

2025 Fall Linear Systems Syllabus

Reference materials

R. W. Randal, ‘Linear Operator Equations with Applications in Control and Signal Processing,’ IEEE Control Systems Magazine, April 2002, pp. 69-79.

Grading policy

1. Final exam: 40%
2. Midterm exam: 30%
3. Classes attendance: 20%
4. Homework assignments 10%

Contents

General Dynamics for Mechanical Graduates

Preface

This is a course designed for graduate freshmen of engineering college, instilling students in manage dynamics in computer-time and real-time fashions. The name of General Dynamics is analogy of General Physics or General Chemistry for students in the college of science. Likely, the purpose is to help students build an understanding and maneuvering of dynamics and lay the foundation for future learning and work in the fields of science, engineering or technology.

The courses about dynamics are required for students, in the journey of research and design, to explore the phenomena of nature or manage the behavior of engineering design. Each branch of dynamics is mostly concerned with mathematical modeling that infers governing (differential) equations from physical rules. However, there are other tasks awaiting to deep the understanding of nature or design of engineering, which involves several courses about general dynamics, such as Engineering analysis and Linear Systems in the first-year graduate courses. Therein Engineering Analysis applies functional analysis to dynamical analysis, and Linear Systems is about dynamic programming and real-time processing of dynamics. This book is written to overview these tasks, which is a systematic fusion of Engineering Analysis, Linear Systems, Classical Control, and System Dynamics especially for engineering graduates whose theses or future jobs relate to dynamics.

As we know, merely a small set of differential equations has meaningful solutions. Therefore, this book comprises weekly monographs presenting a set of typical dynamics, from which most of real dynamics are extended or combined. After deep learning of these monographs, the readers can have a bag of tricks on their own dynamics under concern or design. Specifically, these tricks include matrix algebra and functional analysis especially for dynamics analysis and processing. Students are no need of taking a series of courses for those details therein. The students ready to read this book are assumed to take courses about Differential Equations and Linear algebra in advance. With these tricks, four types of inference are implemented: deduction, induction,

construction and programming, to derive dynamic principles, lemmas and theorems.

#1 Population

- / The birth of natural functions
- / The state
- / Exponential functions
- / Finite-time unbounded example

#2 Single-degree vibration

- / The birth of sinusoidal functions
- / Introduction of State Space
- / Phase plane
- / State flow and state field

#3 RC circuit

- / Laplace transform
- / Transfer function
- / The birth of frequency domain
- / Bode plot

#4 RLC circuit

- / Canonical second-order dynamics
- / Lyapunov analysis
- / Second-order dynamics
- / Dynamic analogy for **Gradient descents** being the AI-algorithm kernel

#5 Van der pol oscillator: limit cycle

- / The first example of linear analysis for nonlinear dynamics
- / Time averaging
- / Describing functions
- / Extension of eigenvalue analysis: dynamic eigenvalue

#6 Heat conduction

- / Infinite-dimensional linear dynamics
- / Parabolic and Hyperbolic dynamics
- / Introduction to functional analysis
- / Modal analysis
- / Galerkin transform
- / Galerkin-Laplace transform

/ Spatiotemporal transfer function

/ Lyapunov and Lasalle's analysis

#7 Wave equation

/ Laplacian operator

/ Eigenvalue vs Eigenvector

/ Mode shapes

/ Geometric isomorphism

/ Mass and stiffness operators

/ Hyperbolic dynamics is dynamic analogous to RLC circuit, while parabolic dynamics is to RC circuit

/ Atomic structure

/ Matrix mechanics of Werner Heisenberg versus matter wave of Erwin Schrödinger

/ Hilbert space

#8 Virtual sources

/ The second example of linear analysis for nonlinear dynamics

/ Temporal Inhomogeneity: RC circuit

/ Spatial Inhomogeneity: heat conduction

/ Green theorems

#9 Pendulum

/ The third example of linear analysis for nonlinear dynamics

/ Mean flow and perturbation

/ Bifurcation analysis

/ Flow turbulence

#10 Operation Amplifier

/ The first example of feedback dynamics

#11 Thermoacoustics

/ The second example of feedback dynamics

#12 Thermal inertia

/ Dynamics analogy vs system dynamics

/ The third example of feedback dynamics

#13 State-state realizations of a transfer function

/ Canonical forms

- / State flow vs state field
- / Two-side convolution principle
- / Full-information principle
- / Stability: Lyapunov equation

14 **Luenberger observer**

- / State observer
- / Kalman filter

15 **Controllability and observability**

- / Definitions
- / Duality
- / Schur Complement
- / Pole-zero cancellation

16 **GD-Luenberger observer**

- / State-input observer
- / AI-based Luenberger observer

Appendix: Hilbert space