Actuators
Control system
Causes of errors in physical robotic systems

– inaccuracies in the model of the robot,
– tolerances in the work piece,
– static friction in joints,
– mechanical compliance in linkages,
– limitations in the precision of computation
Steady state error
Open loop control system computes its input into a system using only the current state and its model of the system.
Where it is applicable

Used for “well-defined systems” which have a proper relationship between input and resultant state

**Advantage:** simplicity and low cost

**Disadvantage:** High SSE (steady state error)
A typical example of an open loop control system can be the voltage being fed to a motor driving a constant load to achieve a constant speed.
Closed Loop control system
Basic closed loop system

The inverse flowing information is called “feedback”
Velocity control loop

Position control loop
Electric Motors

- An electric motor is an electromechanical device that converts electrical energy into mechanical energy.

- DC Motors
- Stepper Motors
- Servo Motors
- Linear Motors
DC Motor

• Designed to work on DC power.

• Mainly of three types:
  – Permanent Magnet Type
  – Brushed DC Motors
  – Brushless DC Motors
Permanent Magnet Motor
Advantages of Brushless over Brushed:
- Better Speed Vs. Torque
- High Efficiency
- Long operating life (No brushes)
- Noiseless Operation
- Higher Ratio of Torque wrt Size
Theory of Servomechanisms

• Closed loop control whose output is some mechanical position or velocity set by a reference input (required output).

• Two types
  – Positional Control
  – Velocity Control
    • Instead of Position sensor, Hall Sensors are used.
Servo Motor

The basic behind Servo Control is *Pulse Width Modulation*. 

Pulse Parameters:
- Minimum Pulse
- Maximum Pulse
- Repetition Rate
• All servos have three wires: **Black** or **Brown** is for ground. **Red** is for power (~4.8-6V). **Yellow, Orange, or White** is the **signal** wire (3-5V).

• The general concept is to simply send an ordinary logic **square wave** to your servo at a specific wave length, and your servo goes to a particular angle (or velocity if your servo is modified). *The wavelength directly maps to servo angle.*
Stepper Motors

Steppers are used when incremental motion is required.

A stepper motor possesses the ability to move a specified number of revolutions or fraction of a revolution in order to achieve a fixed and consistent angular movement.

Movement is achieved when power is applied for short periods to successive magnets.
Advantages

• High accuracy of motion possible
• Cheaper and effective in open loop systems
• Brushless construction

Disadvantages

• Low torque capacity compared to DC motors
• Limited speed
• High vibrational levels
• Large errors and vibrations if a pulse is missed
Motor Drivers

a device or group of devices that serves to govern in some predetermined manner the performance of an *electric motor*.

Mainly used Motor Drivers:
- L293/L293D
- L298
- L297
- Stepper Motor Controllers
- Servo Motor Controllers
H-Bridge

- An electronic circuit that enables a voltage to be applied across a load in either direction.
How to run motors through an MCU?

• Never connect the MCU pins directly to the motors.

• The Atmega16 has a current rating of 5-10 mA.

• The normal DC motor’s current ratings start from 150 mA and above which arises a need for a Motor and MCU interface.

• So the motor cannot be directly attached to the ATmega, hence a motor-driver is used... (eg: L293/L293D, L298, etc...)
Piezoelectric actuators

Piezoelectric effect is the generation of electric charge resulting from an applied mechanical force.
Applications

Used both as a sensor and actuator

A piezo disc in an electric buzzer

A piezo disc in a guitar pick up
Chain And Sprocket
Rack And Pinion

• Can convert rotational motion into linear motion
Pneumatic principle
Why Pneumatics?

- **Weight**
  - Much lighter than motors (as long as several used)

- **Simple**
  - Much easier to mount than motors
  - Much simpler and more durable than rack and pinion

- **More rugged**
  - Cylinders can be stalled indefinitely without damage
  - Resistant to impacts

- **Disadvantage:** All the way in or all the way out
Linear Motion

• Much simpler, easier, more durable than rack and pinion
• Can maintain constant force
Applications
Short Rotation

- Arm Joints
- Grabbers
SMA's, or Shape Memory Alloys

materials that change shape when energy is applied to, or removed from, them. The most commonly used alloy is NiTinol.

- Have a shape memory.
- Tries to achieve the memorized energized.
- A restoring force(spring action) is needed.
SMA Robotic Hand
Applications
Estimating load torque

**Hoisting application**
- **SI units**
  \[ T = \frac{1}{2} D \cdot W \text{ (N}\cdot\text{m}) \]
  - \( D \): Diameter of drum (m)
  - \( W \): Load (N)

**Flywheel application**
- **SI units**
  \[ T = \frac{J}{9.55 \times 10^4} \cdot \frac{N}{t} \text{ (N}\cdot\text{m}) \]
  - \( J \): Inertia (kg\cdotcm²)
  - \( N \): Rotating speed (r/min)
  - \( N/t \): Time (s)

**Belt conveyor application**
- **SI units**
  \[ T = \frac{1}{2} D (F + \mu Wg) \text{ (N}\cdot\text{m}) \]
  - \( D \): Diameter of roll (m)
  - \( W \): Mass of load (kg)
  - \( g \): Gravitational acceleration
  - \( \mu \): Friction coefficient
  - \( F \): External force (N)

**Horizontal travel on contact face**
- **SI units**
  \[ T = \frac{1}{2} D \cdot \mu Wg \text{ (N}\cdot\text{m}) \]
  - \( D \): Diameter of drum (m)
  - \( W \): Mass (kg)
  - \( \mu \): Friction coefficient

**Ball screw drive**
- **SI units**
  \[ T = \frac{1}{2\pi} P (F + \mu Wg) \text{ (N}\cdot\text{m}) \]
  - \( F \): External force (N)
  - \( W \): Mass of load (kg)
  - \( \mu \): Friction coefficient of sliding surfaces (approx. 0.05 to 0.2)
  - \( g \): Gravitational acceleration (m/s²)
  - \( P \): Lead of ball screw (m)
Determination of the driving mechanism

Calculation of motor speed and load

Selection of motor model

Temporary selection of the motor

Final determination of motor & gear head
## Linear actuator selection

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Spring</th>
<th>Pneumatic</th>
<th>Rack and Pinion</th>
<th>Solenoid</th>
<th>Shape Memory Alloy</th>
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<td>+</td>
<td>+</td>
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<tr>
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<td>-</td>
<td>-</td>
<td>+</td>
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<tr>
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<td>+</td>
<td>+</td>
<td>+</td>
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<tr>
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<td>Time between shots</td>
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<tr>
<td>Cost</td>
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<td>-</td>
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</tbody>
</table>
Inside some famous robot (how do they actuate)

- MagLev:

  Autumn concept MagLev

  MagLev in Shanghai
A MagLev can be called a glorified linear motor
One with the track extended as the rails of a train and the carriage transported being the train itself
Mowgli – pneumatic air muscles

- Pneumatic artificial muscles (PAMs) are contractile or extensional devices operated by pressurized air filling a pneumatic bladder.
Mowgli
The shadow hand developed by CMU uses PAMs to mimic nearly all the degrees of freedom of a human hand using 40 muscle fibres and 80 valves to control the flow to them.