E11 – Autonomous Vehicles

Sensors & Actuators

Outline

- **Actuators**
- **Sensors**

Outline

- **Actuators**
  - DC Motor
  - Servo Motor
  - Stepper Motor
- **Sensors**

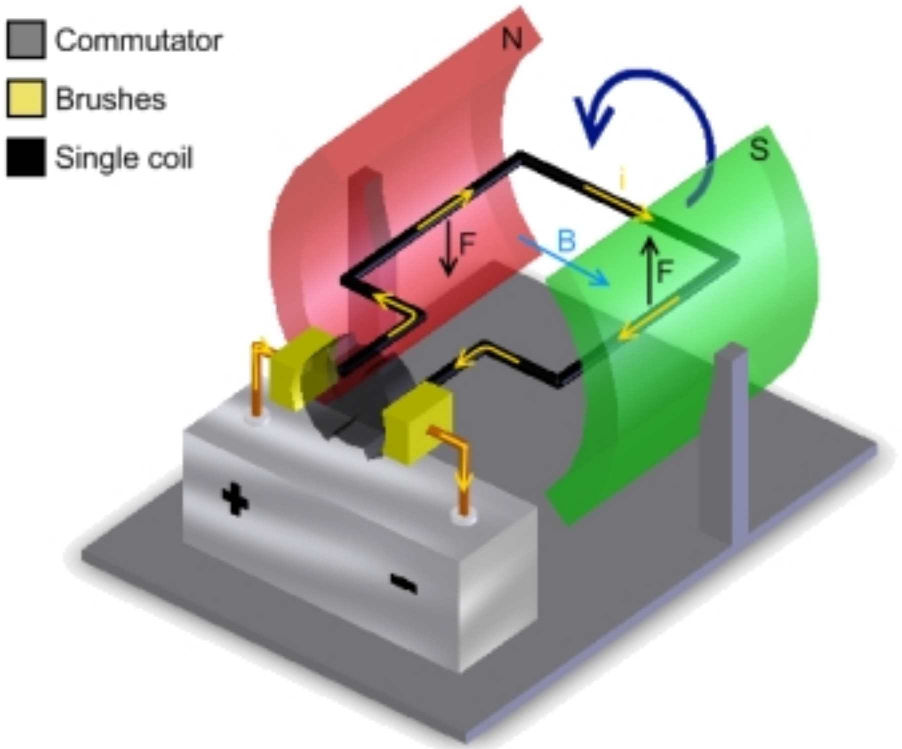
How does a DC Motor work?

1. The **stator** generates a stationary magnetic field surrounding the rotor.

2. The **rotor/armature** is composed of a coil which generates a magnetic field when electricity flows through it.

3. The **brushes** provide mechanical contact between the rotor and the commutators and help switch polarity of rotor windings.

4. **Commutators** reverse the current every half a cycle to keep the motors turning.



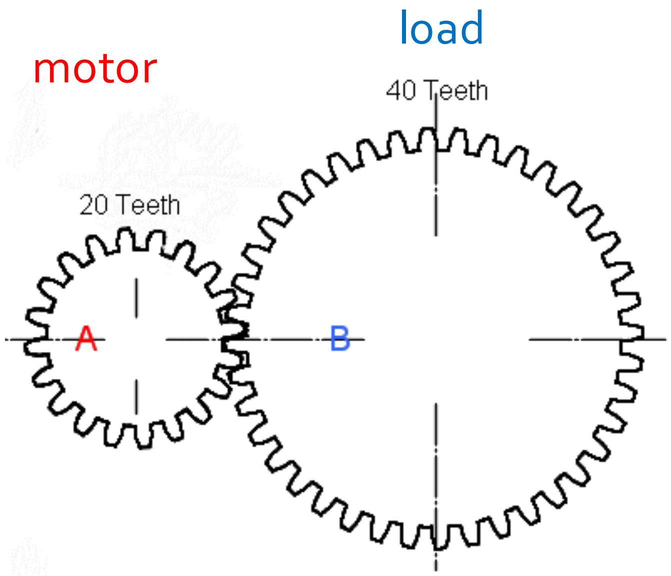
http://humanoids.dem.ist.utl.pt/servo/overview.html

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

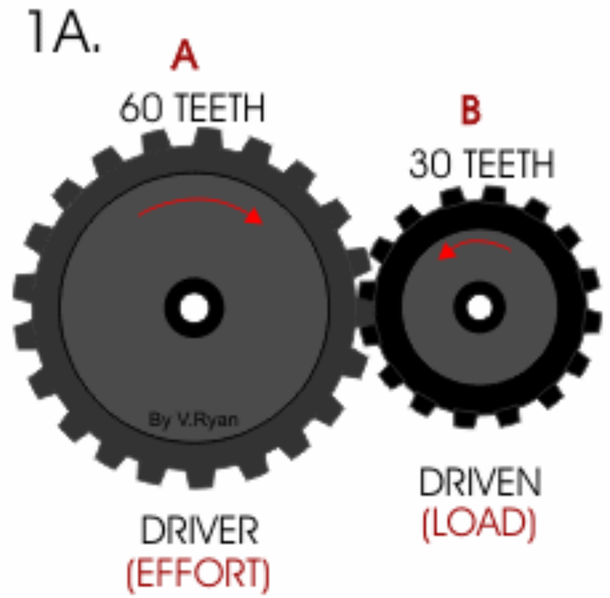
Gearing

- DC motors spin too fast with too little torque
- Gears slow the load rotation and increase torque



Gear Trains and Ratios

- Gear trains reduce speed and magnify torque.
- The gear ratio is the ratio of number of teeth on driver gear A to those on driven gear B:



$$GR = \frac{\text{number of teeth on gear A}}{\text{number of teeth on gear B}}$$

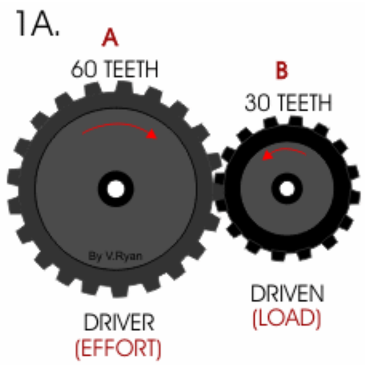
Gear Ratio and Angular Velocity

- The gear ratio is also proportional to the ratio of radii:

$$GR = \frac{r_A}{r_B}$$

- The surface speeds at the point of contact of the gears must be identical, so

$$v_A = v_B \Rightarrow \omega_A r_A = \omega_B r_B$$

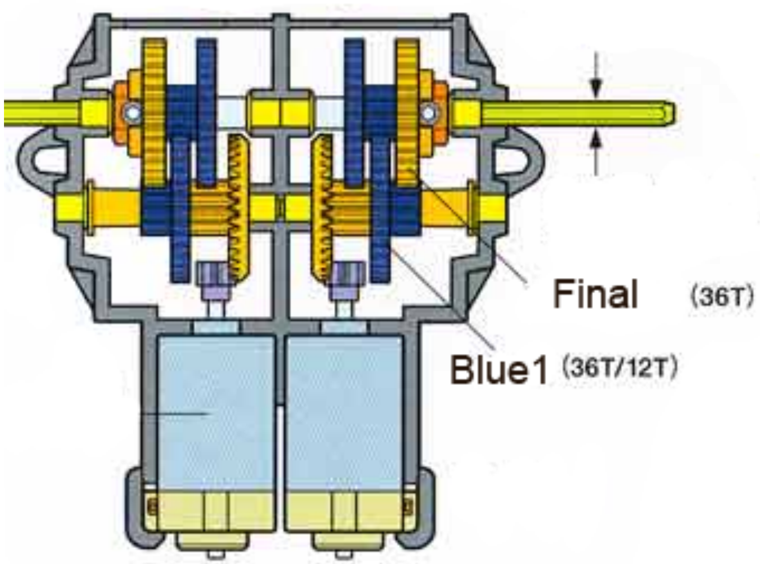


- Therefore,

$$GR = \frac{n_A}{n_B} = \frac{r_A}{r_B} = \frac{\omega_B}{\omega_A}$$

Example: Tamiya Gear Box

- Gear Ratio:
  - Final to Blue1 36:12
  - Blue1 to Blue2 36:12
  - Blue2 to Crow 36:12
  - Crown to Pinion 34:8
  - Total: 114.75:1

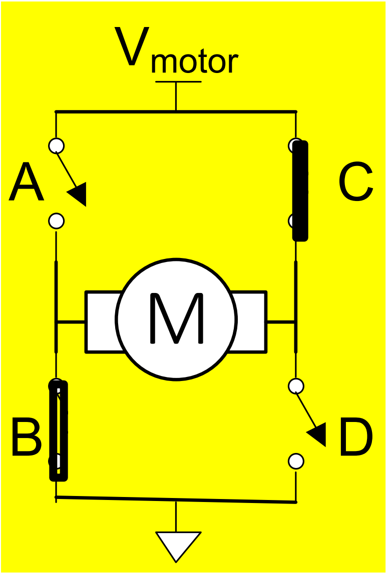


pololu.com

H-Bridge

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

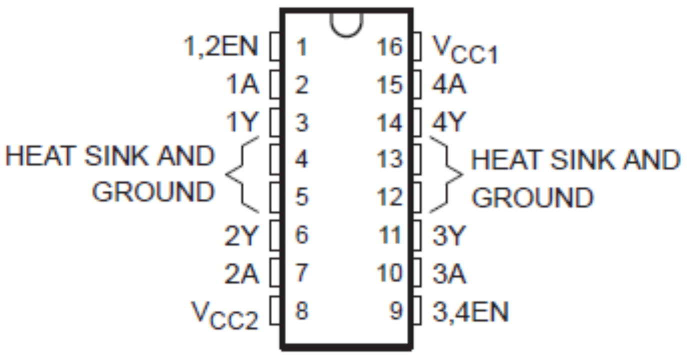
A	B	C	D	Motor
ON	OFF	OFF	ON	Forward
OFF	ON	ON	OFF	Backward
ON	OFF	ON	OFF	Brake
OFF	OFF	OFF	OFF	Coast
ON	ON	OFF	OFF	H-Bridge Magic Smoke

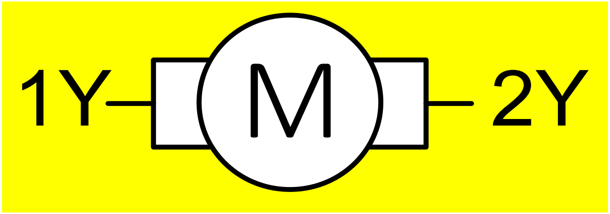


SN754410 H-Bridge

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

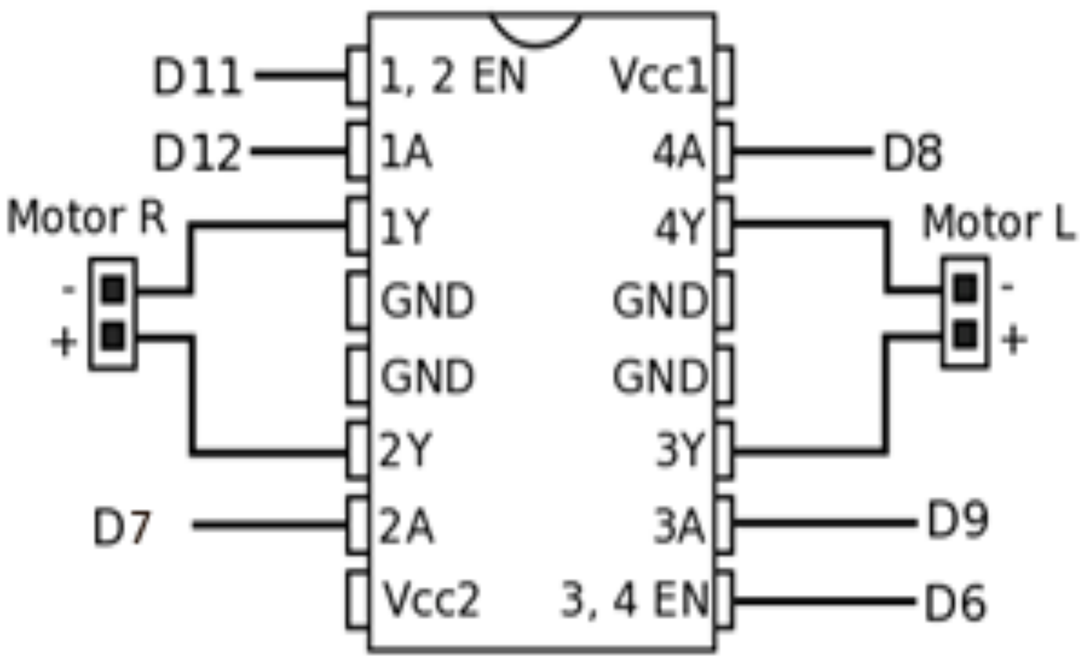
12En	1A	2A	Motor
0	X	X	Coast
1	0	0	Brake
1	0	1	Backward
1	1	0	Forward
1	1	1	Brake





- Contains two H-Bridges to drive two motors

Mudduino H-Bridge Interface

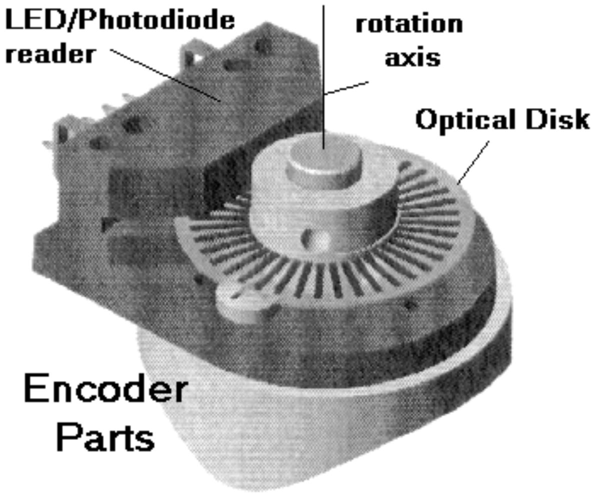


Motor Driver Software

```
#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

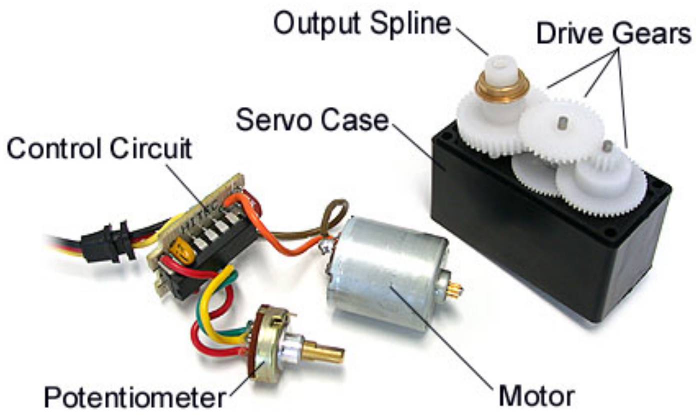
- Sometimes it helps to know the position of the motor
- Optical shaft encoder
  - Disk with slits attached to motor shaft
  - Light and optical sensor on opposite sides of disk
  - Count light pulses as the disk rotates
- Analog shaft encoder
  - Connect potentiometer (variable resistor) to shaft
  - Resistance varies as shaft turns



http://www.bogan.ca/astro/telescopes/digtcrcl.html

Servo Motor

- Servo motors are designed to be easy to use
  - DC motor
  - Gearing
  - Analog shaft encoder
  - Control circuitry
  - High-current driver



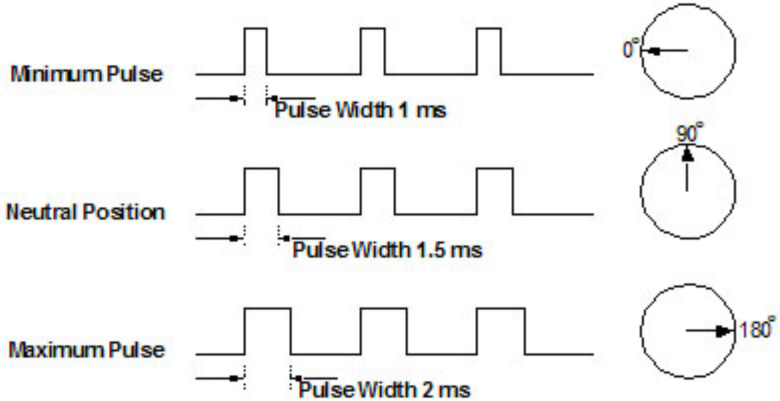
servocity.com

- Three wires: 5V, GND, Control
- Turn from 0 to 180 degrees
  - Position determined by pulses on control wire

Servo Pulse Width Modulation

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

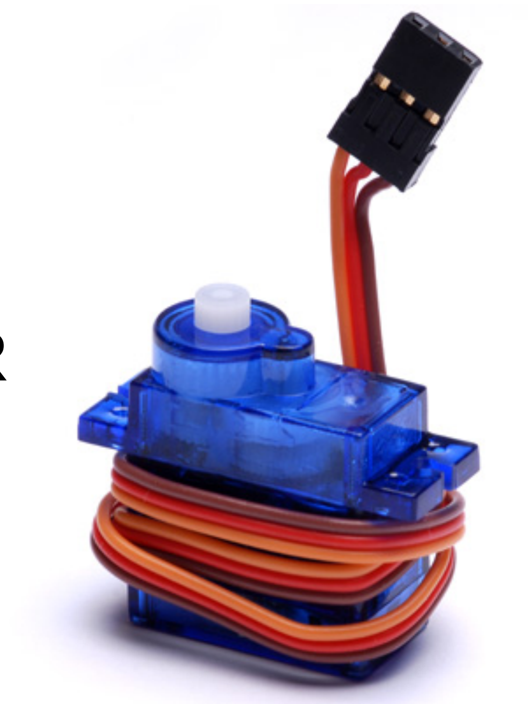
  - 1 ms = 0°
  - 1.5 ms = 90°
  - 2 ms = 180°



servocity.com

SG90 Servo

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



hobbypartz.com

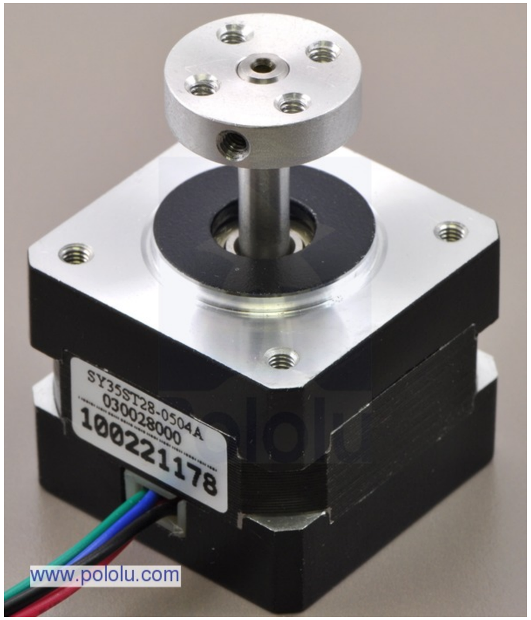
Arduino Servo Library

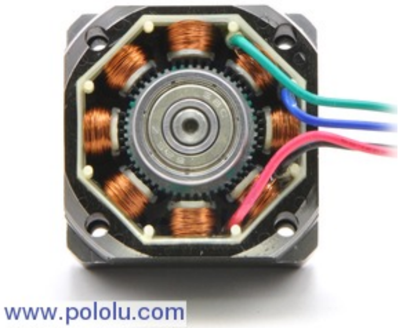
- Arduino offers a servo library for controlling servos

```
// servotest.ino
// 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);
}
```

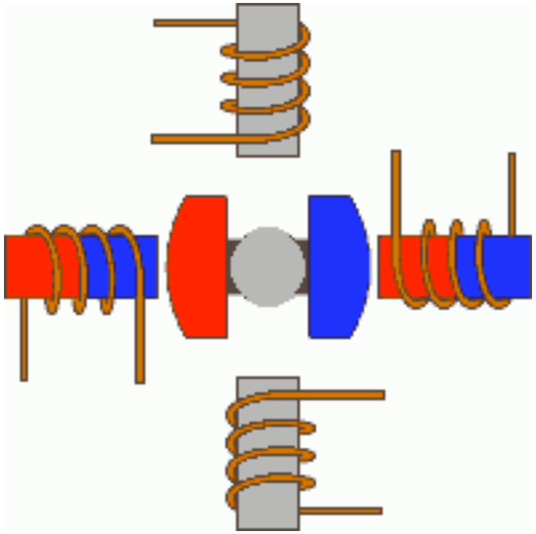
Stepper Motor

- 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





Stepper Motor



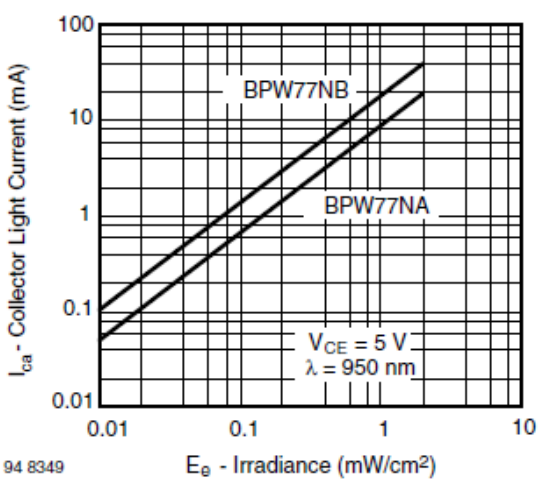
http://www.pcbheaven.com/wikipages/How_Stepper_Motors_Work/

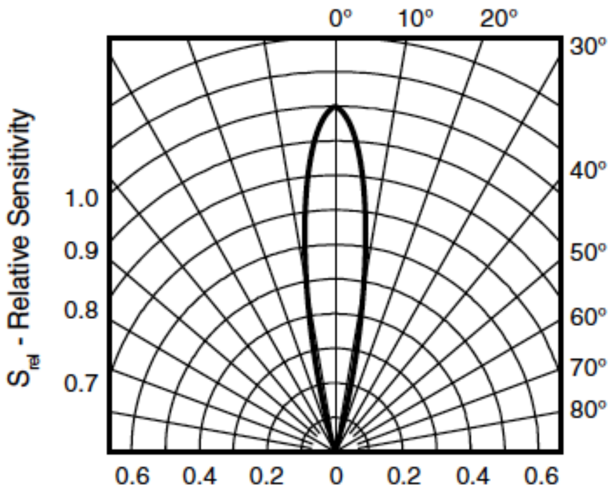
Outline

- **Actuators**
- **Sensors**
  - Phototransistor
  - Reflectance Sensor
  - IR Distance Sensor
  - Contact Switch
  - Other Sensors

Phototransistor

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



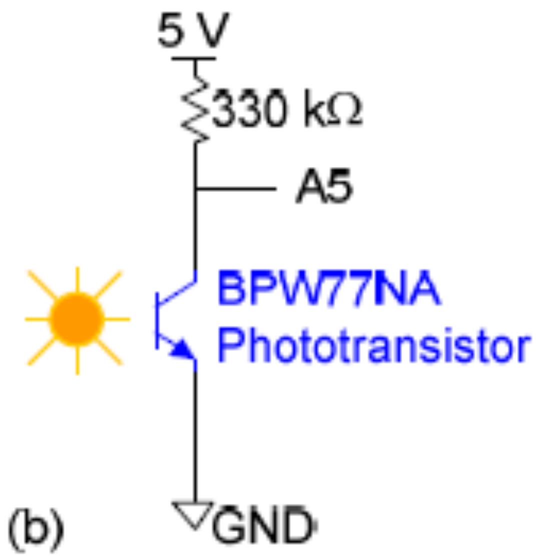


vishay.com

jameco.com

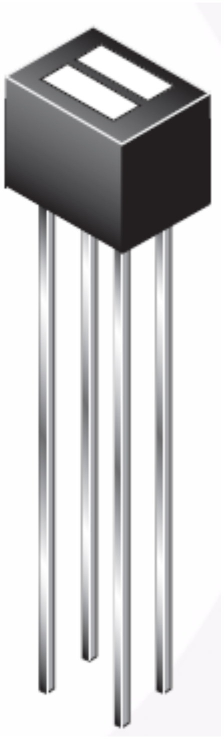
Phototransistor Circuit

- $V_{out} = 5 - I_{photo} \times 330\ k\Omega$
  - 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



Reflectance Sensor

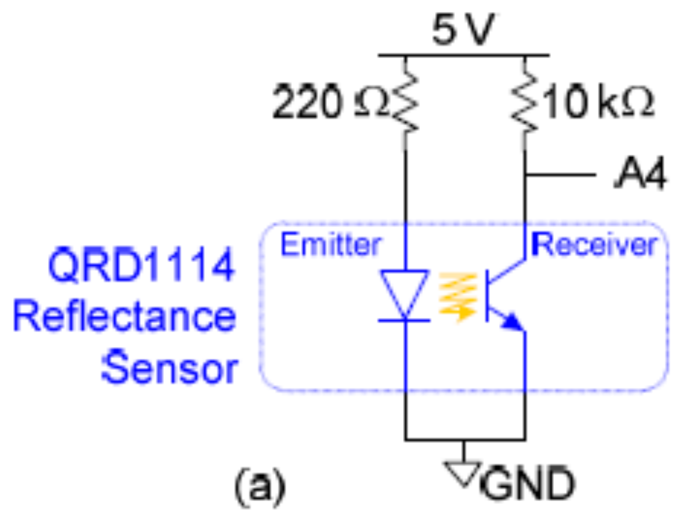
- Infrared LED and phototransistor pair
  - LED illuminates surface
  - Phototransistor receives reflected light
  - Daylight filter on sensor reduces interference
  - Sensitive to distance, color, reflectivity
- Fairchild QRD1114 Reflectance Sensor
  - ~20 mA LED current
  - 1.7 V LED ON voltage
  -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



fairchild.com

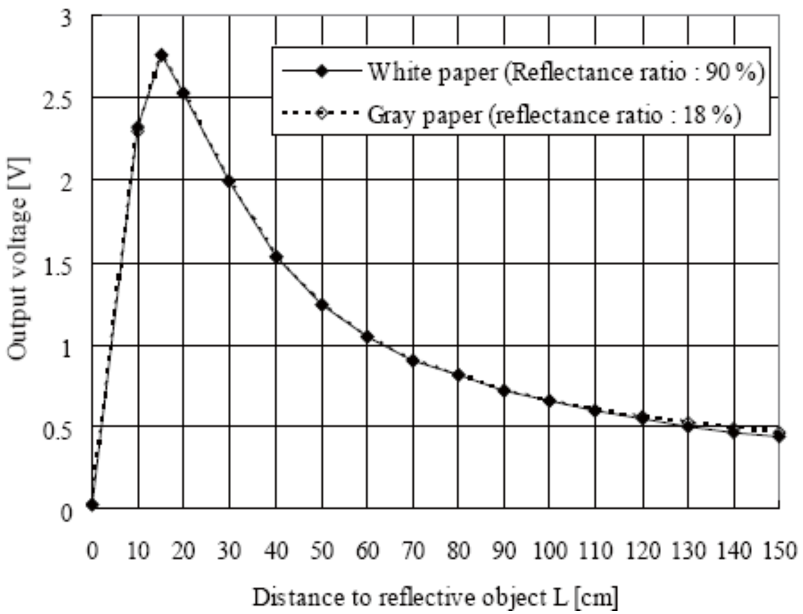
Reflectance Sensor Circuit

- 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

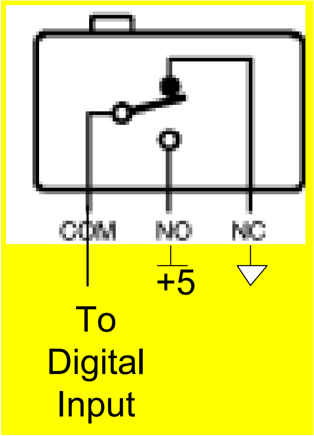
- Measure flight time of ultrasonic pulse
  - Less sensitive to ambient light
  - More precise
  - More expensive

maxbotix.com

- Example: LV-MaxSonar-EZ
  - 42 KHz ultrasonic beam
  - Range of 254″ with resolution of 1″
  - 2.5 – 5.5 V operation
  - Analog voltage output

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



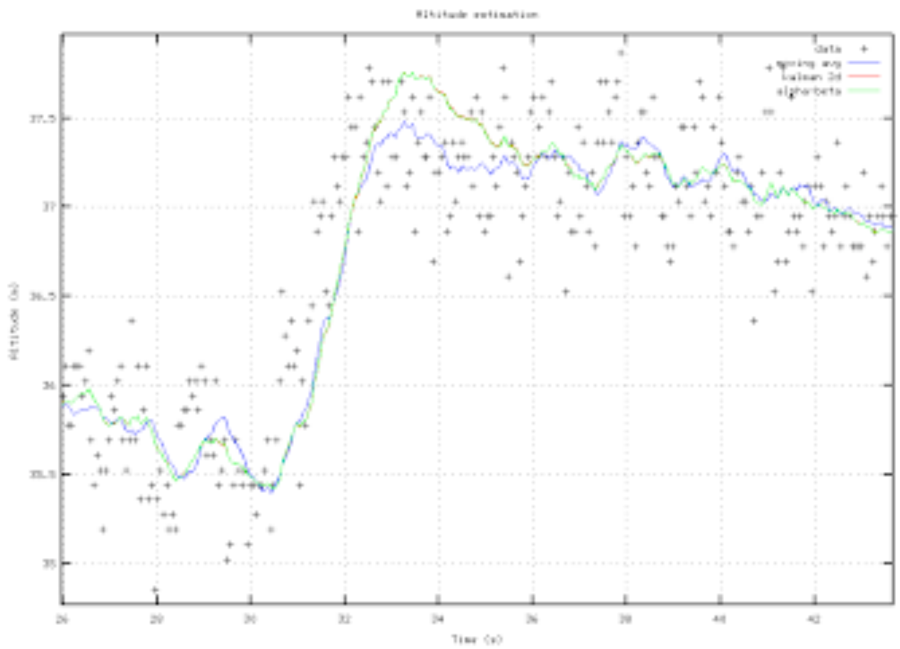
sparkfun.com

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

Sensor Averaging

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



http://kedder.livejournal.com/13372.html

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)
- Some E11 stock of various sensors
- Boundless possibilities!

Announcements

- Bring your laptop, robot, and programming cable to the rest of the lab sessions this fall
- Pick your partner for Lab 6 & Final Project
  - Write partner names on sign-up sheet
  - Rank order all lab sections both you and your partner can make (leave blank those you cannot make)