Actuators & Motors

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Topics

- Definition of an actuator.
- Control signals
- Relays – electromechanical.
  - Bipolar Junction Transistors
- Solid State Power Switching
  - Silicon Controlled Rectifiers
  - Triac
- DC motors, RC servos and stepper motors:
  - Unijunction transistor
  - Field effect transistors
- Stepper motors and linear actuators.
- Fluid pumps and flow sensors
- Pneumatic systems.
What is an actuator?

- A device that responds to a control signal and accomplishes something useful!
  - An injector mechanism of an insulin pump in response to a patient’s manual command or feedback loop with an integrated glucose sensor.
  - A relay driven by the a low current output pin of a microcontroller, switching on a high power circuit.
  - An alarm that sounds when vital signs are critical.
  - A microvalve made of pH sensitive hydrogel, opening and closing a fluid conduit in a lab-on-chip device.
  - A piezoelectric, magnetic or electrostatic micropump.
Industrial actuators are typically performing motion – derived by pneumatic, electrical, or hydraulic systems – and are useful for many prototyping projects.

- e.g. relays, valves, pumps, motors, stepping motors, linear actuators, servos and pneumatic cylinders.

With microfabrication we can incorporate a variety of energies and materials:

- Piezoelectric effects, electrostatic forces, magnetic forces, thermal transformation, shape memory alloys, hydrogels, electroactive polymers (ionic and non-ionic), and dielectric electroactive polymers.

- These topic are covered in BMEn 5151 Intro to BioMEMS and Medical Microdevices.
MiniMed Paradigm Revel™ Insulin Pump has built-in continuous glucose monitoring (CGM), and offers round-the-clock glucose monitoring.

This pump also delivers early notification of oncoming lows and highs so that the patient can react quickly to changes in sugar level.
The Medtronic SynchroMed II® programmable infusion system for intrathecal drug delivery includes an implanted pump that can be noninvasively programmed.

Once implanted, the SynchroMed pump stores and delivers medication according to instructions programmed by the physician.
Typically there is a low energy *control signal* to a device (mechanism) that responds by performing some sort of work.

The *control signal* may be the push of a finger, an electrical voltage or current, a pneumatic or hydraulic pressure, or even an environmental stimulus (temperature, gas, magnetic field, presence of an ion, pH etc.)

Some *action* takes place – movement, pumping, switching, signalling etc.

There will be a *transduction of energy*, and energy will be expended in the process.
Essentially a switch.

When voltage is applied to the coil, the moveable contact comes down by magnetic attraction, switching the circuit between the upper to lower fixed contact.

A 12 VDC coil for example, may require 200 mA, while the contacts can handle a load of much higher voltage and current dependent on the contact ratings.

Many relays today are “solid state”, based on silicon controlled rectifiers.

Image courtesy of John T. Blair and All About Circuits, EETech Media, LLC.
We previously discussed BPJ transistors in relationship to amplifiers and switching. BJT s are “current operated devices” where a much smaller Base current causes a larger Emitter to Collector current.
BJTs...

- They require a biasing voltage for AC amplifier operation.
- \( I_E = I_B + I_C \)
- A transistor can also be used as an electronic switch between its saturation and cut-off regions to control devices such as lamps, motors, and solenoids, etc.
- Inductive loads such as DC motors, relays, and solenoids require a reverse biased “Flywheel” diode placed across the load. This helps prevent any induced back EMF generated when the load is switched “OFF” from damaging the transistor.
Effects the base current $I_B$ and the emitter-to-collector voltage $V_{EC}$ have on the emitter/collector currents $I_E$ and $I_C$.

Relay Driver with Transient Suppression...

Place a transient suppressor diode across the relay coil.

Components:
- VCC 12V
- D1 1N4004G
- Q1 2N2222A
- R1 470Ω
- C1 .05μF
- S1
- R2 220kΩ

Specifications:
Examples of Relays...

4PDT 12VDC 5A.
14 Pin Terminals Relay and Socket.
Contact Capacity to 5A.

2A DPDT PC Mount Relay

Two-Coil Latching – Set and Reset

Images courtesy of Futurlec.
Relay Modules and Arduino Shield...

Image courtesy of Vetco Electronics

SainSmart 5V Relay Board

Relay Shield for Arduino
Image courtesy of Microbot di Prosseda Mirko
Examples of Solid State Relays...

- SCR Chip, Photo Isolation.
- Output Switching Voltage: 48 – 280 VAC.
- Maximum Load Current: 0.1 – 5 A.
- Maximum Surge Current: 250 A.

Dual SPST DIP Solid State Relay.
- Input Control Current: 5–50 mA.
- Output Switching Voltage: 0 – 60 V AC/DC.
- Load Current up to 400mA.

Images courtesy of Futurlec.
The Silicon Controlled Rectifier (SCR) is simply a conventional rectifier controlled by a gate signal.
Two anti-parallel SCRs. Generally used for motor speed control and in light dimmer.

It can be triggered by either a positive or a negative voltage being applied to its gate electrode (with respect to T1, otherwise known as MT1 or A1).

- Once triggered, the device continues to conduct until the current through it drops below a certain threshold value, the holding current, such as at the end of a half-cycle of alternating current (AC) mains power.
Controlling a High Voltage Device...

- **5V/0V (on/off)**
- **Gnd**

**Optocoupler**

- **MOC3021**
- **BT136**

- **360 Ohms**
- **470 Ohms**
- **R1**
- **R2**
- **C1**
- **C2**
- **R3**
- **0.05uF**

**Triac**

- **BT 136**

**Snubber Circuit**

- Required only for inductive load (e.g., motor)

**Power Supply**

- 220V 50Hz

*Image courtesy of Sigmatone.*
Unijunction Transistor (UJT)...

- Three-lead electronic semiconductor device with only one junction that acts exclusively as an electrically controlled switch. The UJT is not used as a linear amplifier.
- With the emitter unconnected, the bar acts as a potential divider, and about 0.5 volts appears at the emitter. If a voltage is connected to the emitter, as long as it is less than 0.5 volts, nothing happens, as the P–N junction is reversed biased. (see the right hand diagram).
- When the emitter voltage exceeds 0.5 volts, the junction is forward biased and emitter current will flow. This increase in current is equal to a reduction of resistance between base 1 and the emitter.
- Useful for triggering thyristors.

Left: Hobby Projects.com
Middle: Learning about electronics.com
Right: Image courtesy of Allied Electronics
Here we see control of motor speed by sending short pulses of current to the SCR.

A UJT relaxation oscillator generates a series of pulses that drives an SCR on and off.

To vary the speed of the motor, the UJT’s oscillatory frequency is adjusted by changing the RC time constant.

Field Effect Transistors (JFETS & MOSFETS)...

<table>
<thead>
<tr>
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<th>FET</th>
<th>vs</th>
<th>BJT</th>
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<tbody>
<tr>
<td>Low voltage</td>
<td>Low voltage gain.</td>
<td>High voltage gain.</td>
<td>gain.</td>
</tr>
<tr>
<td>High current</td>
<td>High current gain.</td>
<td>Low current gain.</td>
<td>gain.</td>
</tr>
<tr>
<td>Low input</td>
<td>High input and output impedance.</td>
<td>Low input and output impedance.</td>
<td>impedance.</td>
</tr>
<tr>
<td>Robust</td>
<td>Easily damaged by static</td>
<td>Robust</td>
<td></td>
</tr>
<tr>
<td>Voltage</td>
<td>Voltage Controlled</td>
<td>Current Controlled</td>
<td>Controlled</td>
</tr>
<tr>
<td>Controlled</td>
<td>High current</td>
<td>Low current relays, LEDs, lamps, amps, &amp; oscillators</td>
<td></td>
</tr>
<tr>
<td>High current needs like motors &amp; servos</td>
<td>&amp; oscillators</td>
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The speed of the motor is controlled by the oscillator’s RC time constant.

Notice that if one of the input leads of the left NAND gate is pulled out, it is possible to create an extra terminal that can be used to provide on/off control that can be interfaced with CMOS logic circuits.

By inserting a diode between pins 7 and 6, as shown, the 555 is placed into low-duty cycle operation.

R1, R2, and C set the frequency and on/off duration of the output pulses.

Arduino Interface Shield

Adafruit Motor/Stepper/Servo Shield for Arduino v2 Kit – v2.3

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**Motor Direction Control...**

**Bipolar H-Bridge**

A signal must not be applied here when a signal is being applied to the forward lead.

**MOSFET H-Bridge**

A HIGH on “Run” pin turns Q7 ON driving its collector LOW and through CD4011b inverts signal to a “HIGH” on gate Q5 turns MOSFET ON, causing motor to run.

A LOW on the Direction pin sets the collector of Q6 HIGH and also Q1’s gate HIGH, and through CD4001a, Q4 is ON (Q2 and Q3 are off) creating a current path through Q1, the motor and Q4. When the Direction pin goes HIGH (5V), Q6 switches ON, driving its collector LOW, switching off Q1 and Q4 and turning on Q2 and Q3, creating a reverse current path through Q2, the motor, and Q3.

The L293NE/SN754410 is a very basic H-bridge. It has two bridges, one on the left side of the chip and one on the right, and can control 2 motors. It can drive up to 1 amp of current, and operate between 4.5V and 36V.

Pin 1 (1,2EN) enables and disables the motor whether it is give HIGH or LOW.
Pin 2 (1A) is a logic pin for motor (input is either HIGH or LOW).
Pin 3 (1Y) is for one of the motor terminals.
Pin 4–5 are for ground.
Pin 6 (2Y) is for the other motor terminal
Pin 7 (2A) is a logic pin for motor (input is either HIGH or LOW).
Pin 8 (VCC2) is the power supply for motor, this should be given the rated voltage of the motor.
Pin 9–11 are unconnected as if using one motor.
Pin 12–13 are for ground.
Pin 14–15 are unconnected.
Pin 16 (VCC1) is connected to 5V.
Simple RC servos typically consists of a motor, feedback device (e.g. a potentiometer) and control circuit.

An external PWM signal controls the position of the shaft.

Angular rotation of an RC servo’s shaft is limited to around 180 or 210°.
Shown are the DC motor, gearbox, potentiometer and control circuit.

Using gear reduction, the load and the potentiometer rotate with the motor shaft, within the limits of the potentiometer.

Images courtesy of Binoy’s Tech Blog, and Wikimedia
An internal potentiometer rotates with the shaft, allowing a measurement of resistance to determine how far the shaft has rotated.

The control circuit uses this resistance, along with a pulse-width-modulated input control signal, to drive the motor a specific number of degrees and then hold.

When the pulse width is set to 1.5 ms, the servo rotates its shaft to neutral position.

Increase or decreasing the width from 1.5 ms will rotate the shaft CCW and CW respectively.

Stepper Motors & Linear Actuators

- Brushless motor that rotates with digital pulses – typically 1.8 degrees per pulse.
- Run at lower speed than DC motors, but with higher torque.
- Velocity of rotation is related to frequency of the pulses.
- Torque is maintained even at rest.
- Very good at starting, stopping and reversing direction.
- No feedback potentiometer is required.
- “Steps” include:
  - Full step: $360\,\text{deg}/200\,\text{step} = 1.8\,\text{deg/step}$.
  - Half step: $0.9\,\text{deg/step}$
  - Microstep: $.007\,\text{deg/step}$
- Types include variable reluctance, permanent magnet and hybrid.
Stepper motors are used in linear motion controllers.
- The pitch of the lead screw controls the amount of linear distance traveled in one revolution of the screw.
- Therefore if the lead is 1 IPR, and the stepper motor is 200 SPR, then the resolution \( \frac{1}{200} = 0.005 \) IPS.
Stepper Motor Driver or Indexer...

- The driver takes RS-232 or RS-485 signals from the computer and sends pulses to the stepper.
- Output control of step frequency, direction, acceleration, deceleration and distance.
- Additional features include auxiliary input/output for monitoring from external sources such as “Go”, “Home”, “Jog”, or “Limit” switches.

Phidget Stepper, Zen Tool Works, Circuit Specialists
Fluid Pumps & Flow Sensors

Peristaltic Pumps
Image courtesy of Adafruit

8v–12v Small DC Submersible Water Pump

Hall–Effect Flow Sensor
(Careful – British Fittings!)

Ultrasonic Flow Sensor

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Peristaltic Pump...

- The pump never touches the fluid which makes this an excellent choice for any food/drink/sterile based pumping.
- Geared down DC motor with a lot of torque.
- Silastic tubing is squeezed by revolving rollers.
- Working Temperature: 0°C – 40 °C.
- Motor voltage: 12VDC.
- Motor current: 200–300mA.
- Flow rate: up to 100 mL/min.
- Weight: 200 grams.
- Dimensions: 27mm diameter motor, 72mm total length.
- Mounting holes: 2.7mm diameter, 50mm center-to-center distance.
Water Flow Sensor...

- Mini. Working Voltage: DC 4.5V
- Max. Working Current: 15mA (DC 5V)
- Working Voltage: DC 5V~24V
- Flow Rate Range: 1~30L/min
- Load Capacity: ≤10mA (DC 5V)
- Operating Temperature: ≤80℃
- Liquid Temperature: ≤120℃
- Operating Humidity: 35%~90%RH
- Water Pressure: ≤1.75MPa
- Storage Temperature: -25～+ 80℃
- Storage Humidity: 25%~95%RH
- G1&2 Pipe Fittings
Pneumatic Systems

Image courtesy of Direct Industry

Image courtesy of Allenair

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Non-Invasive Intracranial Pressure Measurement Test Apparatus.
Simulated Cribiform Plate Pressure Pneumatic/Laser Sensor.
Definition of an actuator.
Control signals
Relays – electromechanical.
  ◦ Bipolar Junction Transistors
Power Switching
  ◦ Silicon Controlled Rectifiers
  ◦ Triac
DC motors, RC servos and stepper motors:
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