System Dynamics & Control

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Instructor Information

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Course Description

- **Description**: Mathematical modeling of dynamics systems with mechanical, hydraulic, thermal and/or electrical elements. Analysis including linearization, transient and frequency response, and stability. Design and analysis of linear feedback control systems using time and frequency domain techniques.
- **Prerequisite**: MATH 2403, MATH 2413 or MATH 24X3 and Dynamics
# Textbooks


**Recommended Texts:**


# Evaluation

- **Quizzes (37%)**
  - 5/semester, 20 minutes long
  - Pop Quizzes
- **1 Midterm (23%)**
- **Final Examination (35%)**
- **Computer Assignments (5-10%)**
### Important Dates

- Scheduled Quizzes: 5/27, 6/8, 6/30, 7/13, 7/22
- Midterm: Monday June 20, 2005
- Final Project: Friday July 29, 2005
- Final Exam: Monday August 1, 2005

### Academic Honesty

All items in the Honor Code under the topic of Academic Misconduct apply to this class. In particular, the following items are considered to be *cheating*:

- Submission of an assignment that is copied from another student
- Copying from another student's paper during an exam
- Alteration of graded tests submitted for regarding
- Academic misconduct will be reported to the Vice President for Student Affairs.
Course Topics

- Introduction to Modeling and Control
- Laplace Transform
- Modeling of Mechanical, Electrical, Fluid, Thermal and Mixed Systems
- Vibration Analysis
- Feedback System Design & Analysis
- Root-Locus
- Frequency Domain Control Design & Analysis

Automatic Control

- Control Systems are an integral part of a modern society. Many devices ranging from home appliances to automobiles to sophisticated aerospace systems use some form of feedback control.
- Control Systems are not limited to “man-made” technologies. Biological species cannot function and survive without feedback control, e.g., regulating temperature, hormones, heart-rate, motor control, etc.
- Micro-processors are a vital component of most modern control systems and have changed the way control systems are built.
Brief History of Automatic Control

- Water Clock (ancient times): Automatic control of liquid level
- Drebbel’s Incubator (1620): Temperature control of a furnace used to heat an incubator

Brief History of Automatic Control: Fly-Ball Governor (FBG)

- FBG was used to regulate the speed of a steam engine by James Watt (1788)
Feedback controller automatically adjusts the input based on the sensed output in order to make the output to follow the desired output.

It is generally robust to modeling uncertainties and disturbances.

Two Main Approaches

Control theory has been approached from two main directions:

- Classical approach (1930): Transfer functions and frequency domain techniques
- Modern approach (1950): State models and time domain techniques
- Classical techniques are suited for SISO systems. Modern control was introduced to deal with large scale MIMO systems, mostly encountered in aerospace applications.
Coverage of This Course

- Mathematical Modeling of Dynamic Systems
- Design and analysis of Classical Control techniques based on Transfer Function models in the frequency domain.
- Computer simulation of control systems

Mathematical Modeling (MM)

- A mathematical model represent a physical system in terms of mathematical equations
- It is derived based on physical laws (e.g., Newton’s law, Hooke’s, circuit laws, etc.) in combination with experimental data.
- It quantifies the essential features and behavior of a physical system or process.
- It may be used for prediction, design modification and control.
Engineering Modeling Process

Example: Automobile
- Engine Design and Control
- Heat & Vibration Analysis
- Structural Analysis

Contemporary Applications

- Aerospace Industry
  - aircrafts, satellites, missiles
- Manufacturing & Robotics
  - NC machine tools, robots, automated assembly
- Automotive’s Industry
  - Anti-Lock Break Systems (ABS), active suspension
  - power-train (engine, transmission) control
- Biomedical Applications
  - artificial limbs, prosthetics
  - cardiovascular devices
Definition of System

**System**: An aggregation or assemblage of things so combined by man or nature to form an integral and complex whole.

From engineering point of view, a system is defined as an interconnection of many components or functional units that act together to perform a certain objective, e.g., automobile, machine tool, robot, aircraft, etc.

System Variables

To every system there corresponds two sets of variables:

\[ u \quad \rightarrow \quad System \quad \rightarrow \quad y \]

Input variables originate outside the system and are not affected by what happens in the system.

Output variables are the internal variables that are used to monitor or regulate the system. They result from the interaction of the system with its environment and are influenced by the input variables.
Static vs. Dynamic Systems

A system is said to be **static** if its output at time $t$, $y(t)$, is a function of the input at time $t$, $u(t)$. In another words, a change in input causes an instantaneous change in output.

**Examples:**
- Gear train
- Four-bar linkage
- Transformer

Dynamic Systems

A system is said to be **dynamic** if its current output may depend on the past history as well as the present values of the input variables. Mathematically,

*Example: Automobile*
Linear Automobile Motion

Assuming traction force $\propto$ throttle position, $F=ku_1$

Newton’s 2nd law: $F=ku=Ma$ or

$$Md\frac{dv}{dt}=ku$$

After integration,

$$v(t) = v(0) + \frac{k}{M} \int_{0}^{t} u(\tau) d\tau$$

- $v(t)$ depends on the history of the input

Steering Dynamics
Power Steering Dynamics

- For large scale analysis of power steering dynamics may be ignored
- It may be needed for design and analysis of the power steering unit itself

Liquid Tank Example

Rate of Change of Liquid Volume = net flowrate

\[ A \frac{dh}{dt} = u - q_o \quad \Rightarrow \quad q_o = \frac{1}{R} h \]

- \( R \) is the flow resistance
- \( u \to h \) relation is given by a differential equation:

\[ \dot{h} + ah = bu \]

where \( a = 1/AR \) and \( b = 1/A \). It can be shown that \( h(t) \) in terms of \( u(t) \) can be expressed as

\[ h(t) = e^{-at}[h(0) + \int_0^t e^{as}u(\tau)d\tau] \]

- \( h(t) \) depends on the history of the input
### Mathematical Classification of Dynamic Systems: Linear vs. Nonlinear

- In this course we consider single input single output dynamic systems whose input-output relationship governed by an ordinary ordinary differential equation.

- **Linear ODE:**
  \[
  y + \dot{y} = u \\
  \ddot{y} + 5\dot{y} + 10y = u + \dot{u}
  \]

- **Nonlinear ODE:**
  \[
  \dot{y} + \sin y = u \\
  \ddot{y} + y\dot{y} + 10y^2 = u
  \]

Laplace Transform technique is a powerful tool for solving linear (constant-coefficient) differential equations.