Actuators and Drive Systems

Introduction to Robotics- Part II

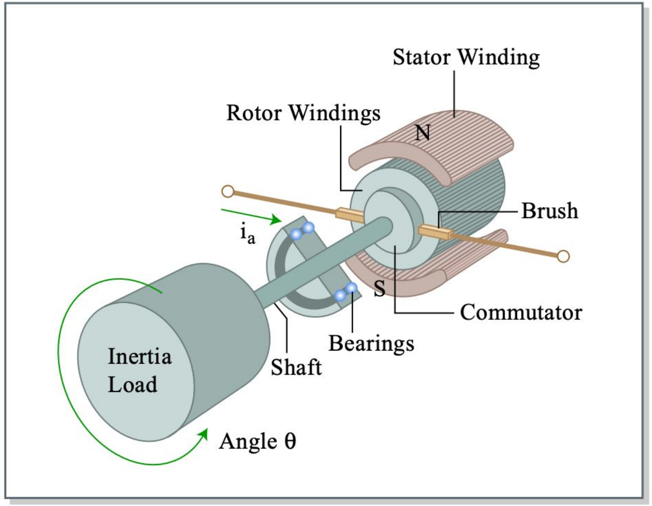
Introduction

Actuators are one of the key components contained in a robotic system. A robot has many degrees of freedom, each of which is a servoed joint generating desired motion. We begin with basic actuator characteristics and drive amplifiers to understand behavior of servoed joints.

Most of today’s robotic systems are powered by electric servomotors. Therefore, we focus on electromechanical actuators.

DC Motors

Figure illustrates the construction of a DC servomotor, consisting of a stator, a rotor, and a commutation mechanism. The stator consists of permanent magnets, creating a magnetic field in the air gap between the rotor and the stator. The rotor has several windings arranged symmetrically around the motor shaft. An electric current applied to the motor is delivered to individual windings through the brush-commutation mechanism, as shown in the figure. As the rotor rotates the polarity of the current flowing to the individual windings is altered. This allows the rotor to rotate continually.



Let τ_m be the torque created at the air gap, and i the current flowing to the rotor windings. The torque is in general proportional to the current, and is given by

$$\tau_m = K_t \cdot i$$

where the proportionality constant K_t is called the ***torque constant***, one of the key parameters describing the characteristics of a DC motor. The torque constant is determined by the strength of the magnetic field, the number of turns of the windings, the effective area of the air gap, the radius of the rotor, and other parameters associated with materials properties.

In an attempt to derive other characteristics of a DC motor, let us first consider an idealized energy transducer having no power loss in converting electric power into mechanical power. Let E be the voltage applied to the idealized transducer. The electric power is then given by $E \cdot i$, which must be equivalent to the mechanical power:

$$P_{in} = E \cdot i = \tau_m \cdot \omega_m$$

where ω_m is the angular velocity of the motor rotor. Substituting eq.(1) into eq.(2) and dividing both sides by i yield the second fundamental relationship of a DC motor:

$$E = K_t \omega_m$$

Stepper Motor

A stepper motor is an electric motor whose main feature is that its shaft rotates by performing steps, that is, by moving by a fixed amount of degrees. This feature is obtained thanks to the internal structure of the motor, and allows to know the exact angular position of the shaft by simply counting how many steps have been performed, with no need for a sensor. This feature also makes it fit for a wide range of applications.

Stepper Motor Working Principles

As all with electric motors, stepper motors have a stationary part (the stator) and a moving part (the rotor). On the stator, there are teeth on which coils are wired, while the rotor is either a permanent magnet or a variable reluctance iron core. We will dive deeper into the different rotor structures later. **Figure 1** shows a drawing representing the section of the motor is shown, where the rotor is a variable-reluctance iron core.

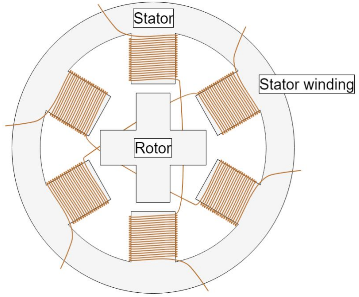


Figure 1: Cross-Section of a Stepper Motor

The basic working principle of the stepper motor is the following: By energizing one or more of the stator phases, a magnetic field is generated by the current flowing in the coil and the rotor aligns with this field. By supplying different phases in sequence, the rotor can be rotated by a specific amount to reach the desired final position. **Figure 2** shows a representation of the working principle. At the beginning, coil A is energized and the rotor is aligned with the magnetic field it produces. When coil B is energized, the rotor rotates clockwise by 60° to align with the new magnetic field. The same happens when coil C is energized. In the pictures, the colors of the stator teeth indicate the direction of the magnetic field generated by the stator winding.

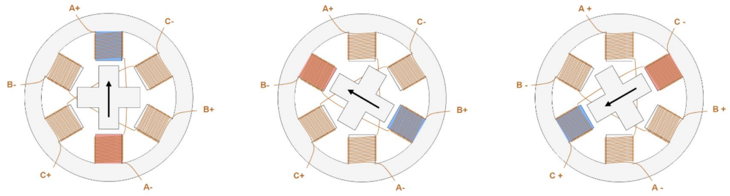


Figure 2: Stepper Motor Steps

Servo Motor

A servo motor is defined as an electric motor that allows for precise control of angular or linear position, speed, and torque. It consists of a suitable motor coupled to a sensor for position feedback and a controller that regulates the motor's movement according to a desired setpoint.

Servo Motor Working Principles

A servo motor is an electric motor that adjusts its position, speed, or torque in response to controller inputs.
A servo motor consists of three main components:

- A motor: This can be either a DC motor or an AC motor depending on the power source and the application requirements. The motor provides the mechanical power to rotate or move the output shaft.
- A sensor: This can be either a potentiometer, an encoder, a resolver, or another device that measures the position, speed, or torque of the output shaft and sends feedback signals to the controller.
- A controller: This can be either an analog or a digital circuit that compares the feedback signals from the sensor with the desired setpoint signals from an external source (such as a computer or a joystick) and generates control signals to adjust the motor's voltage or current accordingly.

The basic working principle of a servo motor involves the controller receiving two types of input signals:

- A setpoint signal: This is an analog or digital signal that represents the desired position, speed, or torque of the output shaft.
- A feedback signal: This is an analog or digital signal that represents the actual position, speed, or torque of the output shaft measured by the sensor.

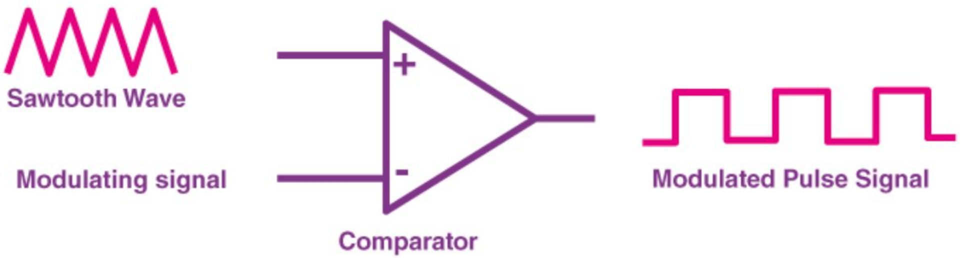
The controller compares these two signals and calculates an error signal that represents the difference between them. The error signal is then processed by a control algorithm (such as PID) that generates a control signal that determines how much voltage or current should be applied to the motor. The control signal is sent to a power amplifier (such as an H-bridge) that converts it into an appropriate voltage or current level for driving the motor. The motor then rotates or moves according to the control signal and changes its position, speed, or torque, and sends a new feedback signal to the controller. The process repeats until the error signal becomes zero or negligible, indicating that the output shaft has reached the desired setpoint.

Pulse Width Modulation

Pulse width modulation reduces the average power delivered by an electrical signal by converting the signal into discrete parts. In the PWM technique, the signal's energy is distributed through a series of pulses rather than a continuously varying (analogue) signal.

How is a Pulse Width Modulation Signal generated?

A pulse width modulating signal is generated using a comparator. The modulating signal forms one part of the input to the comparator, while the non-sinusoidal wave or sawtooth wave forms the other part of the input. The comparator compares two signals and generates a PWM signal as its output waveform.

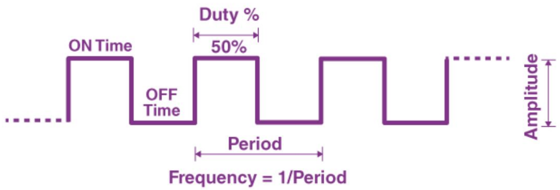


If the sawtooth signal is more than the modulating signal, then the output signal is in a “High” state. The value of the magnitude determines the comparator output which defines the width of the pulse generated at the output.

Important Parameters associated with PWM signal

$$Duty\ Cycle = \frac{Turn\ On\ Time}{Turn\ On\ Time + Turn\ Off\ Time}$$

Frequency of PWM



Frequency = 1/Time Period
Time Period = On Time + OFF time

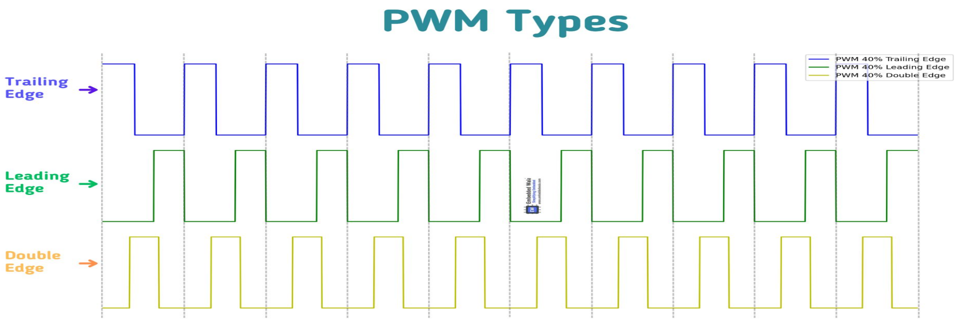
Output Voltage of PWM signal

The output voltage of the PWM signal will be the percentage of the duty cycle. For example, for a 100% duty cycle, if the operating voltage is 5 V then the output voltage will also be 5 V. If the duty cycle is 50%, then the output voltage will be 2.5 V.

Types of Pulse Width Modulation Technique

There are three conventional types of pulse width modulation technique and they are named as follows:

- **Trail Edge Modulation –** In this technique, the signal's lead edge is modulated, and the trailing edge is kept fixed.
- **Lead Edge Modulation –** In this technique, the signal's lead edge is fixed, and the trailing edge is modulated.
- **Pulse Center Two Edge Modulation –** In this technique, the pulse centre is fixed and both edges of the pulse are modulated.



Task: Application and Advantages of PWM.

References: https://byjus.com/physics/pulse-width-modulation/

END