CONTROL SYSTEM DESIGN

ELE2038 • SIGNALS AND CONTROL

Instructions: Please, take into account the following instructions

(1) Study the marking rubric (it is available on the assignment page on Canvas). Each team member will receive an individual mark. Marks will be allocated based on your technical report and the interviews. You can use any method to solve this problem, but note that you do not need anything more than the syllabus of this module. If you use more advanced methods such as LQR, MPC, SMC, etc, during your interview you will need to be able to explain how these methods work.
(2) Read the document "how to write a good technical report," which is available on Canvas (go to Modules > Control: Materials)
(3) Prepare you report using the LaTeX template provided on Canvas. You can use a Word processor if you prefer, but your report needs to be formatted similar to the provided template: double column format, 10pt text, minimum margins of 0.95 inches. Note that with Word it will be significantly more difficult and time-consuming to write equations and the final result will, most likely, not be of the best possible quality. Handwritten reports will not be accepted.
(4) Compile your report into a single PDF file (you will not be able to upload `doc(x)` or other files).
(5) Each team needs to upload a single PDF file.
(6) The maximum length of your report should be eight A4 pages using the above template, excluding your collaboration report. You should try to keep the technical part of your report below six pages.
(7) Submit your report to Canvas before the deadline. If you experience any exceptional circumstances, contact the advisor of studies and submit an EC request.
(8) Do not forget to include a link into to your code (e.g., GitHub repository).
(9) Start by reading the assignment. Have a kick-off meeting to decide how you will work as a team, how the various tasks will be distributed, how you will share your code, and how everyone will be able to contribute to the report.

Groups: You have been allocated to a group of three students. You can find your team members on Canvas (Go to People > Control Groups). You should contact your team members as soon as this assignment is released. In the unfortunate case where you have contacted your colleagues twice (via Teams and by email), but they have not returned your messages, please contact me as soon as possible (but not later than two weeks after the commencement of the assignment) and so that you can be moved to another team.

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1. System Description

1.1. **System.** Consider the system shown in Figure 1.

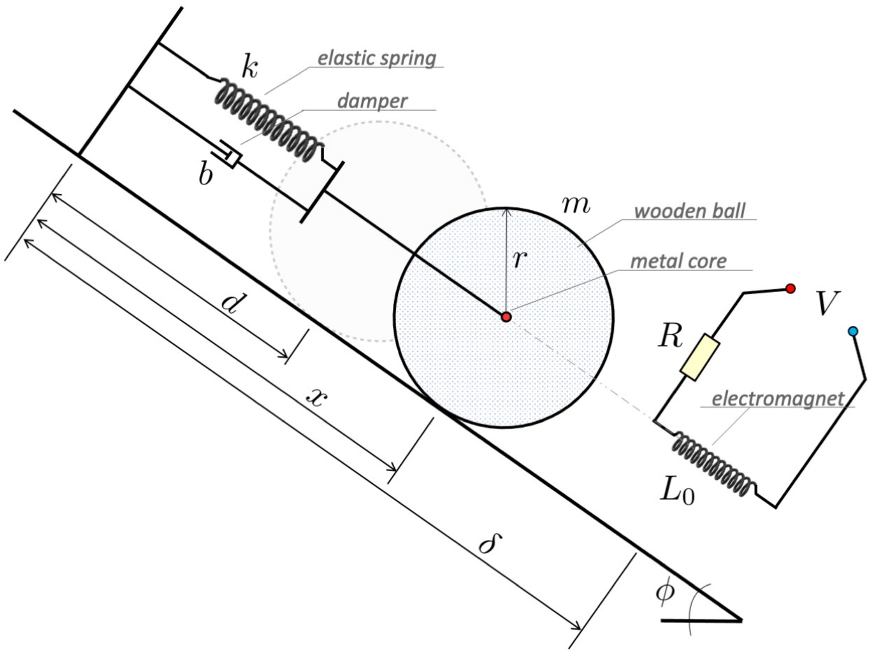

Figure 1. System of a wooden ball on an inclined plane. The ball can be attracted downwards by an electromagnet, which is controlled by the voltage V.

A wooden ball of total mass m and radius r is placed on an inclined plane, which is at an angle ϕ with respect to the horizontal plane as shown in Figure 1. The ball can roll on the inclined plane without sliding. The ball is connected to an elastic spring of stiffness k and a linear damper with viscous damping coefficient b. Let x denote the distance of the centre of the ball from the wall. When $x = d$, the spring is at its natural length and no restoring force is applied. The ball is considered to be approximately isotropic.

At the centre of the ball there is a metal core of very small radius which can be attracted by an electromagnet (which is essentially an inductor). The centre of the electromagnet is positioned at $x = \delta > d$. This inductor is connected in series with an Ohmic resistor of resistance R and a voltage V is applied to the circuit as shown in Figure 1. The nominal inductance of the inductor is L_0; however, as the ball approaches at a distance y from the centre of the inductor, its inductance increases and is given by

$$L = L_0 + L_1 \exp(-\alpha y), \tag{1}$$

where L_1 and α are given positive constants.

The electromagnet can exercise an attractive force to the metal core of the ball, whose magnitude is given by

$$F_{\mathrm{mag}} = c\frac{i^2}{y^2}, \tag{2}$$

where c is a positive constant, i is the current that runs through the circuit and y is the distance between the centre of the wooden ball and the centre of the electromagnet.

Lastly, the position of the ball, x, on the inclined plane can be measured with a sensor that can be modelled as a first-order system with time constant τ_m[1].

[1]You do not know the value of K_m, but you can make a reasonable assumption

1.2. **System parameters.** The following parameters have been estimated from data: $m = 462\,\mathrm{g}$, $g = 9.81\,\mathrm{m/s^2}$, $d = 42\,\mathrm{cm}$, $\delta = 65\,\mathrm{cm}$, $r = 12.3\,\mathrm{cm}$, $R = 2.2\,\mathrm{k\Omega}$, $L_0 = 125\,\mathrm{mH}$, $L_1 = 24.1\,\mathrm{mH}$, $\alpha = 1.2\,\mathrm{m}^{-1}$, $c = 6.811\,\frac{\mathrm{m^3\,g}}{\mathrm{A^2\,s^2}}$, $k = 1885\,\mathrm{N/m}$, $b = 10.4\,\mathrm{Ns/m}$, $\phi = 41°$, and $\tau_m = 30\,\mathrm{ms}$.

2. Assignment

You are a team of engineers who need to design a controller for the above system. The controller should be able to control the system at set points close to $x^{\mathrm{sp}} = 0.4\,\mathrm{m}$. The closed-loop system is expected to (i) be BIBO-stable, (ii) have zero offset, (iii) be properly tuned to avoid oscillations of large amplitude during the operation of the controlled system, and (iv) reject possible disturbances. You may want to impose additional requirements (e.g., related to stability margins, sensitivity of the closed-loop system to various noise signals, and more).

You should prepare a technical report with the proposed solution, with all involved steps (e.g., derivation of system equations, linearisation, controller design, stability analysis, stability margins, etc). Prove theoretically — where appropriate — that the closed-loop system has the desired properties, and provide simulation results. Do not forget that the original system is a *nonlinear* system[2]. You also need to discuss whether you believe that the proposed controller would work in practice.

Where necessary, you may use Python for your simulations. Do not include your code in the report. Instead, include a link to your code (e.g., a Python notebook or a GitHub repository).

[2] Although you will most likely linearise the nonlinear system, it is useful to see whether your controller works for the nonlinear system.

3. Planning, Organisation & Collaboration

In an appendix, include a collaboration report with a table where you will summarise your progress as recorded in your meeting minutes. An example is shown in Table 1 below.

Table 1. Summary of meeting minutes

Date	Attendees	Progress review	Conclusions / Actions
1 Feb	AB, CD, EF*	Draft Gantt chart	Kick off meeting. (Actions) A1.1. AB** to set up Overleaf document, A1.2. EF** to set up a private git repository and invite all team members, A1.3. CD** to create figure in LaTeX showing forces, A1.4. All** to apply Newton's 2nd law of motion to derive one ODE and check derivations at next meeting
7 Feb	AB, CD	A1.1, A1.3: completed, A1.2: not done, A1.4: AB and CD derived ODE; discrepancy identified in derivations	Identified and fixed mistake in derivations of ODEs. (Actions) A1.2 is now assigned to CD, A2.1. AB to contact EF who was absent today, A2.2. AB to model the electrical part of the system and write the dynamics in SSR, A2.2 CD to implement the Newtonian dynamics in Python, run simulations are report results at next meeting.
14 Feb	AB, CD	...	...
21 Feb	AB, CD	...	...

**Initials of attendees.*
***Make sure everyone leaves the meeting with a task and that tasks are assigned to specific people or to everyone (make this explicit)*

Furthermore, in your appendix include the following information:

(1) **Collaboration technologies.** How did your team collaborate on writing code? Did you use a source versioning system such as `git`? If so, provide a link.
(2) **Management.** How did your team distribute tasks and responsibilities, and how did you manage the involved tasks? Did you use an issue tracker? If yes, provide a link.
(3) **Individual contributions.** What did each member of the team contribute to this project? Be specific[3].
(4) **Additional information:** You may want to comment on things that went well: what were three (or more) ways you did well in functioning as a team? Likewise, what problems/challenges did you face interacting as a team? How did you address them?

4. Interviews

4.1. **Structure of the interviews.** Each group will attend a 15-minute interview after the submission of the report. Please note that the interview is a mandatory element of this assignment. Students should be prepared to answer questions on their assumptions, to justify their control design choices, and explain specific segments of their report and/or Python code.

[3]Although a part of your work will be a result of a joint effort, you should be able to clearly state the individual contributions of each member of the team.

The interview serves as a moderation tool; individual marks may be adjusted upwards or downwards from the group average based on demonstrated technical understanding.

4.2. **Expectations on contributions.** There is expectation that there will be a *balanced contribution* from all team members. This does not mean an equal number of lines of code or pages written. It means that (i) every member has actively participated in the synthesis of the design, and (ii) has an understanding of all parts of the design. For example, a student cannot claim during the interview that they focused only on modelling, and they cannot answer questions on the proposed controller. "Passive" contributions (e.g., only fixing typos, formatting, or writing the report) is insufficient for a passing grade in the technical marking criteria (C2, C3) and will also have a negative impact on criterion C4. Lastly, the names of all contributors must be mentioned on the first page of your report. Any student whose name is not listed as an author will automatically receive a mark of zero.