ELCT3024 Project Description

April 5, 2024

Application of DC Motor Drive in Elevator System In this project, you will design a scaled version of a high-precision DC motor drive system tailored for an elevator in a skyscraper corporate complex, like the one in Fig. 1. The objective is to achieve precise *speed control* of the DC motor, to ensure smooth elevator operation and provide an appropriate level of comfort for its users.

Figure 1: Elevator in a skyscraper corporate complex (image © Nikada/iStockPhoto)

Project Scope Overview

1. **Control System Design**. Develop a detailed design of the DC motor speed control system suitable for elevator applications, considering motor specifications and performance requirements.

2. **Control Strategy**. Analyse differences between open-loop and closed-loop speed control strategies. Design and implement a closed-loop speed control system, enabling accurate regulation and compliance with transient performance specifications.

3. **Simulation and Testing**. Utilize simulation tools to validate the performance of the control system. Conduct practical testing on a scaled prototype to verify functionality and performance.

4. **Documentation and Analysis**. Document the design process, controller design strategy, and test results comprehensively. Perform a detailed analysis of the system's performance, highlighting strengths, limitations, and areas for improvement.

Project Deliverables

- Detailed design report outlining the DC motor drive system specifications, and control strategy.
- Simulation results demonstrating how the control system's performance meets the design specifications.
- Prototype demonstration showcasing the dc motor control system's functionality.
- Final presentation summarizing the project objectives, methodologies, and outcomes.

System Specifications

- Drive system includes a brushed DC motor with integrated gearbox (GB).
- The DC motor drive is supplied by a battery cascaded to a DC-DC converter.
  - The DC-DC converter is used to change the input voltage to the DC motor, and to change rotating direction of the DC motor if an H-bridge is adopted.
  - In this application, the interest is to characterise the behaviour of the DC motor drive system when rotating only in one direction.
  - In this application, it is necessary to control the rotational speed of the motor (spinning in one direction only).

Schematic The following draft schematic is given for guidance purposes.

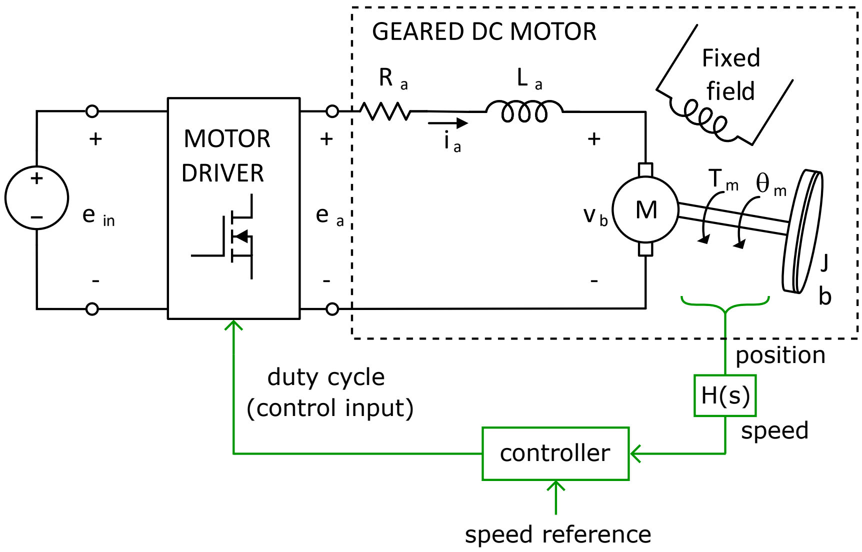

Figure 2: DC motor drive system (**black: plant**, **green: control**)

System Parameters The drive system is a scaled version of the actual configuration. The scaled version is powered by a 12 V battery (e_{in}) and includes a 6 V brushed DC geared motor. The geared motor is a the Polou 4824:

- 34:1 Metal Gearmotor 25Dx67L mm LP 6V with 48 CPR Encoder

Motor Type	Rated Voltage	Pololu Item #	Gear Ratio	Typical No Load		At Maximum Efficiency					Max Power	Stall Extrapolation[2]		Graph Page
				Speed	Current	Speed	Torque	Current	Output	Efficiency		Torque	Current	
			:1	RPM (±20%)	mA (±50%)	RPM	kg·mm	A	W	%	W	kg·mm	A	
Low-Power (LP 6V)	6 V	4820 [1]	1	6200	100 w/o encoder	-	-	-	-	-	2.1	1.5	2.0	
		1581, 4821	4.4	1300		1100	0.82	0.32	0.94	49	2.1	6.3		6
		1582, 4822	9.68	630		490	2.0	0.38	1.0	44	1.9	13		7
		1583, 4823	20.4	290		240	3.6	0.34	0.91	44	1.9	25		8
		1584, 4824	34.01	180		150	5.2	0.31	0.78	42	1.7	39		9
		1585, 4825	46.85	130		110	6.9	0.33	0.75	38	1.5	48		10
		1586, 4826	74.83	80	120 with encoder	66	11	0.33	0.72	36	1.5	75		11
		1587, 4827	98.78	61		50	14	0.36	0.73	34	1.4	91		12
		1588, 4828	171.79	35		29	21	0.33	0.63	31	1.2	140		13
		1589, 4829	226.76	27		22	24	0.31	0.55	30	1.1	170		14
		1590, 4830	377.93	16		13	41	0.34	0.56	27	- [3]	250		15
		1591, 4831	498.87	12		- [4]	- [4]	- [4]	- [4]	- [4]	- [3]	310		16

Figure 3: Table from Polou 4824 geared DC motor datasheet

Physical parameters of the geared DC motor should be extracted from the datasheet values (at the rated voltage), or other method. The parameters have been preliminary estimated, however the correctness of these values is not warranted. Students are expected to critically assess these parameters, and confirm their correctness.

- $J = 0.0013\,\mathrm{kg\,m^2}$
  moment of inertia (DC motor rotor inertia plus gearbox mass inertia, without any load attached to the motor shaft)

- $b = 3.2848 \times 10^{-5}\,\mathrm{N\,m\,s}$
  viscous friction constant (could be estimated from no load current)

- $K_e = 0.318\,\frac{\mathrm{V\,s}}{\mathrm{rad}}$
  electromotive force constant

- $K_t = 0.318\,\frac{\mathrm{N\,m}}{\mathrm{A}}$
  torque constant (the assumption $K_e = K_t$ is made here, however in practice it may be $K_t < K_e$ due to losses and other nonlienarities)

- $R_a = 3\,\Omega$
  armature resistance (DC motor terminal resistance)

- $L_a = 380 \times 10^{-6}\,\mathrm{H}$
  armature inductance (DC motor terminal inductance)

Assessment This team project contributes 50 % towards the final result for this unit. The assessment for this project consists of:

- Individual assessment
  - Oral presentation and demonstration of the project (Week 14)
  - Evaluation of project log book of each team member (Week 13)
  - Peer assessment of each team member contribution to the project (Week 13)
- Team assessment
  - Project report to be submitted in iLearn by each team (end of Week 13)

Learning Outcomes This project will contribute to the following unit learning outcomes:

- Develop and use mathematical models of electrical/mechanical systems, with integrated control.
- Design feedback control systems using tools such as MATLAB/Simulink.
- Solve real problems and use appropriate computer based tools and laboratory instrumentation.
- Implement real-time control to physical systems using the Arduino control board.
- Collaborative work in teams and pear learning.
- Communication of technical concepts and results in written reports.

Indicative Progress Schedule An inidcative schedule of the weekly progress and milestones is reported below. These milestone deadlines may vary, depending on the team effort and issues encountered along the way.

- week 8: project introduction and real-time Arduino-hardware interfacing
- week 9: system modelling and analysis
- week 10: controller design (continuous time)
- week 11: controller design (discrete time) and hardware implementation
- week 12: controller tuning on the hardware and experimental results collection
- week 13: final hardware experiments and data collection wrap-up

Detailed Project Objectives

- Analyse and design a feedback control system to regulate the DC motor speed using estimated motor parameters::
  - Find DC motor drive system control-to-speed transfer function from datasheet (and estimated) DC motor constants
  - Verify accuracy of the derived transfer function
  - Design a closed-loop speed-control the DC motor speed in the continuous and discrete time domain
    - It is important do demonstrate sound understanding of controller design techniques: Root Locus, Frequency Ressponse, or preferably both.
  - Verify the effectiveness of the control systems designed by means of simulation

After completing the simulation part, each group will be provided with a hardware kit to implement a closed-loop speed control of the DC motor (Polou 4824).

- Implement a discrete-time feedback control system for a physical DC motor using Arduino Uno control board and MATLAB/Simulink (use provided DC motor).
- Estimate the transfer function parameters of the physical DC motor using system identification techniques (using provided Lab equipment)*. Students may make use of:
  - system identification techniques based on open-loop step response (Nise: *Control Systems* textbook).
  - MATLAB system identification toolbox.
- Tune the controller parameters so that the hardware setup performs conforming to specifications, and in reasonable accordance with previously derived simulation results.
- Verify the effectiveness of the control systems designed by means of experiments on the hardware.

*Note: this is a higher difficulty task, and it is required for targeting top marks for the Project assessment.

Control design specifications The closed-loop speed control system should meet the following requirements relating to transient specification, and steady-state error:

- Settling time of 0.3 s ± 20 %
- Overshoot less than 10 %
- Steady-state error less than 1 %

Hardware components: A box of hardware components will be provided to each Team. The box will contain common and project-specific components:

- Arduino Uno control board
- Breadboard and jumper wires
- Motor driver
- DC motor with quadrature encoder
- Other miscellaneous components

Revision History

Revision	Date	Author(s)	Description
0	April 5, 2024	LC, FT, RE	First release.