FRT001F - Linear Systems

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Course Flier & Syllabus

Learning Outcomes

The course objective is to equip students with the working knowledge of modern linear systems theory. This course concerns linear operators and linear equations in systems theory. This course will be mathematically rigorous, and shall build upon concepts from linear algebra, ordinary differential equations, and feedback control theory. It provides the required tools for modelling, control and serves as a prerequisite for more advanced courses in control theory, robotics, and optimisation. While the course is quite classical, it is also increasingly becoming more modern and topical in the sense that it provides several new perspectives for interesting fields such as reinforcement learning, computer vision, game theory and other current areas of strong research activity.

Course Information

- **Course Credits:** 9 hp (ects credits)
- **Course Duration:** February 07, 2022 - April 11, 2022
- **Course Location:** Department Seminar Room
- **Course Link:** https://canvas.education.lu.se/courses/15428
- **Zoom Link:** https://lu-se.zoom.us/j/62991874041?pwd=T082Qi80bGVFSWRQbVQyeXlmRlVadz09
- **Class Timings:** Mondays 10:15AM - 12:00PM
- **Exercise Session Location:** KC 3S1 Classroom
- **Exercise Session Timings:** Thursdays 9:00AM - 11:00AM
- **Zoom Link:** https://lu-se.zoom.us/j/62888668632?pwd=b1JUZWowajl5Vy9aTUZWZy9BYUN3dz09

Topics Covered

The course will mostly cover all the standard required material and will also touch upon the most recent advancements in learning based control literature, thereby making the students be aware of the state-of-the-art concerned with the linear system theory. The tentative list of topics to be covered in this class will be as follows,

- Linear algebra review
- Solutions of linear differential equations, state space representations
- State transition matrix, time varying systems, the fundamental matrix.
- Controllability, observability and stability, realizations and minimality.
- Synthesis of linear controllers, pole placement, state feedback, observer design.
- Least Squares & Adjoint Systems, LQR, Hardness of Learning Linear Systems

Class Schedule With Topics

Every class session in the start of the week will be followed by an exercise session 3 days later where students are expected to actively participate and solve exercise problems.

DATE	DAY	TOPIC
February 07, 2022	Monday	Course Introduction, Review of Linear Algebra
February 10, 2022	Thursday	Exercise Session - 1
February 14, 2022	Monday	State Space, Linearisation, Solutions to LTI, LTV & LTP Systems
February 17, 2022	Thursday	Exercise Session - 2
February 21, 2022	Monday	Internal Stability, Lyapunov Stability Theorems
February 24, 2022	Thursday	Exercise Session - 3
February 28, 2022	Monday	Controllability, Observability, Gramians, Kalman-PBH Tests, Duality
March 03, 2022	Thursday	Exercise Session - 4
March 07, 2022	Monday	Canonical Forms, Kalman decomposition, Realization Theory
March 10, 2022	Thursday	Exercise Session - 5
March 14, 2022	Monday	Polynomial matrices, Hermite & Smith normal forms, Smith McMillan form
March 21, 2022	Monday	**Lecture skipped for encouraging CDC submission**
March 24, 2022	Thursday	Exercise Session - 6
March 28, 2022	Monday	State Feedback, State Estimation, The Separation Principle.
March 30, 2022	Wednesday	Least Squares & Adjoint Systems (Same Timing 10:15-12:00)
March 31, 2022	Thursday	Exercise Session - 7
April 04, 2022	Monday	LQR, Learning Linear Systems
April 07, 2022	Thursday	Exercise Session - 8 & Course Review
April 11, 2022	Monday	**Final Exam (Take-home 36 Hours) Posted at 6AM**
April 12, 2022	Tuesday	**Final Exam Due at 18:00**

Table 1: Class & Exercise Session Schedule

Hand-ins Schedule

Typically, students will have one hand-in every ten days. The hand-ins are due on the date specified at the start of the either lecture session or exercise session on that date.

DUE DATE	DAY	Hand-in Number
February 16, 2022	Thursday	Hand-in #1
February 28, 2022	Monday	Hand-in #2
March 7, 2022	Monday	Hand-in #3
March 14, 2022	Monday	Hand-in #4
March 28, 2022	Monday	Hand-in #5 (Will be heavy!)
April 04, 2022	Monday	Hand-in #6

Table 2: Hand-ins Schedule

Assessment

The student shall be assessed based on assignments/hand-ins, final examination and a healthy participation during the exercise sessions. The final course grading will be either **pass or fail**. Based on the assessment criteria shown in Table 3, the student will pass the course if she/he scores more than 50% overall through combination of the given three criteria.

Rules for Submitting Hand-ins

- Each hand-in will be worth 100 points and will be posted in the canvas website well ahead in advance.

CRITERIA	WEIGHT
Class Participation	5%
6 Hand-ins (Best 5 will be considered)	35%
1 Take-home (36 Hours) Final Exam	60%

Table 3: Assessment Criteria

- The deadline for submitting the hand-ins will be strict and no extensions shall be awarded unless otherwise for unavoidable circumstances, which the instructor has complete authority to make the decision.
- Students are strongly encouraged to submit their solutions to the hand-ins in a neatly typed LaTeX document with all supporting code attached to the same document. If typing is not possible, hand-written submissions will be considered as long as they are legibly written with neat presentation. As a helping guide, the students are welcome to use the following overleaf LaTeX template for submitting their individual solutions to the hand-ins. Overleaf link: https://www.overleaf.com/latex/templates/assignment-homework-solutions-template/nfjybpqbdrrn
- The students are encouraged to work on the hand-ins individually and the instructor shall be available via email throughout to aide them with any doubts and questions.
- It is strongly encouraged for the students to go environmental friendly by submitting their solutions to the hand-ins as pdf through email to the instructor instead of paper submission.

Final Exam Information

The final exam will be a take-home 36 hours exam worth 100 points. The students should strictly do the work individually without collaborating with each other and the instructor shall be available via email throughout to aide them with any doubts and questions. The tentative date of final exam is Monday, April 11, 2022. The exam shall be posted exactly at the 6AM in the canvas website on April 11, 2022 and will be due by the next day on Tuesday, April 12, 2022 at 18:00. The deadlines will be strict.

Main Textbook

The instructor will upload all the required lecture notes well in advance. The students are strongly encouraged to read the corresponding chapters before coming to the lecture in order to actively participate in the lecture. The main textbook for this course shall be

- J P Hespanha, *Linear Systems Theory*, 2nd edition, Princeton University Press, ISBN-13: 9780691179575
- Wilson J Rugh, *Linear System Theory*, 2nd edition, Prentice-Hall Inc., 1996, ISBN 0-13-441205-2.

Apart from the main textbook, the textbooks mentioned in the reference section namely [1] and [2] serve as great references too in general. For learning the linear algebra content, the students are welcome to use the references [3] and [4].

References

[1] T. Kailath, *Linear systems*, vol. 156. Prentice-Hall Englewood Cliffs, NJ, 1980.

[2] C. T. Chen, *Linear System Theory and Design - 4th Edition*. The Oxford University Press, 2013.

[3] G. Strang, *Introduction to linear algebra, 5th edition*. Wellesley-Cambridge Press Wellesley, MA, 2016.

[4] S. Boyd and L. Vandenberghe, *Introduction to applied linear algebra: vectors, matrices, and least squares*. Cambridge university press, 2018.