EE 451 - Practical Aspects of Motor Control

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December 13, 2015
Actuation – DC Motors & Control

Introduction
Motor Selection
DC Motor Control
1. Calculate: Required torque and RPM to meet functional requirement
2. Research: DC motor manufacturers to determine the motors that satisfy these criteria
3. Compare: Published specifications of motors to determine optimal motor selection
4. Choose one or several motors for prototyping and testing.
Design Issues

- Motor requirements:
  - Required joint torque (Nm) - $\tau(t)$
  - Required gear peak torque (Nm) - $\tau_g$
  - Required max input peak speed (rpm) - $n_{in}$

- Supplied voltage

- Physical constraints – Motor size
Design Constraints- Ex

- Accelerating a 6.8 kg, two-wheel diff. robot with wheel diameters 9.7 cm at a rate of 91 cm/sec^2.
- Top speed - Around 1.2 m/sec
- Supplied voltage = 12 V
- Motor size - Diameter around 5 cm, length around 10 cm
Torque Calculation

- \( \text{Force}_{\text{total}} = ma \rightarrow F_{\text{total}} = 6.8 \times 0.91 = 6.1 \text{ N} \)
- Two wheels \( \rightarrow 3.1 \text{ N/wheel} \)
- Torque - \( F \times r = 3.1 \times 0.049 \approx 0.15 \text{ Nm} \approx 150 \text{ mNm} \)
Required Wheel RPM

- Wheel diameter 9.7cm $\rightarrow$ Wheel perimeter $\pi \times 0.097 = 0.305$ m
- Required speed: 1.2 m/sec $\rightarrow$ 3.93 rps $\rightarrow \approx 236$ rpm
- Torque \( \approx 150 \text{ mNm} \)
- Required speed: \( \approx 236 \text{ rpm} \)
Actuation Issues

- DC Motor selection
- Gearbox selection
- DC motor control
Motor + Gearbox (Drive Train) Model for a Single Joint
Use Motor with Gear

- Output Torque (Transmission Shaft) = Input Torque (Motor) × Gear Reduction × Transmission Efficiency
Design Issues

- **Ultimate goal**
  - Required joint torque (Nm) - $\tau(t)$
  - Required gear peak torque (Nm) - $\tau_g$
  - Required max input peak speed (rpm) - $n_{in}$

- **Motor + gear requirements**
  - Required motor torque (Nm) - $\tau_m$
  - Required motor peak torque (Nm) - $\tau_p$
  - Required motor peak speed (rpm) - $n_p$
Two motor groups - brushed and brushless DC motors.

- Nominal torque $T_m$ - Maximum continuous torque
- The stall torque $T_{mmax}$: The peak torque of the motor.
- Maximum permissible speed $N_{mmax}$
  - Commutation system
  - Mechanical imbalance which shortens the service life of the bearings
Motor Selection Criteria

- **Nominal torque limit**: The root mean square (RMS) value of the required motor torque $\leq$ Nominal torque of the motor $T_m$

- **Required peak torque** $\tau_p \leq$ Stall torque $T_{m}^{max}$

- **Required peak speed** $n_p \leq$ Maximum permissible speed $N_{m}^{max}$

- Motor technical datasheet
Gearbox Parameters

- Maximum rated torque of the gearbox $T_g$
- Allowable peak torque $T_g^{\text{max}}$
- Maximum permissible input speed $N_g^{\text{max}}$
Gearbox Selection

- RMC Torque value
  - A measure of the accumulated fatigue on a structural component
  - Reflects typical endurance curves of steel and aluminium
  - Gearbox lifetime

- RMC Torque value $\tau_{rmc} \leq$ Maximum rated torque of the gearbox $T_g$

- Required peak torque $\tau_g \leq T_g^{\text{max}}$

- Required maximum input peak speed $n_{\text{in}} \leq$ Maximum permissible gearbox input speed $N_g^{\text{max}}$
Simple Calculations

- $E_{\text{drop}} = I_{\text{no load}} R_{\text{armature}}$ (Free running motor at a given voltage)
- $E_{\text{battery}}$ – Given
- $E_{\text{battery}} = K_E \omega + E_{\text{drop}} \rightarrow \omega$
- Output shaft speed $\omega = \frac{\omega}{\text{Transmission ratio}}$
Pulse Width Modulation (PWM)

- $T_H$ – Time that a signal is at high state
- $T$ – Period
- Duty cycle = $\frac{T_H}{T} \times 100$
PWM & Control

- PID cycle time (0.1 sec)
- Motor speed (30 rpm)
- Encoder resolution (500 counts/rev)
- PWM frequency (1kHz)
PWM Circuit

![PWM Circuit Diagram]

- IC1: 74AC14 Hex (six) Schmitt-Trigger Inverters
- R2: 10 kΩ variable
- D1: 1N914
- D2
- C1: 0.1 μF
- C2: 0.1 μF

Variable Duty Cycle Square Wave
H-Bridge

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<th>S3</th>
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<tr>
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<td>0</td>
<td>1</td>
<td>0</td>
<td>Motor brakes</td>
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H-Bridge: Operation Modes
H-Bridge: MOSFET H-Bridge
H-Bridge Motor Circuit
Control System

Diagram:

- Processor
- H-Bridge Circuit
- DC Motor
- Encoder
PID Control

- **Error term:**
  - The difference btw input and output of the system
  - Measured in terms of a number of encoder counts per unit time.

- **Proportional gain:** $K_p$ multiplied by error

- **Integral gain**
  - $K_I$ times error term and added to previous integral term
  - Provides response to accumulated error

- **Derivative gain:**
  - $K_d$ times the difference between the previous error and the current error
  - Responds to change in error from one PID cycle to the next.
Watch out for!

- Integral windup
- PWM term overflow
- PID variable overflow
PID Tuning - Brute Force

- How to determine coefficients?
- What is the response?
PID Tuning - Brute Force

- For a variety of $K_p$, $K_D$, $K_I$ values
- Store the feedback speed value into an array element for the first 20 PID executions. (2 seconds)
- Change the set speed from 0 to 60% of the motors maximum speed.
- After 2 seconds, stop the motor and print the array data
- Choose the best response