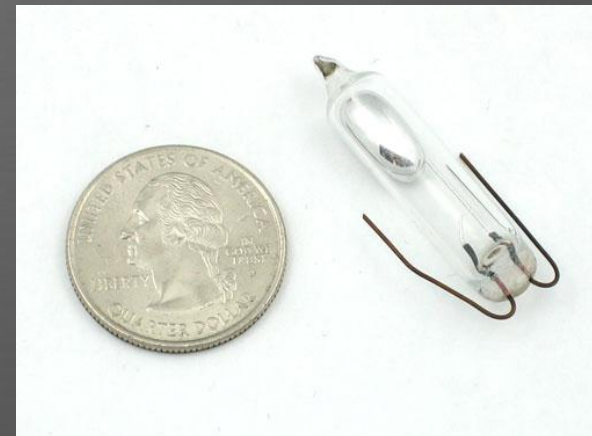
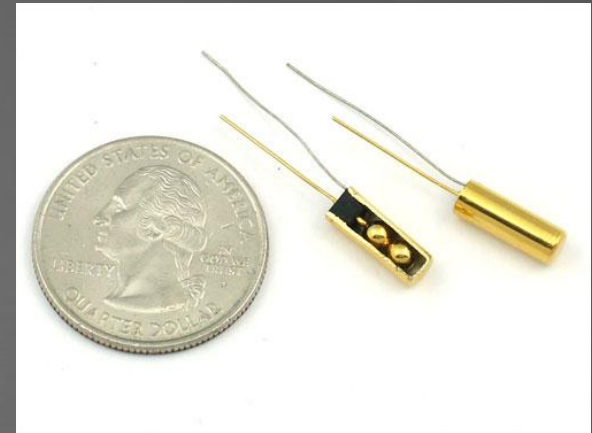
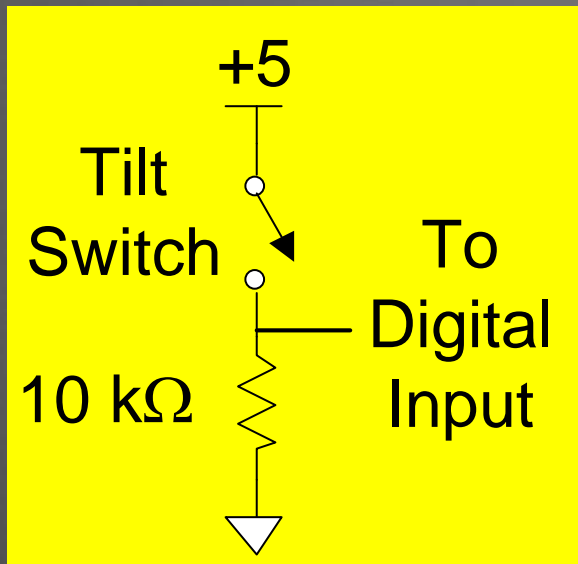
- $V_{\text{out}} = 2.5\text{ V}$ when flat
- Increases when bent



sparkfun.com

Tilt Switches

- Mercury or Ball
- Warn if your bot is about to topple!



Navigation Sensors

- Track your position
 - Watch for operating voltage and analog/digital interface
 - Some of these sensors are expensive!
- Sparkfun
 - HMC6352 Digital Compass
 - MLX90609 Single Axis Gyroscope
 - ITG-3200 Triple Axis Gyroscope
 - ADXL322 Dual Axis Accelerometer
 - Inertial Measurement Units

Mounting Sensors & Actuators

- Secure mounting is half the challenge
 - Poorly mounted sensors will fail at an inopportune time
 - Tangles of cables will catch on obstructions and pull loose
 - High center of gravity leads bots to topple in collisions
- Consider building a custom mount
 - Machine shop
 - 3D printer
- Use Breadboard to test electronics
 - Solder final electronics onto front of Mudduino for security

Adhesives

- Cynoacrylate (CA) Glue (aka Super Glue)
 - Fast drying, good for bonding plastic
 - Low shear strength
 - Don't bond your fingers – wear gloves
- Hot Glue
- Electrical Tape
 - Insulator, low strength
- Gaffer's Tape
 - Like duct tape, but stronger and removes cleanly

Suppliers

- Engineering Stockroom
- Hobbyist
 - Pegasus Hobbies
 - 5515 Moreno St., Montclair, an easy bike ride from campus
 - Sparkfun
 - Pololu
 - Jameco
 - All Electronics, Futurlec, Inventables, Goldmine Electronics, ...
- Professional
 - DigiKey (very wide selection, fewer hobby parts, higher cost)

Summary

- On-Board Actuators:
 - Twin DC Motors + Gearbox
 - Servo Motor
- On-Board Sensors:
 - Phototransistor (A5)
 - Reflectance Sensor (A4)
 - Distance Sensor (A0)
- In E11 Stock:
 - Snap Action Switch
 - Flex Sensors
- Boundless possibilities!