Linear Control & Estimation

Dept. of Bioengineering, CMC Vellore

Instructor: Sivakumar Balasubramanian
TA: Ann David
Office hours: SB: Thur 2:00-3:00PM, AD: Sat 10:00-11:00AM
Course Webpage: Please refer to this page for the up-to-date lecture notes and assignments.
https://siva82kb.github.io/teaching/lce/lce.html

What is the course about?

- Introduction to applied linear control and estimation.
- Focuses on linear algbera, state space representation and analysis, state feedback control and state estimation.
- First half of the course focuses on applied linear algebra, and the second half focuses on linear dynamical systems, control and estimation.

What to expect from the course?

- Important concepts in applied linear algebra
- State space representation and analysis of physical systems
- Design and analysis of linear state feedback controllers
- Design and analysis of linear state observers

Course Scoring and Grading

Course Activities

- **Homework assignment** 25%
  Assignments will be provided to the student by the instructor and will be due one week after the assignments are provided. Late submissions will not be evaluated. Assignments will include both regular paper-and-pencil and programming problems. The student is free to use any programming language to solve the problems. You are encourged to work in groups to solves these problems, and learn from each other. But write down your own solutions and do not copy.
- **Surprize Quiz** 15%
  These will be given throughout the duration of the course. They will be short 20-30 min open book, in-class quizes.
- **Mid-term** 15%
  Take home exam, due the next day. This can include both paper-and-pencil and programming problems. Students are not allowed to discuss among themselves in solving these problems.
- **Final** 45%
  Take home exam, due the two days after it is given. This can include both paper-and-pencil and programming problems. Students are not allowed to discuss among themselves in solving these problems.

Grading policy:No relative grading

A+ : $90 \leq$ Score; **A** : $80 \leq$ Score < 90; **B** : $70 \leq$ Score < 80; **C** : $60 \leq$ Score < 70; **D** : $50 \leq$ Score < 60; **E** : $40 \leq$ Score < 50; **F** : Score < 40;

Policy for academic dishonesty

There will be zero tolerance towards academic dishonesty, and anyone found carrying such activties will recieve an 'F' grade in the course.

References

1. G Strang, *Introduction to linear algebra.* Wellesley, MA: Wellesley-Cambridge Press, 1993.
2. CD Meyer, *Matrix analysis and applied linear algebra.* Siam; 2000 Jun 1.
3. S Boyd and L Vandenberghe, *Introduction to Applied Linear Algebra – Vectors, Matrices, and Least Squares* . Online book

Other Resources

1. Online course on *Linear Algebra* by G Straing at MIT OCW. Course Link
2. Online course on *Linear Dynamical Systems* by S Boyd. Course Link

Course Contents

1. Vectors
2. Matrices
3. Orthogonality
4. Matrix Inverses
5. Least squares methods
6. Eigenvectors and eigenvalues
7. Matrix norm, Positive definiteness
8. Singular Value Decomposition
9. Linear dynamical systems (LDS)
10. Modelling physical systems
11. Solution to LDS
12. Stability
13. Controllability
14. Observability
15. State feedback control
16. Linear observers
17. *Linear quadratic regulators*
18. *Kalman Filter*

Course content details

Vectors

1. Vectors; 2. Vector spaces; 3. Suspaces; 4. Linear independence; 5. Span and sponning sets; 6. Inner product; 7. Norm; 8. Angle between vectors; 9. Basis;

Matrices

1. Linear functions; 2. Matrices; 3. Matrix Operations; 4. Matrix Multiplication; 5. Properties of Matrix Multipilication; 6. Geometry of Linear Equations; 7. Gaussina Elimination; 8. Gauss-Jordan Method; 9. Row Echelon and Reduced Row Echelon Forms; 10. Homogenous systems; 11. Non-homogenous systems; 12. LU factorization; 13. Four fundamental subspace; 14. Matrix inverse

Orthogonality

1. Orthogonality; 2. Orthogonal subspaces; 3. Relationship between the four fundamental subspaces; 4. Gram-Schmidt orthogonalization; 5. QR factorization; 6. Orthogonal projection

Matrix Inverses

1. Representation of vectors in a basis; 2. Matrix Inverse; 3. Left Inverse; 4. Right Inverse; 5. Pseudo-inverse; 6. Inverses and QR factorization

Least squares methods

Eigenvectors and eigenvalues

Matrix norm, Positive definiteness

Singular Value Decomposition

Linear dynamical systems (LDS)

Modelling physical systems

Solution to LDS

Stability

Controllability

Observability

State feedback control

Linear observers

Linear quadratic regulators

Kalman Filter