Systems Laboratory, Spring 2025

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notes

- welcome to the course!
- on this side of this document you will find notes that accompany the text typically visualized in class
- these notes are meant to convey the messages that are not displayed in the text on the side, and basically constitute what the teacher intends to say in class

Table of Contents I

notes

- this is the table of contents of this document; each section corresponds to a specific part of the course

Bureaucracy

notes

Motivations

notes

Why control systems?

https://www.youtube.com/watch?v=-7xvqQeoA8c

notes

- Control systems are everywhere: from self-driving cars to robotics and industrial automation.
- They help make systems more efficient, reliable, and safe.
- Mastering control theory opens doors to careers in aerospace, energy, biomedical engineering, and more.
- Control enables futuristic technologies like drone swarms, autonomous ships, and exoskeletons.
- It's not just equationsit's about solving real-world problems that impact society.

Systems laboratory:

notes

- the course shall give a foundation to build up the next understandings

Grading system

notes

Exam?

- pre-written (multiple choice)
- written (multiple choice & open)
- oral (10 minutes each)

notes

- Each exam type evaluates different skills: recall, reasoning, and verbal articulation.
- Oral exams help assess deep understanding and adaptability.
- Written exams are more structured and test problem-solving under constraints.

Pre-written Exam?

- 10 multiple choice questions extracted from a public database with solutions
- you pass if scoring at least 9 of them correctly
- if you know your stuff you won't have any problem in passing
- goal: discourage trying the exam for the sake of trying it

notes

- this is a well-tested strategy - and actually helpful for improving metacognition

"How will I be assessed?"

check the rubrics in moodle!

notes

- Rubrics help clarify expectations and grading criteria.
- Understanding them can improve performance by aligning effort with assessment goals.
- They also provide transparency in grading.

Extra points?

- up to 1 for active participation (see below)
- up to 1 for helping others via creating / improving shareable material (code, questions, drawings, etc. See below)
- up to 2 for the Capstone Project (see below)

notes

- Extra points encourage engagement beyond just exams.
- Contributing materials benefits both you and your peers.
- The Capstone Project allows applying knowledge in a real-world scenario.

Classroom contract

notes

Attendance?

- not mandatory (not even the labs)
- useful to learn
- what may be recorded will be recorded, and be made available asap

notes

- Flexibility allows self-paced learning.
- Attending live sessions offers opportunities for direct interaction and clarifications.
- Recordings are a useful resource for review.

Physical or digital?

- hybrid is possible, but we cannot make it the default option (so, valid when being sick / issues with public transport / etc)
- we may move to zoom some of the lectures

notes

- in case you need to take some lectures digitally, ask!

Interactions with the teacher?

- as informal as possible
- standing reference group meetings
- one-on-one meetings via `damiano.varagnolo@unipd.it`
- in clasee, often we'll do peer instructions

notes

- Open and informal discussions encourage engagement.
- Reference group meetings allow collective feedback and improvements.
- One-on-one meetings provide personalized guidance.

Interactions among students?

- as collaborative as possible
- form study groups!
- peer instructions = great way of meeting new people

notes

- let's see what peer instructions are

Peer instructions - what are they?

- purpose = be active
- algorithm = for each question:
  - first time, answer individually
  - then form groups, discuss, try to convince each other, but eventually answer individually
  - then I show the solution
  - after that you pose questions

notes

- this is how peer instructions work. If you want more information, please see the video in `https://youtu.be/wont2v_LZ1E?si=jZJuIxf4b4o-gwRD`

Peer instructions - how to answer

- if attending physically: "1 - 2 - 3 - . . . " with your fingers
- if attending digitally: "reactions" with zoom

ready for a demo?

notes

- depending on how you are participating you will give feedback in a different way

Question 1

Which of these effects:

- a: the height of the sun in the sky during the day
- b: the distance of the Earth from the sun
- c: how many hours the sun is up each day

are reasons for the seasons?

Potential answers:

I: **(wrong)** a + b
II: **(correct)** a + c
III: **(wrong)** b + c
IV: **(wrong)** a + b + c
V: **(wrong)** I do not know

notes

- see the associated solution(s), if compiled with that ones :)

Extra point for active participation?

Examples:

- be particularly proactive in answering questions
- asking questions that aid further understanding for the class
- any behavior that helps the class learn

How to: Damiano will say "you, good point! One Maggy point to you!" and you shall send an email with subject "Maggy point to me!" to `damiano.varagnolo@unipd.it`.
4 Maggy points = 1 extra point at the exam (max 1, fractions up to 1 will count too)

notes

- we want to reward active participation
- note: **up to 1** point

Extra point for helping others?

Goal = creating / improving shareable material, like:

- code
- questions (in the `IFAC94.sty` format)
- drawings or plots

How to: send things to Damiano (but let him know your plans, you'll get feedback!)

notes

- note: also here it is **up to 1** for helping others
- we want to reward active participation
- the IFAC style is here: `https://www.overleaf.com/read/qfkmmdgkwysx#92bd75`
- as licensing, shall be CC0 1.0 Universal, `https://creativecommons.org/publicdomain/zero/1.0/?ref=chooser-v1`

Example of material that helps learning

`https://leastsquaresapp.onrender.com/`

notes

- note how we want stuff that is interactive and that helps hands-on active learning

But where will the material be?

- everything in moodle
- be sure to check the handouts of the slides!

notes

- All essential materials are centralized in Moodle.
- Includes lecture slides, assignments, and additional readings.
- Regularly checking Moodle ensures you stay updated.

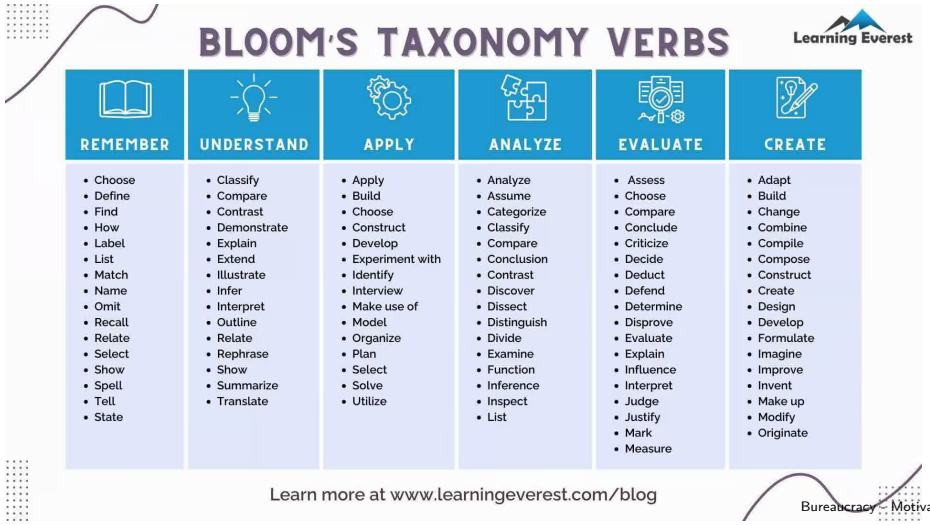
Overall approach on the course?

- focus on (relatively) few concepts
- on those, push for max conceptual understanding!
- very often, you will be pushed for a hands-on learning approach
- on other ILOs, you shall learn by yourself
- note: all cognitive aspects are important, from retrieval to creation

notes

- Deep understanding is prioritized over covering excessive topics.
- Emphasis on conceptual clarity ensures long-term retention.
- Encourages both analytical and creative thinking.

Again: this course will push for all the cognitive aspects there may be



notes

- Blooms taxonomy outlines different levels of learning.
- The course aims to move beyond memorization to application and creation.
- Understanding these levels can help students develop better study strategies.

Labs

notes

Labs what?

- not mandatory
- using both Matlab and python
- a hands-on occasion for learning

Based on:

- physical system: `https://github.com/Hansolini/Take-home-Maglev-lab/`
- simulators in python notebooks (`https://jupyter.org/`) and/or Matlab & Simulink

notes

- Labs provide hands-on experience to reinforce theoretical knowledge.
- Even if optional, they help in better understanding control systems.
- Active participation can make learning more engaging.

When and where?

- on Fridays, but not all of them (i.e., first 3 weeks of the course "no", then "one Friday yes, one Friday no", but "last three Fridays yes")
- we will need to do 2 turns (one in the morning, one in the afternoon)
- should be in Ue and Te

notes

- more information for the Labs will be available around March 15th

May I do the labs at home?

- yes, when working with simulators
- no, if working with Maggy and you don't have your own
- yes also if working with Maggy, if you have your own

notes

- more information for the Labs will be available around March 15th

How do I get Maggy?

interested in building one for your own?
absolutely feasible and relatively cheap

→ see the information in `https://github.com/Hansolini/Take-home-Maglev-lab/tree/main/physical_system/hardware`
(and anyway tell Damiano if so - ordering together means better prices)

notes

- depending on how many we order, we have different prices; especially for printing the PCBs

Shall I prepare some reports on the labs?

- no, but you are encouraged to answer the questions you'll find in the various lab assignments

notes

- each Labs will be associated with some notebook where there will be some small conceptual assignment to be done
- answering them means preparing for the exam

Which ILOs are associated to the labs?

(more detailed ILOs when we will actually do the labs!)

- demonstrate an ability to debug and troubleshoot control issues systematically
- collaborate effectively within a team to conduct experiments and document findings
- reflect on the challenges of real-world control implementation, including non-idealities like sensor noise, delays, and saturation

notes

- these are general ILOs, we will see the more detailed one every time we will have a lab session

May we use AI tools?

- yes please!
- especially use it to check your knowledge level

notes

- Feel free to use ChatGPT and alike as much as you wish.
- Strong suggestions: ask for tips in coding, and to explain code that you do not understand.
- Be careful if you find yourself doing mindless delegation.

Suggestion

install python & a LaTeX compiler asap

notes

- be proactive!
- the simplest may be to install miktek (for windows users) and anaconda - but ask ChatGPT how to do for your system

Capstone project

notes

How do I get these 2 extra points you were mentioning before?

- goal: make Maggy do some new things, and document the process
- assessment: the more clear the documentation and the fancier the new trick (or algorithm), the better
- can be a group work; the bigger the group the fancier stuff you shall develop

notes

- this is to promote you to push yourself

Examples of project

- make the magnet levitate with Maggy placed vertically
- implement some more advanced noise filtering technique
- get a recursive system identification filter work
- ...

Feel free to propose!

notes

- we are not limited to these ones of course

When shall I start doing the project?

- wait at least 1 month before starting even thinking at it!

notes

- has no sense to think now at this. Put a reminder in your calendar "start thinking whether to do a capstone project or not"

Will I get help implementing the project?

- yes, only though on the concepts and not on the coding - and for a limited amount of time!

notes

- the teachers have limited capacity, and you shall prove that you can do something new by yourself

How shall the report of the Capstone project be?

no requirements, only one indication:
think at how to simplify the life for a
developer that picks up your project

notes

- to be creative and be able to think at who comes next is an essential skill

Why do we do this in this way?

you shall learn how to learn new things by yourself

notes

- this is an essential skill too!!

How can I self-assess myself?

notes

How may I self-assess how ready I am for the exam?

For each of the questions in the slides and in the pre-oral test, besides knowing how to answer it, are you able to:

- define mathematically all the content units in the statement of the question?
- Make drawings that explain what these content units mean?
- Explain which role these content units play in the "control engineer workflow"?
- Make examples of automatic control situations where these content units would play some role?
- Explain which kind of mistakes one may do if a control engineer has not understood / heard about these content units? (This may not apply to all the content units in the course)
- Explain how these content units connects with the other ones in the course?

notes

- If you can confidently say "yes" to each of the questions above for each of the questions you will meet in the course, then very likely you will get a good grade at the exam. If you are not able to answer the first two questions above for some of the questions - especially the pre-oral ones, then you risk failing the exam
- A good way to self assess yourself is also to go through the slides of the course. There you may find the various 'content maps' (i.e., that tables that list, at the beginning of each module, what is being developed there, and what are the prerequisites of that specific part). If you can answer all the questions in the list above ("define mathematically . . . ") for all the concepts listed in such contents maps, then you are in a good spot. Note: the first two bullets above (defining mathematically + drawing explanations) are paramount and more important than the remaining bullets. Thus if you cannot answer these first two bullets then you are at risk of getting a bad grade or even fail. And of course the more bullets you can answer the better you may consider yourself prepared.
- If you need to prioritize because you don't have time to study everything, then we suggest to open the learning flow map in the FaceIt portal, and prioritize by going from the most central nodes (i.e., biggest and with most connections with other stuff) to the least connected ones.

How can I increase my metacognition?

- go through the "self-assessment sections" in the various slides in groups, using the handouts to check the correct questions
- make ChatGPT or alike interrogate you
- use FaceIt to get/generate new questions, and think at whether the concept map of the course is clear or not

notes

- imagine you're trying to learn how to play an instrument. If you just practice blindly without reflecting on what works, what doesn't, and how youre improving, progress will be slow. The same applies to learning control systems (or any subject). Metacognition (thinking about how you learn) helps you identify gaps in your understanding, refine your study strategies, and become a more efficient learner

The FaceIt portal

notes

https://faceittools.com/

notes

- this is an instrument to aid metacognition!
- to get a guide about how to use it, watch the video recorded in class about this instrument

Course structure

notes

In a nutshell

- continuous time modelling
- discretization
- stability
- filtering
- system identification
- control design
- Capstone Project

notes

- Overview of the key topics covered in the course
- Each topic builds upon the previous one

Note: course objectives ↦ course structure

objective: get the Intended Learning Outcomes

notes

- Learning activities designed to reinforce theoretical concepts
- Emphasis on hands-on and practical applications

(Macro) Intended Learning Outcomes

notes

Learning Outcomes: Continuous-Time Modeling

- **LO1:** analyze the behavior of continuous-time systems using ODEs, phase portraits, and state-space representations under varying initial conditions and inputs
- **LO2:** compute and interpret the impulse and forced responses of LTI systems based on the principles of superposition
- **LO3:** apply linearization techniques to approximate nonlinear dynamic systems near equilibrium points and understand the limitations of the operation

notes

- All this shall be read as "be able to . . . "
- Focus on mathematical tools for modeling dynamic systems
- Importance of state-space representations

Learning Outcomes: Stability Analysis

- **LO4:** evaluate the stability properties of equilibria in continuous and discrete-time systems using graphical criteria in the general case, and numerical criteria for the LTI systems case
- **LO5:** assess BIBO (bounded-input, bounded-output) stability of input-output relations for LTI systems using graphical criteria

notes

- All this shall be read as "be able to . . . "
- Connection between eigenvalues and stability
- Real-world applications of stability analysis

Learning Outcomes: Discrete-Time Modeling

- **LO6:** as LO1, LO2, LO3 but for discrete time systems
- **LO7:** discretize continuous-time systems using sampling techniques
- **LO8:** list and discuss the limitations that sampling has as an operation, plus which problems a practitioner may encounter when discretizing a continuous time system

notes

- All this shall be read as "be able to . . . "
- Trade-offs between continuous and discrete-time models
- Applications in digital control systems

Learning Outcomes: Filtering and Data Processing

- **LO9:** compare different definitions of noise reduction efficiency, and select the most appropriate one depending on the situation at hand
- **LO10:** recognize which signal smoothing needs a specific measurement system may have, and design and apply suitable types of filters for the situations encountered during the course

notes

- All this shall be read as "be able to . . . "
- Importance of noise reduction in control applications
- Practical implementation of filtering methods

Learning Outcomes: System Identification

- **LO11:** apply least squares estimation techniques to identify the parameters of dynamic models from sampled data
- **LO12:** recognize potential overfitting and underfitting problems by looking at the performance of the estimator on different parts of the dataset
- **LO13:** implement simple regularization techniques to robustify the system identification process

notes

- All this shall be read as "be able to . . . "
- System identification as a bridge between modeling and data
- Challenges in parameter estimation

Learning Outcomes: Control Algorithms

- **LO14:** design simple PID and MPC controllers for LTI systems and tune them towards meeting specified performance criteria
- **LO15:** compare the effectiveness of PID and MPC control strategies under varying operating conditions

notes

- All this shall be read as "be able to . . . "
- Fundamental trade-offs in control design
- Practical control implementation

Learning Outcomes: Capstone Project

- **LO16:** develop and implement a control solution for the maglev system, integrating modeling, stability analysis, filtering, identification, and control techniques

notes

- All this shall be read as "be able to . . . "
- Application of all previous concepts in a real-world project
- Encourages teamwork and independent problem-solving

BSc theses and internship projects

notes

Macroproject 1: autodocking

notes

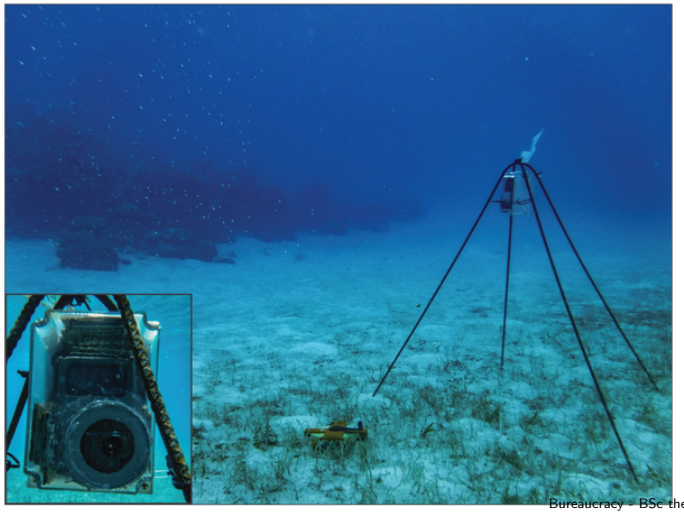
- watch the video in class to get an intuition about what this is about

Macroproject 2: Sonsub

notes

- watch the video in class to get an intuition about what this is about

Macroproject 3: marine wildlife monitoring



notes

- watch the video in class to get an intuition about what this is about

Macroproject 4: marine eDNA collection

notes

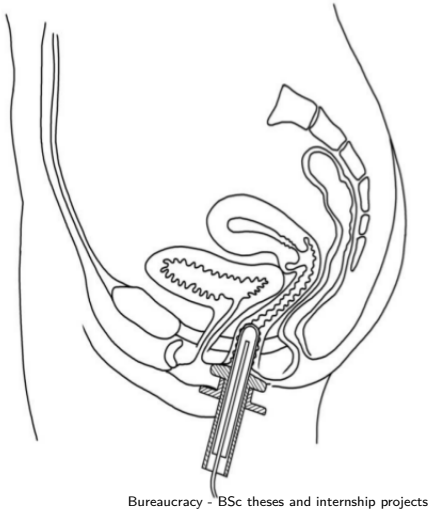
- watch the video in class to get an intuition about what this is about

Macroproject 5: learning analytics on FaceIt

notes

- watch the video in class to get an intuition about what this is about

Macroproject 6: female sexual rehab



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