Robot Actuators

Stepper motors
DC motors
AC motors

Physics review:
- Nature is lazy. Things seek lowest energy states.
- Iron core vs. magnet
- Magnetic fields tend to line up

Electric fields and magnetic fields are the same thing.

Stepper Motor Basics
- Stator: made out of coils of wire called "winding"
- Rotor: magnet rotates on bearings inside the stator
- Direct control of rotor position (no sensing needed)
- May oscillate around a desired orientation (resonance at low speeds)
- Low resolution
- Compressed computer drives

Increased Resolution
- Half stepping
- Torque vs. angle graph
Increased Resolution

More teeth on rotor or stator

Half stepping

How to Control?

4 Lead Wire Configuration

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<th>Blue</th>
<th>Yellow</th>
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Clockwise Facing Mounting End

Each step, like the second hand of a clock => tick, tick
Increase the frequency of the steps => continuous motion

Motoring along...

- direct control of position
- precise positioning (The amount of rotational movement per step depends on the construction of the motor)
- Easy to Control
- under-damping leads to oscillation at low speeds
- torque is lower at high speeds than the primary alternative…
DC motors -- exposed!

DC motor basics

DC motor basics

DC motor basics

DC motor basics
Position Sensors

- Optical Encoders
  - Relative position
  - Absolute position
- Other Sensors
  - Resolver
  - Potentiometer

Optical Encoders

- Relative position
  - Direction
  - Resolution

- Relative position
  - Direction
  - Resolution

A diffuser tends to smooth these signals.
**Optical Encoders**

- **Relative position**
  - Direction
  - Resolution
  - Grating
  - Light emitter
  - Light sensor
  - Decode circuitry

A lags B

- **Detecting absolute position**

Phase lag between A and B is 90 degrees

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**something simpler?**
Gray Code

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Other Sensors

- **Resolver**
  - = driving a stepper motor

- **Potentiometer**
  - = varying resistance

Torque

In physics, **torque** can be thought of informally as "rotational force". Torque is measured in units of **newton metres**, and its symbol is \( \mathbb{F} \). The concept of torque, also called **moment** or **couple**, originated with the work of Archimedes on **levers**. The rotational analogues of **force**, **mass** and **acceleration** are **torque**, **moment of inertia** and **angular acceleration** respectively. The force applied to a lever, multiplied by its distance from the lever's **fulcrum**, is the torque.

Control

Control: getting motors to do what you want them to.

What you want to control \( \neq \) what you can control

For DC motors: speed voltage

emf: electromagnetic force

\( \mathbb{V} \) is a voltage generated by the rotor windings cutting the magnetic field.

winding's resistance: R

back emf
Controlling speed with voltage

- The back emf depends only on the motor speed.
- The motor’s torque depends only on the current, \( I \).

\[ e = k_e \omega \]
\[ \tau = k_t I \]

DC motor model

\[ e = IR + e \]

\[ V = \frac{IR}{k_e} + k_e \omega \]

\[ \omega = -\frac{R}{k_e} \tau + \frac{V}{k_e} \]

Speed is proportional to voltage.

speed vs. torque at a fixed voltage

The linear mechanical power \( P_m = F \cdot v \)

Rotational version of \( P_m = \tau \cdot \omega \)

Comp 417
Motor specs

Back to control

Basic input / output relationship:

We can control the voltage applied $V$.

We want a particular motor speed $\omega$.

How to change the voltage?

$V$ is usually controlled via PWM — "pulse width modulation"
PWM

- PWM = "pulse width modulation"

- Duty cycle:
  - The ratio of the "On time" and the "Off time" in one cycle
  - Determines the fractional amount of full power delivered to the motor

Open-loop vs. Close-loop Control

Open-loop Control:
desired speed $\omega_d$ → Controller → $V(t)$ → Motor → $\omega_a$

If desired speed $\omega_d \neq$ actual speed $\omega_a$, So what?

Closed-loop Control: using feedback
desired $\omega_d$ → compute $V$ from the current error $\omega_d - \omega_a$ → PID controller → $V$ → Motor → $\omega_a$

PID Controller

PID control: Proportional / Integral / Derivative control

$V = K_p (\omega_d - \omega_a) + K_i \int (\omega_d - \omega_a) \, dt + K_d \frac{d\omega}{dt}$

$V = K_p \left( e + K_i \int e + K_d \frac{de}{dt} \right)$
Note: sampling is a ubiquitous issue.

How many measurements do we need to measure some signal.

Vision (picture), audio, 3D laser-based sensing, motor parameters, ….

Proper sampling:
- Can reconstruct the analog signal from the samples

Aliasing:
- The higher frequency component that appears to be a lower one is called an alias for the lower frequency
- Aliasing: the frequency of the sampled data is different from the frequency of the continuous signal

If a 90 cycle/second sine wave being sampled at 1000 samples/second, in another word, there are 11.1 samples taken over each complete cycle of the sinusoid.

Aliasing occurs when the frequency of the analog sine wave is greater than the Nyquist frequency (one-half of the sampling rate); in other words, the sampling frequency is not fast enough. Aliasing misrepresents the information, so the original signal cannot be reconstructed properly from the samples.

Definitions:
- Given a signal bandlimited to $f_{BL}$, must sample at greater than $2f_{BL}$ to preserve information. The value $2f_{BL}$ is called Nyquist rate (of sampling for a given $f_{BL}$).
- Given sampling rate $f_s$, the highest frequency in the signal must be less than $f_s/2$ if samples are to preserve all the information. The value $f_{BL} = f_s/2$ is called the Nyquist frequency (associated with a fixed sample frequency).

For a closed-loop control system, a typical choice for the sampling interval $T$ based on rise time is $1/5$ th or $1/10$ th of the rise time. (i.e., 5 to 10 samples for rise time)
Electric Motors - Power rating:
electric motors offer the horsepower required to drive a machine, which is typically referred to as electric motor load.

The most common equation for power based electric motors on torque and rotational speed is:
\[ \text{hp} = \frac{\text{torque} \times \text{rpm}}{5,250}. \]

AC/DC motors
- AC motor 1. An outside stationary stator having coils supplied with AC current to produce a rotating magnetic field 2. inside rotor attached to the output shaft, given a torque by the rotating field.
- DC motor: rotating armature in the form of an electromagnet. Rotary switch called a commutator reverses the direction of the electric current twice every cycle, to flow through the armature so that the poles of the electromagnet push and pull against the permanent magnets on the outside of the motor. As the poles of the armature electromagnet pass the poles of the permanent magnets, the commutator reverses the polarity of the armature electromagnet. During switching polarity, inertia keeps the classical motor going in the proper direction.

DC motors
- The brushed DC motor is one of the earliest motor designs. Today, it is the motor of choice in the majority of variable speed and torque control applications.
Brushed DC

- **Advantages**: Cheap and easy to control, design.
- **Design**: Permanent magnetic field is created in the **stator** by either Permanent magnets or Electro-magnetic windings
- Permanent magnets: the motor is said to be a "permanent magnet DC motor" (PMDC).
- Electromagnetic windings: the motor is often said to be a "shunt wound DC motor" (SWDC).
- PMDC motor is the motor of choice for applications involving fractional horsepower DC motors, as well as most applications up to about three horsepower, due to cost & reliability.