# CONTROL SYSTEM DESIGN

ELE2038 • SIGNALS AND CONTROL

**Deadline:** 17 April 2022, 17:00 (UK Time).

**Instructions:** Please, take into account the following instructions

(1) Read the document "how to write a good technical report," which is available on Canvas (go to Modules > Control: Materials)
(2) Prepare you report using the LaTeX template provided on Canvas (you can use your own LaTeX template if you prefer). You may use MS Word, LibreOffice Write or other similar word processing software, but 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.
(3) Compile your report into a single PDF file (you will not be able to upload `doc(x)` or other files).
(4) Each team needs to upload a single PDF file.
(5) The maximum length of your report should be 10 A4 pages using the above template. Realistically, you do not need to exceed 8 pages. In order not to exceed the page limit use the LaTeX template provided (a figure about the size of Figure 1, or even smaller, is perfectly legible).
(6) Submit your report to Canvas before the above deadline. If you experience any exceptional circumstances, contact the advisor of studies and submit an EC request.
(7) 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.

**Marking criteria:** This coursework is a glimpse into a typical day of a control engineer at work. The idea is that you need to design a control system for a client, and you need to prepare a technical report to convince them that your control system is well designed (it is stable, does not have offset, can reject disturbances, and so on). In particular, you need to convince them that it will work well in practice by providing a theoretical analysis and simulation results.

This coursework counts towards 20% of your total marks. Each team member will receive an individual mark based on their contributions. The following grading criteria will be used:

(1) Technical correctness [55%]: Correct application of control theory, unambiguous articulation of assumptions (e.g., you should not apply the final value theorem without checking whether its conditions are satisfied first), checking the conditions of the theorems being used; the main focus will be on the correctness of the methodology you will follow and less so on the correctness of your results.
(2) Discussion of results and convincingness [20%]: Discuss your results: avoid mathematical derivations with no discussion; likewise, if you decide to include simulation

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results, provide a discussion. Try to demonstrate as clearly as you can that the design you are proposing will work in practice.

(3) Quality of presentation and typesetting [20%]: clarity of presentation of your solutions, quality of typesetting of your equations, quality of illustrations, and organisation of the report. For full marks, follow the instructions in the document "how to write a good technical report."

(4) Collaboration [5%] quality of collaboration based on the evidence you will provide in your collaboration statement (e.g., use of appropriate technologies, time and task management and reporting). See Section 3 for details.

**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 on MS Teams 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.

**Teamwork:** Here are some things to keep in mind for your team to function well:

(1) **Have frequent meetings** to discuss your progress, brainstorm, and make a plan of actions. After each meeting it should be clear who is expected to do what.
(2) **Keep meeting minutes** so that you can go back and check what you discussed and what actions you agreed on
(3) **Use git** to develop code collaboratively (do not exchange code by email)
(4) **Use an issue tracker** to keep track of what needs to be done and who is working on what. GitHub has a good issue tracker.
(5) **Create and update a Gantt chart**
(6) **Listen** to what the other members of your team have to say

**Bibliographic references:** For this project you do not have to conduct a literature review. However, if you use any resources (books, papers, or online resources) you must cite them. Format your bibliographic references according to the IEEE standard.

**Questions?** Let us use Canvas as a discussion forum. Feel free to ask any questions you like about the coursework there (go to Discussions and hit that red "+Discussion" button).

# 1. System Description

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

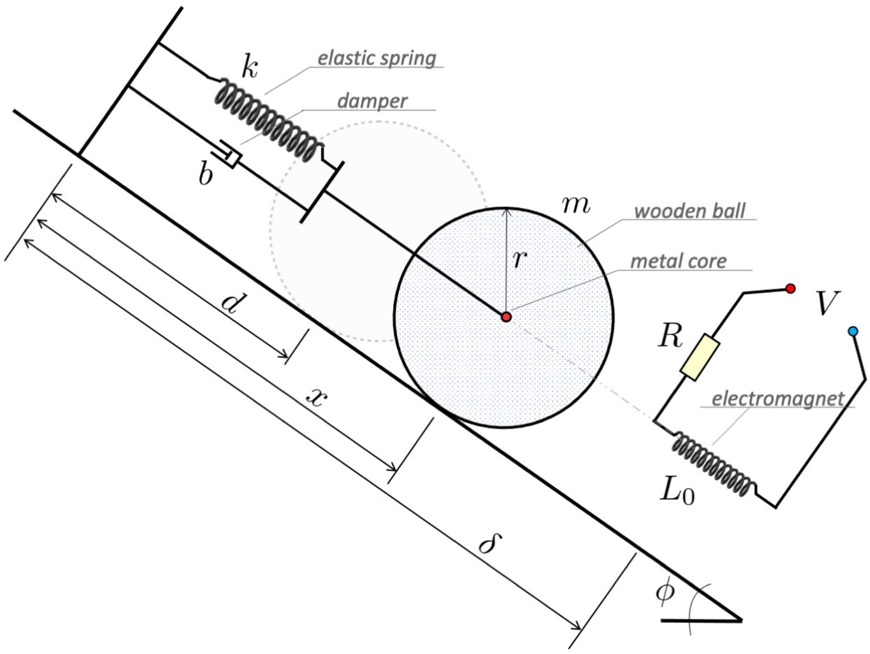


**Figure 1.** System of a wooden ball on an inclined plane. The ball can be attracted downwards by an electromagnet, which is controlled by the voltage $V$.

A wooden ball of total mass $m$ and radius $r$ is placed on an inclined plane, which is at an angle $\phi$ 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 $\alpha$ are given positive constants.

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

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

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 $\tau_m$[1].

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

1.2. **System parameters.** It is given that $m = 462\,\mathrm{g}$, $g = 9.81\,\mathrm{m/s^2}$, $d = 42\,\mathrm{cm}$, $\delta = 65\,\mathrm{cm}$, $r = 12.3\,\mathrm{cm}$, $R = 2.2\,\mathrm{k\Omega}$, $L_0 = 125\,\mathrm{mH}$, $L_1 = 24.1\,\mathrm{mH}$, $\alpha = 1.2\,\mathrm{m^{-1}}$, $c = 6.811\,\frac{\mathrm{m^3\,g}}{\mathrm{A^2\,s^2}}$, $k = 1885\,\mathrm{N/m}$, $b = 10.4\,\mathrm{Ns/m}$, $\phi = 41°$, 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 $x^{\mathrm{sp}} = 0.5\,\mathrm{m}$. 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 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, 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. You also need to discuss whether you believe that the proposed controller would work in practice.

Where necessary, you may use Python, MATLAB, or any other framework 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).

## 3. Planning, Organisation & Collaboration

Write a short collaboration report (one page at most should be sufficient) addresing the following questions:

(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) **Things that went well.** What are three (or more) ways you did well in functioning as a team?
(4) **Challenges.** What problems/challenges did you face interacting as a team? How did you address them?
(5) **Contributions.** What did each member of the team contribute to this project?