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: $\frac{\omega_B}{\omega_A} = \frac{N_A}{N_B}$
Example: Tamiya Gear Box

- **Gear Ratio:**
  - Final to Blue1
  - Blue1 to Blue2
  - Blue2 to Crown
  - Crown to Pinion
  - Total: 114.75:1
H-Bridge

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

<table>
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<tr>
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<th>B</th>
<th>C</th>
<th>D</th>
<th>Motor</th>
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![H-Bridge Diagram]
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)

- Contains two H-Bridges to drive two motors

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<th>2A</th>
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Mudduino H-Bridge Interface
Motor Driver Software

```c
#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
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
Arduino offers a servo library for controlling servos

```cpp
// 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°
Phototransistor Circuit

- Leave base terminal unconnected

- $V_{out} = 5 - I_{\text{photo}} \times 330 \, \text{k}\Omega$
  - In dark, $V_{out} \approx 5 \, \text{V}$
  - For $I_{\text{photo}} > 15 \, \mu\text{A}$, $V_{out}$ drops to $\sim 0$

- 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 $200 \, \Omega$ in full light
  - Slow response time
```c
#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)
Reflectance Sensor Circuit

- $I_{LED} = (5 - 1.7 \, V) / 220 \, \Omega = 15 \, mA$
- $V_{out} = 5 - I_{photo} \times 10 \, k\Omega$
- 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

![IR Distance Sensor image](www.pololu.com)
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
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!
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

- Cyanoacrylate (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!**