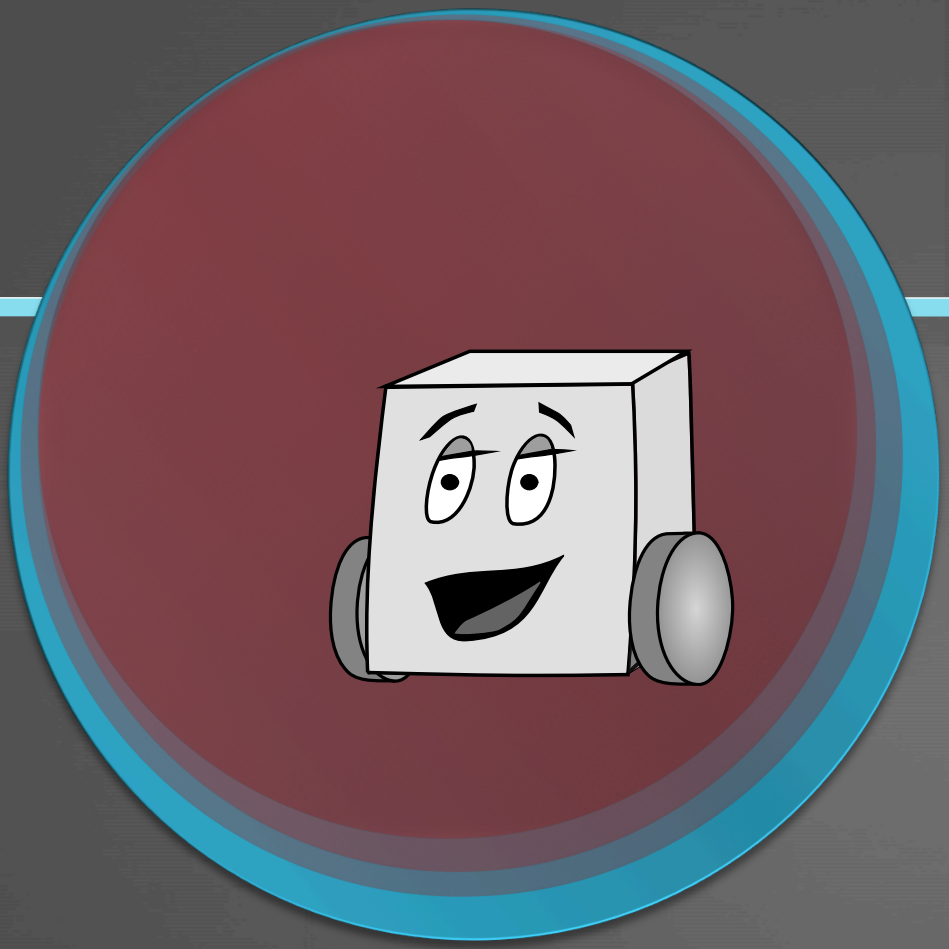


E11 Lecture 11: Sensors & Actuators

Profs. David Money Harris & Chris Clark

Fall 2014

Outline

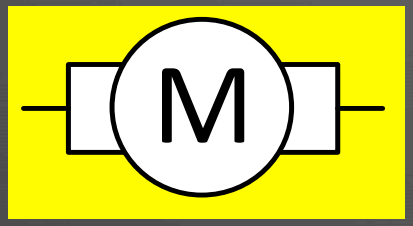
- Actuators
  - DC Motor
  - Servo Motor
  - Stepper Motor
- Sensors
  - Phototransistor
  - Reflectance Sensor
  - IR Distance Sensor
  - Contact Switch
  - Bend Sensor
  - Other Sensors

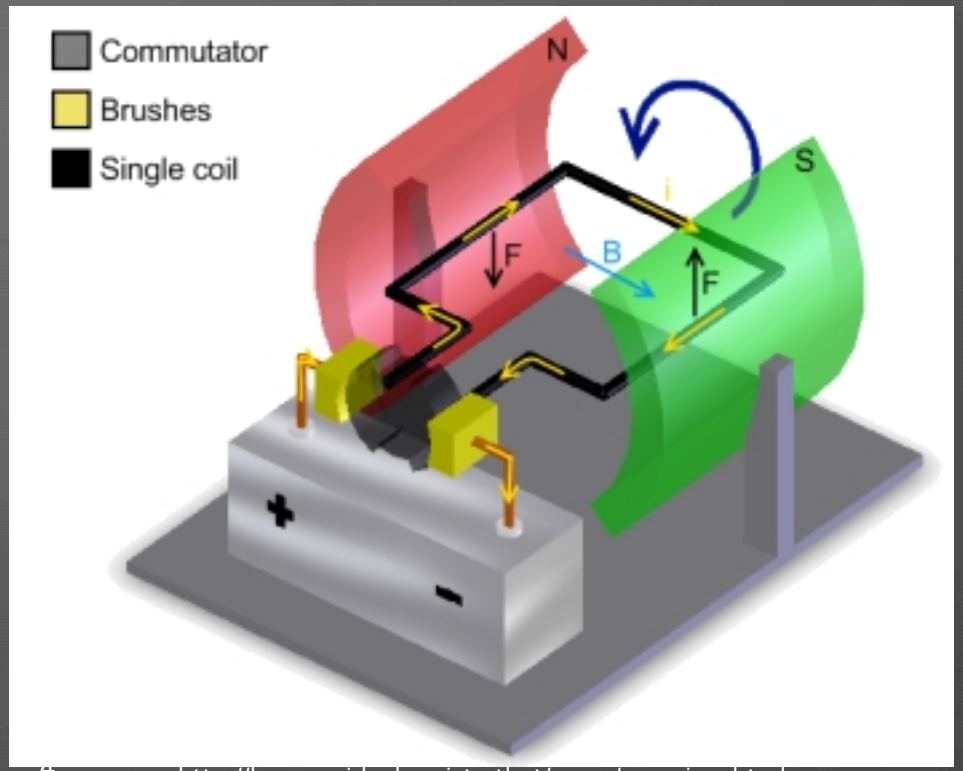
Logistics

- 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





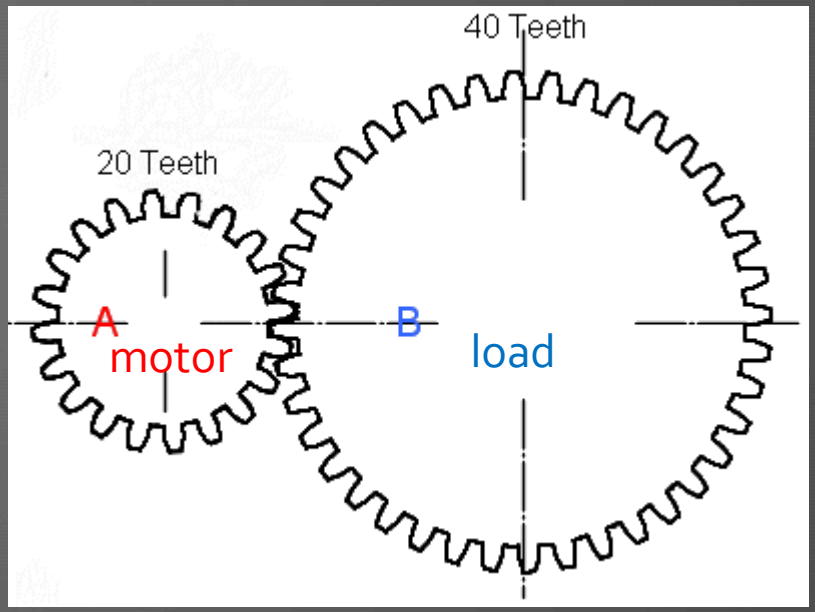
http://humanoids.dem.ist.utl.pt/servo/overview.html

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

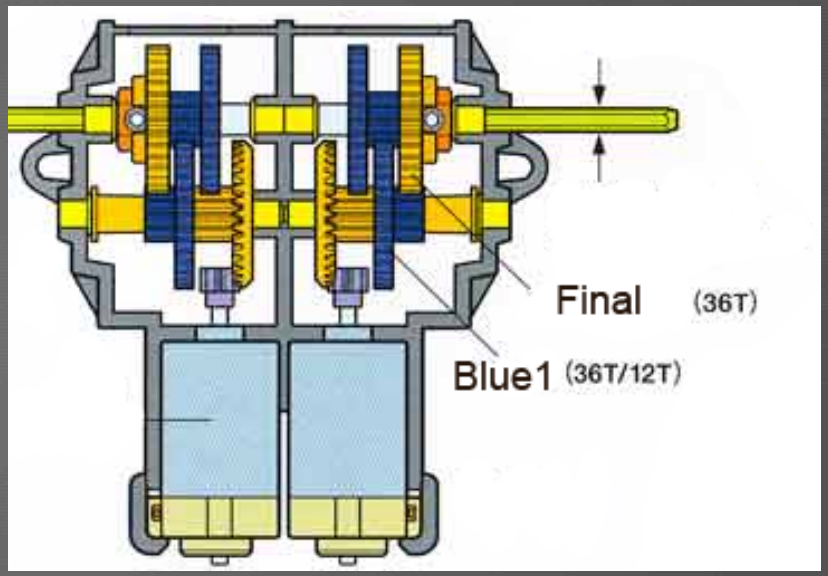
Gearing

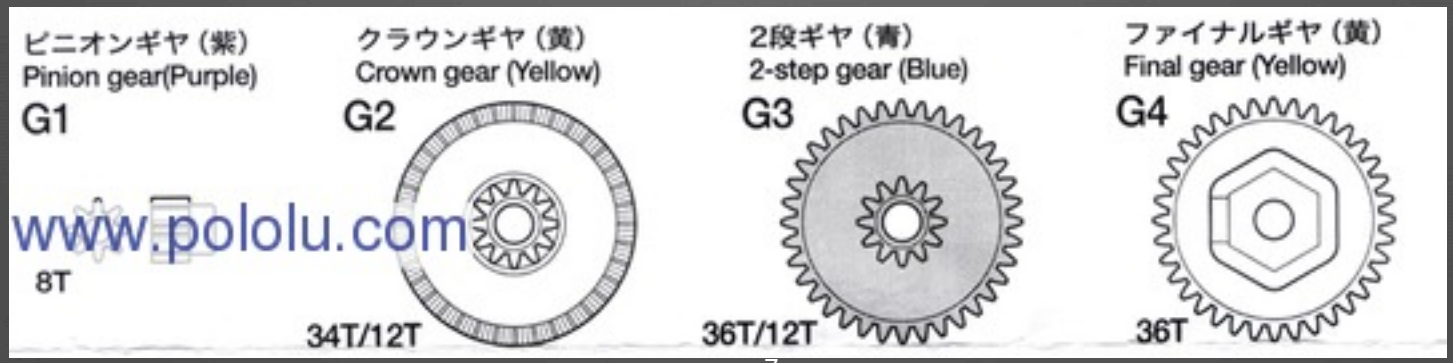
- DC motors spin too fast
  - And too little torque
- Gears slow the load rotation
  - Also increase torque
- In this example, load spins at half the speed of the driver
- Gear ratio: $\omega_B / \omega_A = N_A / N_B$



Example: Tamiya Gear Box

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



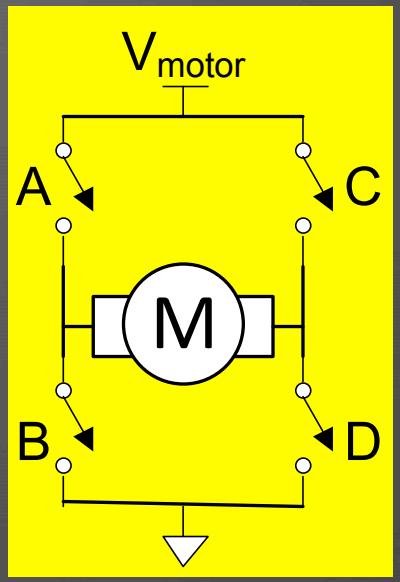


pololu.com

H-Bridge

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

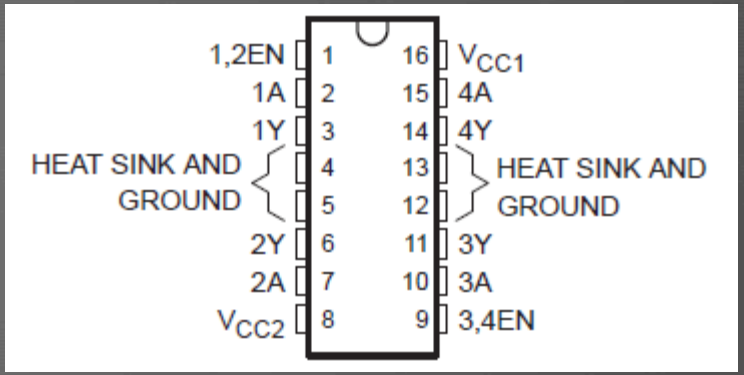
A	B	C	D	Motor
ON	OFF	OFF	ON	
OFF	ON	ON	OFF	
ON	OFF	ON	OFF	
OFF	OFF	OFF	OFF	
ON	ON	OFF	OFF	

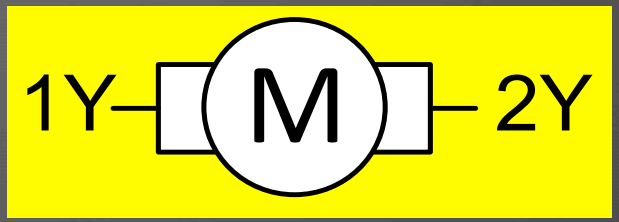


SN754410 H-Bridge

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

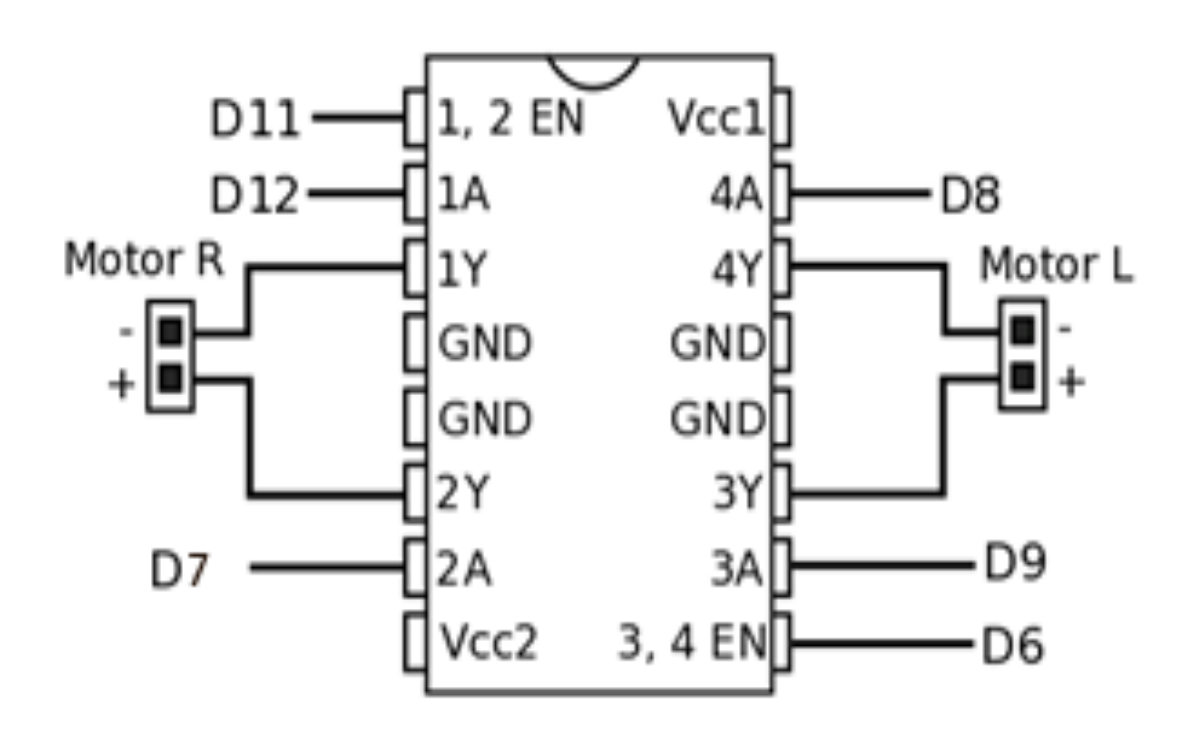
12En	1A	2A	Motor
0	X	X	
1	0	0	
1	0	1	
1	1	0	
1	1	1	





- Contains two H-Bridges to drive two motors

Mudduino H-Bridge Interface



Motor Driver Software

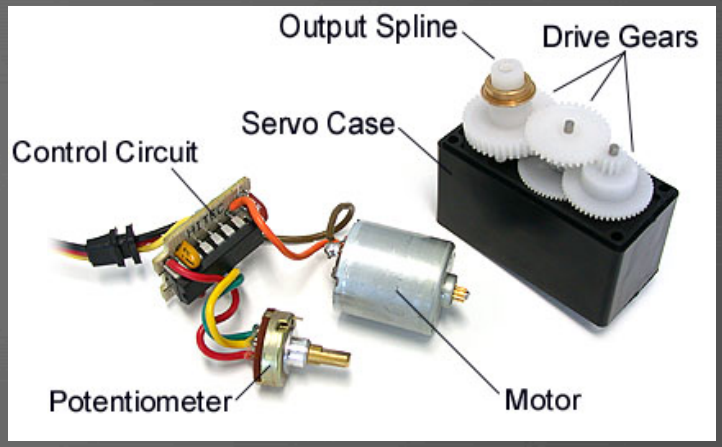
```
#define LEN 6
#define LPLUS 9
#define LMINUS 8

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

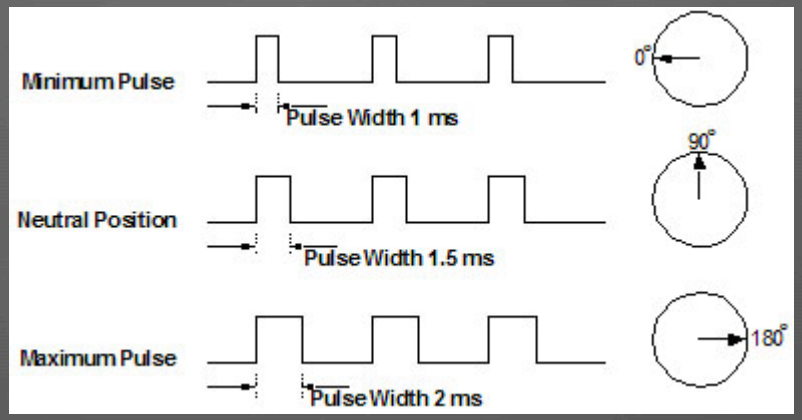
- Servo motors are designed to be easy to use
  - DC motor
  - Gearing
  - Analog shaft encoder
  - Control circuitry
  - High-current driver
- Three wires: 5V, GND, Control
- Turn from 0 to 180 degrees
  - Position determined by pulses on control wire



servocity.com

Servo Pulse Width Modulation

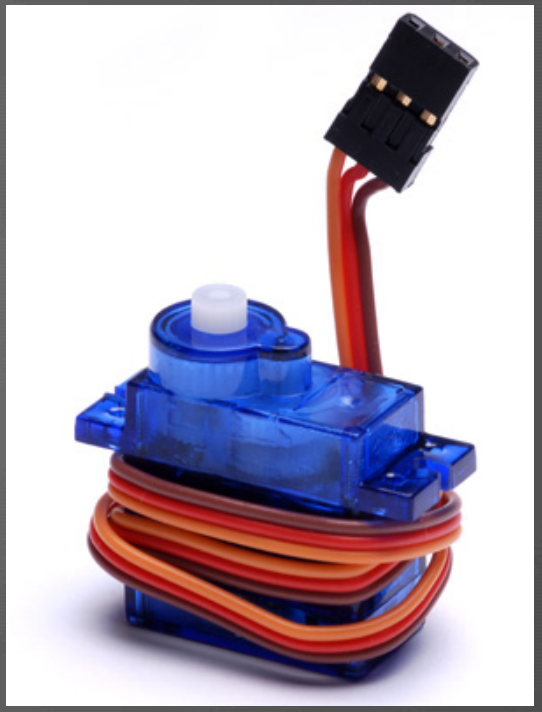
- Control position with 50 Hz (20 ms) pulses
- Pulse width modulation (PWM)
  - 1 ms = 0°
  - 1.5 ms = 90°
  - 2 ms = 180°



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

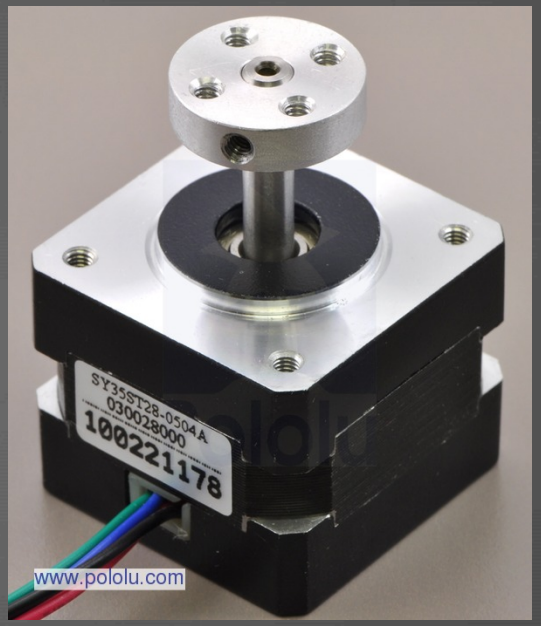
Arduino Servo Library

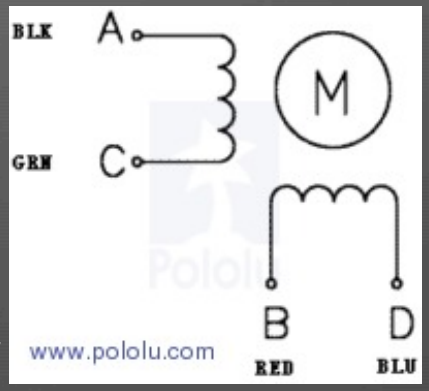
- Arduino offers a servo library for controlling servos

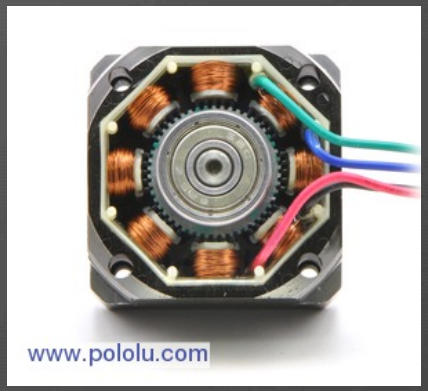
```
// servotest.pde
// David_Harris@hmc.edu 1 October 2011

#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

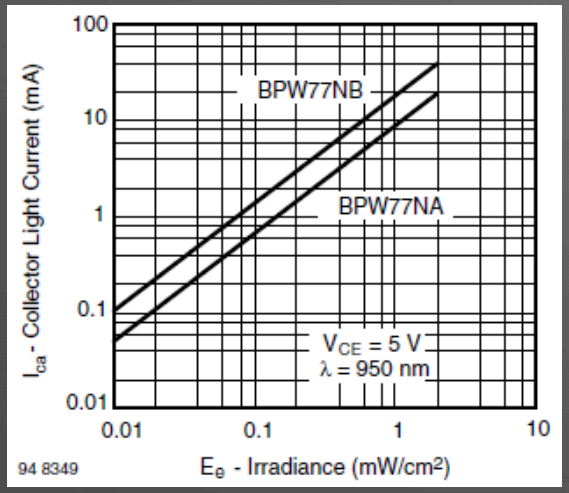


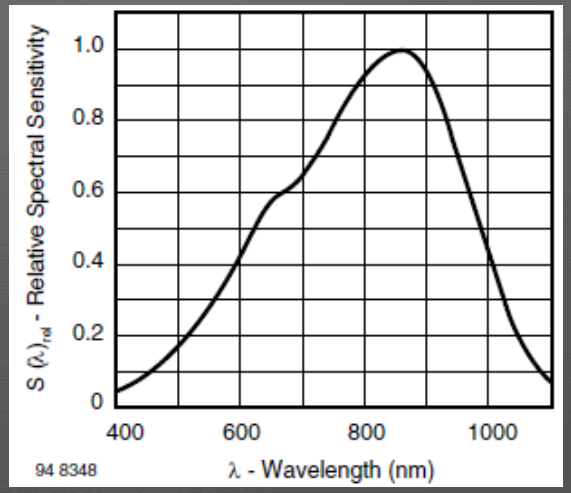




Phototransistor

- Converts light to electrical current
- Vishay BPW77NA NPN Phototransistor
  - Dark current: 1 – 100 nA
  - Angle of half sensitivity: ±10°

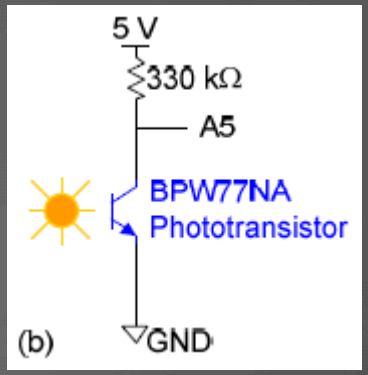




jameco.com

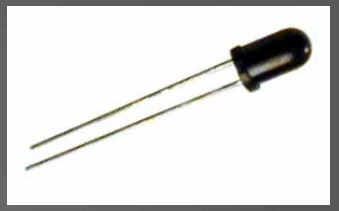
Phototransistor Circuit

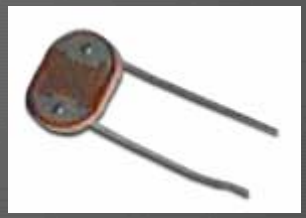
- Leave base terminal unconnected
- $V_{out} = 5 - I_{photo} \times 330\ k\Omega$
  - In dark, $V_{out} \approx 5\ V$
  - For $I_{photo} > 15\ \mu A$, V_{out} drops to ~0
- Large resistor gives sensitivity to weak light



Other Light Sensors

- Photodiodes
  - Similar to phototransistors
  - Lower sensitivity
- Cadmium Sulfide (CDS) Cell
  - Resistance changes with light
    - From > 1 MΩ in dark to 200 Ω in full light
  - Slow response time





goldmine-elec-products.com

Sensor Read Code

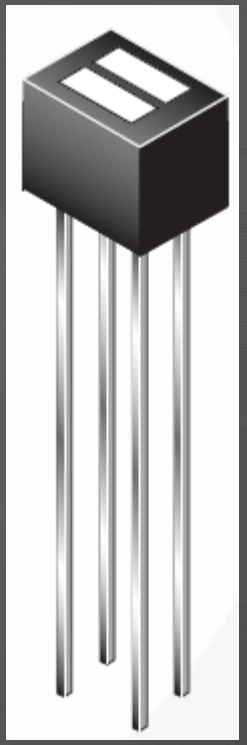
```
#define PHOTO_TRANS 19

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

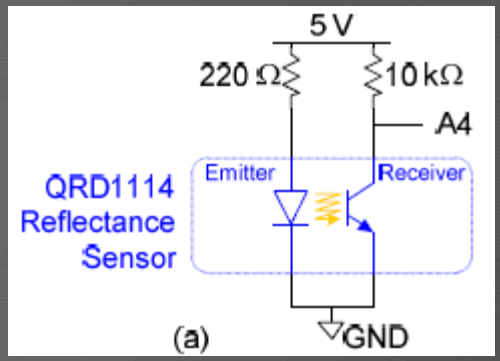
- Infrared LED and phototransistor pair
  - LED illuminates surface
  - Phototransistor receives reflected light
  - Daylight filter on sensor reduces interference
  - Sensitive to distance, color, reflectivity
- Fairchild QRD1114 Reflectance Sensor
  - ~20 mA LED current
  - 1.7 V LED ON voltage
  -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



fairchild.com

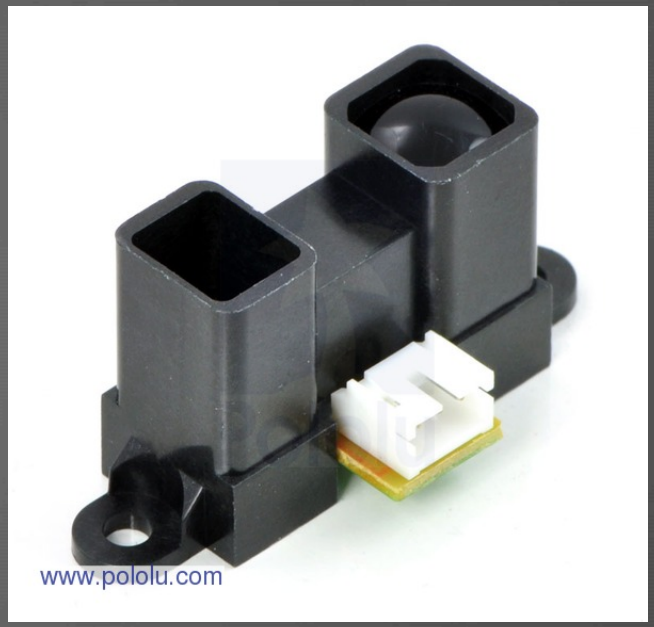
Reflectance Sensor Circuit

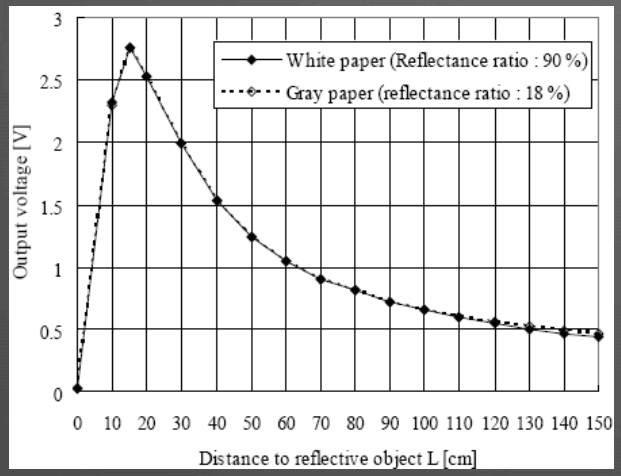
- I_{LED} = (5-1.7 V) / 220 Ω = 15 mA
- $V_{out} = 5 - I_{photo} \times 10\ k\Omega$
- Resistor was selected to give a good range of response



IR Distance Sensor

- Sharp GP2Y0A21YK0F
- Range of 8 to 60”
- Triangulates with linear CCD array
- Three terminals: 5V, GND, Signal





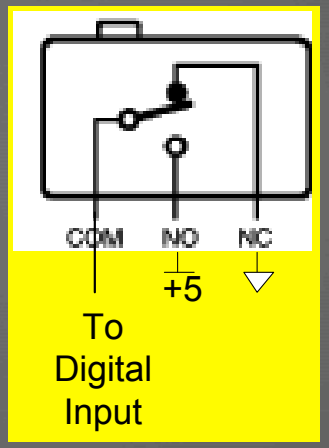
Ultrasonic Distance Sensor

- 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

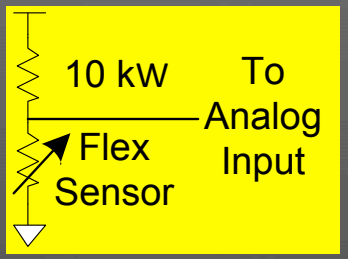
- Switches are useful for proximity detection
- Three terminals
  - COM: Common
  - NO: Normally Open
  - NC: Normally Closed
- Mounting issues
  - Good supporting surface
  - Gang 2 or more with plate between

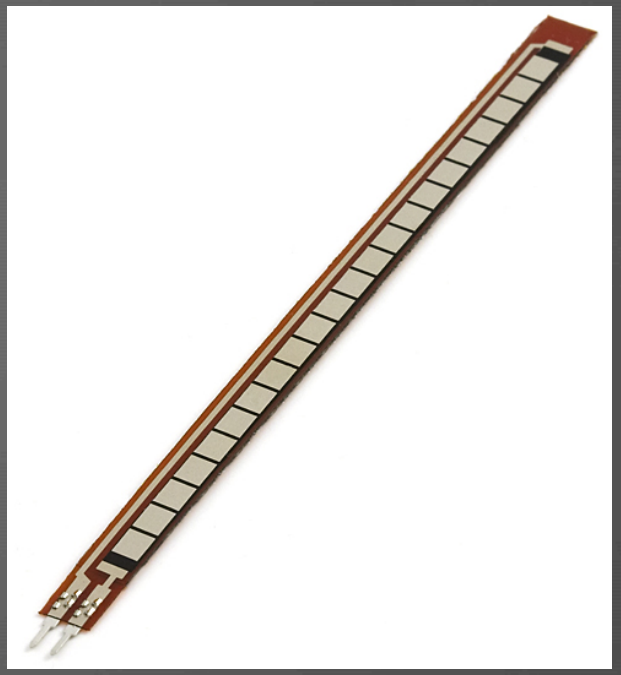


sparkfun.com

Flex Sensors

- Resistance changes with flex
- Example: Spectra Symbol Flex
  - 4.5" length
  - 10 KΩ ± 30% when flat
  - 60-110 KΩ when bent
- Sample Circuit
  - V_{out} = 2.5 V when flat
  - Increases when bent

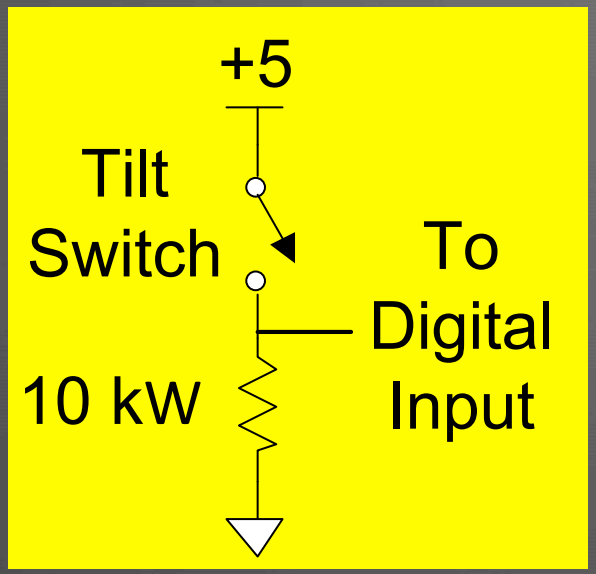


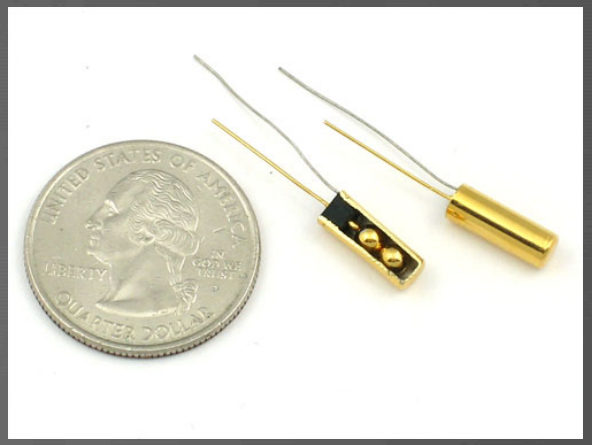


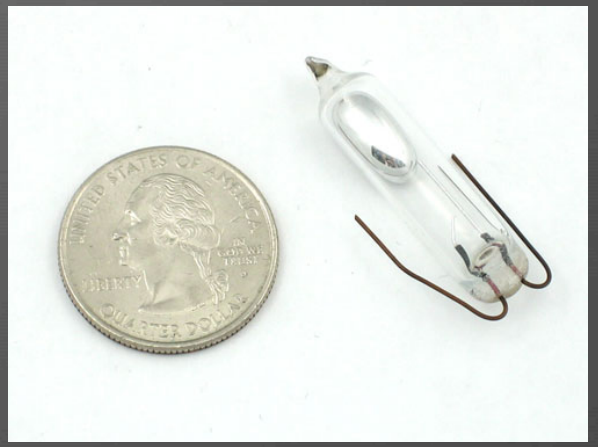
sparkfun.com

Tilt Switches

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







ladyada.net

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!