Lecture Notes

Fundamentals of Control Systems

Instructor: Assoc. Prof. Dr. Huynh Thai Hoang
Department of Automatic Control
Faculty of Electrical & Electronics Engineering
Ho Chi Minh City University of Technology
Email: hthoang@hcmut.edu.vn
   huynhthaihoang@yahoo.com
Homepage: www4.hcmut.edu.vn/~hthoang/
Course objectives

- This course is about the analysis and design of control systems with emphasis on modeling, state variable representation, computer solutions, modern design principles.
Course outline

- Chapter 1: Introduction
- Chapter 2: Mathematical model of continuous systems
- Chapter 3: System dynamics
- Chapter 4: Analysis of system stability
- Chapter 5: Performances of control systems
- Chapter 6: Design of control systems
- Chapter 7: Mathematical model of continuous systems
- Chapter 8: Analysis of discrete control systems
- Chapter 9: Design of discrete control systems
Textbook


- Reference:
Grading

✦ Class participation: 10%
✦ Homework: 20%
✦ Midterm exam: 20%
✦ Project presentation: 20%
✦ Final exam: 30%
(*) After 2 weeks we tend to remember…

- 10% of what we read
- 20% of what we hear
- 30% of what we see

Chapter 1

INTRODUCTION
<table>
<thead>
<tr>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>What is control system?</td>
</tr>
<tr>
<td>Control principles</td>
</tr>
<tr>
<td>Components of control systems</td>
</tr>
<tr>
<td>Examples of control systems</td>
</tr>
<tr>
<td>Review of complex variables and Laplace transform</td>
</tr>
</tbody>
</table>
What is control system?
Exercise

Find examples of control systems?
Exercise

Explain how a control system works?
Example of a control process

- Objective is to keep moving at constant speed.
- Activities in controlling the car:
  1. reading velocimeter
  2. deciding to increase or decrease speed
  3. acting on the gas pedal
Definition of control concept

Control is the process of getting information, processing information and making decision, and acting on a system so that the system responds as desired.
Control loop

Desired speed

+/

Measured speed

Car speed
Components of a control system

\[ R(s) \rightarrow + \rightarrow E(s) \rightarrow C(s) \rightarrow G(s) \rightarrow Y(s) \]

\[ \downarrow \]

\[ Y_{fb}(s) \rightarrow H(s) \rightarrow Y_{fb}(s) \]

Notation:

- \( C(s) \): controller
- \( R(s) \): setpoint
- \( G(s) \): plant
- \( Y(s) \): controlled output
- \( H(s) \): sensor
- \( Y_{fb}(s) \): feedback signal
- \( E(s) \): control error
A simple level control system
Level control system in industry

LC: Level Controller
LT: Level Transmitter
LV: Level valve
Speed control of steam engine
Why control?

- Increase productivity
- Increase quality
- Increase economic benefit
Plants

★ Very diverse
★ Class of systems:
  ▶ Electrical
  ▶ Mechanical
  ▶ Thermal
  ▶ Fluid
  ▶ Chemistry
★ Real systems consist of different kind of basic systems.
Sensors

- Temperature sensor
- Position sensor
- Velocity sensor
- Acceleration sensor
- Distant sensor
- Flow sensor
- Level sensor
- Pressure sensor
- Force sensor
- Color sensor
- ...

© H. T. Hoang - www4.hcmut.edu.vn/~hthoang/
Controllers

- Mechanical controller

- Electrical controller
  - Analog controller
  - Digital controller
    - Microcontroller, DSP based control
    - Computer based control
    - Programmable Logic Controller (PLC)
Basic problems in control

- System Analysis
- System Design
- System Identification
Control schemes
Open-loop control

- Feedforward control
- Control without feedback information
Closed-loop control

- Feedback control
- Need to measure system output
Exercise

- Open-loop or closed-loop control system?
  - Plant?
  - Sensor?
  - Controller?
Feedback and feedforward control

This combined control scheme is widely used in industry
This control scheme is also referred as Cascade Control

Multi-loop control is widely used in industry
Decentralized control

Distributed control
Example: SCADA (Supervisory Control And Data Acquisition)

Hierachy control
Beer making process
Control system classification
Control system classification

- **Continuous system**: All signals in the system are continuous.
- **Discrete system**: There exists discrete signals in the system.
- **Linear system**: The system satisfies the superposition principle.
- **Nonlinear system**: The system don’t satisfies the superposition principle.
- **Time Invariant System**: Parameters of the system don’t change over time.
- **Time Varying System**: Parameters of the system change over time.
- **SISO system**: Single Input Single Output system
- **MIMO system**: Multi-Input Multi-Output system
History of control theory

- Classical control
- Modern control
- Intelligent control
Classical control

• Mathematic models used in analysis and design control systems are transfer functions.

• Features:
  ▶ Simple, easy to understand
  ▶ Advantages: easy to apply to analysis and design SISO linear time – invariant system.
  ▶ Frequency domain techniques.

• Analysis and design techniques:
  ▶ Root locus.
  ▶ Frequency response: Nyquist, Bode.

• Controllers:
  ▶ Lead – lag controllers
  ▶ PID (Proportional – Integral – Derivative)
Modern control

- Mathematical model used in analysis and design is mainly the state-space equation.

- Features:
  - Can be applied to nonlinear systems, time varying systems, multiple input- multiple output system.
  - Time domain technique

- Analysis and design method:
  - Optimal control.
  - Adaptive control.
  - Robust Control

- Controller:
  - State feedback controller
Intelligent control

- In principle, mathematic models are not required in design intelligent control system.

- Features:
  - Simulate / emulate biological intelligence system.
  - The controller is capable of processing uncertain information, learning, and handling large amounts of data.

- Intelligent control techniques:
  - Fuzzy Control
  - Neural Networks
  - Genetic Algorithm
  - …
Course objective

- The course Fundamental of Control Systems mainly presents the classic method for analysis and design of SISO linear time invariant systems.
- The knowledge gained from the course help student to analyze and design control systems at the executive level.
To be able to design the control system at the implementation level, in addition to knowledge of automatic control theory, a designer needs to master the relevant knowledge, such as:

- Circuits, Electronic circuits
- Industrial Measurement
- Digital system, Microprocessor
- Computer based control system, ...

6 December 2013
Graphic Symbols for Process Displays
The purpose of this standard is to establish a system of graphic symbols for process displays that are used by plant operators, engineers, etc., for process monitoring and control. The standard is intended to facilitate rapid comprehension by the users of the information that is conveyed through displays, and to establish uniformity of practice throughout the process industries. Resulting benefits are intended to be as follows:

- A decrease in operator errors
- A shortening of operator training
- Better communication of the intent of the control system designer to the system users
Symbol of process equipments

Pressure vessels

Centrifugal pump

Positive-displacement pump

Single-stage reciprocating compressor

Dual-stage reciprocating compressor

Rotary screw compressor

Motor-driven fan

6 December 2013  © H. T. Hoang - www4.hcmut.edu.vn/~hthoang/
Symbol of process equipments

Motor-driven axial compressor

Turbogenerator

Turbocompressor

Mixer

Conveyor belt

Shell-and-tube heat exchanger

Jacketed vessel
Symbol of valves

Valve (generic)  Globe valve  Butterfly valve  Ball valve

Gate valve  Saunders valve  Plug valve  Characterized ball valve

Pneumatic pinch valve  Diaphragm valve  Angle valve  Three-way valve

Check valve (generic)  Pressure regulator  Ball check valve  Pressure relief or safety valve

6 December 2013  © H. T. Hoang - www4.hcmut.edu.vn/~hthoang/
Symbol of control valves

Diaphragm

Electric motor

Solenoid

Piston

Diaphragm w/ hand jack

Electric motor w/ hand jack

Hand (manual)

Electro-hydraulic

Diaphragm w/ positioner

Piston w/ positioner

6 December 2013  © H. T. Hoang - www4.hcmut.edu.vn/~hthoang/
Symbol of electrical component (cont.)

- Fuse (600 V or less)
- Fuse (> 600 V)
- Circuit breaker (600 V or less)
- Circuit breaker (> 600 V)
- Disconnect
- Overload heater
- Draw-out circuit breaker (600 V or less)
- Draw-out circuit breaker (> 600 V)
- Lightning arrester
- Contactor
- Generator
- Motor
Symbol of electrical component (cont.)

Transformer
Transformer (alternate symbol)
Variable transformer
Variable transformer (alternate symbol)
Rectifier
Inverter
DC motor drive
AC motor drive
Symbol of measurement equipment and indicator

- Voltmeter
- Ammeter
- Wattmeter
- Frequency meter
- Phase meter
- VAR meter
- Lamp
- Kilowatt-hour meter
- KiloVAR-hour meter
- Current transformer
- Potential transformer
- Synchronization meter
### Symbol of power supply

<table>
<thead>
<tr>
<th>Hydraulic pump (fixed displacement)</th>
<th>Hydraulic pump (variable displacement)</th>
<th>Hydraulic motor (fixed displacement)</th>
<th>Hydraulic motor (variable displacement)</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Diagram" /></td>
<td><img src="image2.png" alt="Diagram" /></td>
<td><img src="image3.png" alt="Diagram" /></td>
<td><img src="image4.png" alt="Diagram" /></td>
</tr>
<tr>
<td>Air compressor (fixed displacement)</td>
<td>Air compressor (variable displacement)</td>
<td>Air motor (fixed displacement)</td>
<td>Air motor (variable displacement)</td>
</tr>
<tr>
<td><img src="image5.png" alt="Diagram" /></td>
<td><img src="image6.png" alt="Diagram" /></td>
<td><img src="image7.png" alt="Diagram" /></td>
<td><img src="image8.png" alt="Diagram" /></td>
</tr>
<tr>
<td>Cylinder, single-acting (ram)</td>
<td>Cylinder, double-acting</td>
<td>Cylinder, differential</td>
<td></td>
</tr>
</tbody>
</table>
Various spool valve "box" symbols

- Hand pump
- Solenoid actuator
- Pressure actuator
- Lever actuator
- Roller actuator
- Button actuator
- Return spring
- Pressure relief (shunt regulator)
- Pressure regulator (series)
- Hydraulic line
- Pneumatic line

© H. T. Hoang - www4.hcmut.edu.vn/~hthoang/
# Symbol of signals

<table>
<thead>
<tr>
<th>Process flow line</th>
<th>Instrument supply or process connection (impulse line)</th>
<th>Waveguide</th>
<th>Undefined</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pneumatic signal (continuous)</td>
<td>Pneumatic signal (discrete -- on/off)</td>
<td>Capillary tube</td>
<td>Hydraulic signal</td>
</tr>
<tr>
<td>Electric signal (continuous)</td>
<td>Electric signal (discrete -- on/off)</td>
<td>Data link (system internal)</td>
<td>Data link (between systems)</td>
</tr>
<tr>
<td>Mechanical link</td>
<td>Radio link</td>
<td>Sonic or other wave</td>
<td></td>
</tr>
</tbody>
</table>

6 December 2013  © H. T. Hoang - www4.hcmut.edu.vn/~hthoang/
Symbol of connection

- Generic
- Threaded
- Socket welded
- Flanged
- Heat/cool traced
- (direct) Welded
### Symbol of measurement equipment

<table>
<thead>
<tr>
<th></th>
<th>Field mounted</th>
<th>Main control panel front-mounted</th>
<th>Main control panel rear-mounted</th>
<th>Auxiliary control panel front-mounted</th>
<th>Auxiliary control panel rear-mounted</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Discrete instruments</strong></td>
<td><img src="image" alt="Symbol" /></td>
<td><img src="image" alt="Symbol" /></td>
<td><img src="image" alt="Symbol" /></td>
<td><img src="image" alt="Symbol" /></td>
<td><img src="image" alt="Symbol" /></td>
</tr>
<tr>
<td><strong>Shared instruments</strong></td>
<td><img src="image" alt="Symbol" /></td>
<td><img src="image" alt="Symbol" /></td>
<td><img src="image" alt="Symbol" /></td>
<td><img src="image" alt="Symbol" /></td>
<td><img src="image" alt="Symbol" /></td>
</tr>
<tr>
<td><strong>Computer function</strong></td>
<td><img src="image" alt="Symbol" /></td>
<td><img src="image" alt="Symbol" /></td>
<td><img src="image" alt="Symbol" /></td>
<td><img src="image" alt="Symbol" /></td>
<td><img src="image" alt="Symbol" /></td>
</tr>
<tr>
<td><strong>Logic</strong></td>
<td><img src="image" alt="Symbol" /></td>
<td><img src="image" alt="Symbol" /></td>
<td><img src="image" alt="Symbol" /></td>
<td><img src="image" alt="Symbol" /></td>
<td><img src="image" alt="Symbol" /></td>
</tr>
</tbody>
</table>
Symbol of level measurement equipment (cont.)

Bubbler (dip tube)

Capacitive

Tape-and-float

Hydrostatic

Hydrostatic (w/ seals)

Displacer

© H. T. Hoang - www4.hcmut.edu.vn/~hthoang/
Symbol of level measurement equipment (cont.)

- Radar (guided)
  - LT
  - Radar (vessel)

- Radar (non-contact)
  - LT
  - Radar (vessel)

- Ultrasonic
  - LT
  - US (vessel)

- Laser
  - LT
  - Laser (vessel)
Symbol of flow measurement equipment

- Orifice plate
- Pitot tube
- Averaging pitot tubes
- Flume
- Weir
- Turbine
- Target
- Positive displacement
- Vortex
- Coriolis
- Rotameter
Symbol of flow measurement equipment (cont.)

- Ultrasonic
- Magnetic
- Wedge
- V-cone
- Flow nozzle
- Venturi
- Generic
Symbol of function blocks

PID controllers
\[ \Delta \]
\[ \text{P I D} \]

PI controller
\[ \Delta \]
\[ K \int \frac{d}{dt} \]
\[ \text{P I} \]

D-PI controller
\[ \Delta \]
\[ \text{D} \]
\[ \text{P I} \]

PD-I controller
\[ \Delta \]
\[ \text{P D} \]
\[ \text{I} \]

Manual adjust
\[ A \]

Manual transfer
\[ T \]

Control valve
\[ \text{FCV} \]

Characterized control valve
\[ f(x) \]
Symbol of function blocks

- Automatic function
- Manual function
- Control valve w/ positioner
- Indicator

- Transmitter
- Time delay
- Summer
- Square root
- Characterizer

Analog (variable) signal

Discrete (on/off) signal
<table>
<thead>
<tr>
<th>Measured or initiating variable</th>
<th>First letter (4)</th>
<th>Modifier</th>
<th>Readout or passive function</th>
<th>Output function</th>
<th>Modifier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analysis (5, 19)</td>
<td>A</td>
<td></td>
<td>Alarm</td>
<td>User's Choice (1)</td>
<td>User's Choice (1)</td>
</tr>
<tr>
<td>Burner, Combustion</td>
<td>B</td>
<td></td>
<td>User's Choice (1)</td>
<td>Control (13)</td>
<td></td>
</tr>
<tr>
<td>User's Choice (1)</td>
<td>C</td>
<td></td>
<td>Glass, Viewing Device (9)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>User's Choice (1)</td>
<td>D</td>
<td>Differential (4)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voltage</td>
<td>E</td>
<td></td>
<td>Sensor (Primary Element)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow Rate</td>
<td>F</td>
<td>Ratio (Fraction) (4)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>User's Choice (1)</td>
<td>G</td>
<td></td>
<td>Glass, Viewing Device (9)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hand</td>
<td>H</td>
<td></td>
<td>Glass, Viewing Device (9)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Current (Electrical)</td>
<td>I</td>
<td></td>
<td>Glass, Viewing Device (9)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power</td>
<td>J</td>
<td>Scan (7)</td>
<td>Control Station (22)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time, Time Schedule</td>
<td>K</td>
<td>Time Rate of Change (4, 21)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level</td>
<td>L</td>
<td></td>
<td>Light (11)</td>
<td>Low (7, 15, 16)</td>
<td></td>
</tr>
<tr>
<td>User's Choice (1)</td>
<td>M</td>
<td>Momentary (4)</td>
<td></td>
<td>Middle, Intermediate (7, 15)</td>
<td></td>
</tr>
<tr>
<td>User's Choice (1)</td>
<td>N</td>
<td></td>
<td>User's Choice (1)</td>
<td>User's Choice (1)</td>
<td>User's Choice (1)</td>
</tr>
<tr>
<td>User's Choice (1)</td>
<td>O</td>
<td></td>
<td>Orifice, Restriction</td>
<td>User's Choice (1)</td>
<td>User's Choice (1)</td>
</tr>
<tr>
<td>Measured or initiating variable</td>
<td>Modifier</td>
<td>Readout or passive function</td>
<td>Output function</td>
<td>Modifier</td>
<td></td>
</tr>
<tr>
<td>---------------------------------</td>
<td>----------</td>
<td>-----------------------------</td>
<td>-----------------</td>
<td>----------</td>
<td></td>
</tr>
<tr>
<td>P Pressure, Vacuum</td>
<td></td>
<td>Point (Test) Connection</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q Quantity</td>
<td>Integrate, Totalize (4)</td>
<td>Record (17)</td>
<td>Switch (13)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R Radiation</td>
<td>Safety (8)</td>
<td>Multifunction (12)</td>
<td>Multifunction (12)</td>
<td>Multifunction (12)</td>
<td></td>
</tr>
<tr>
<td>S Speed, Frequency</td>
<td></td>
<td>Well</td>
<td>Switch (13)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T Temperature</td>
<td></td>
<td>Unclassified (2)</td>
<td>Multifunction (12)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>U Multivariable (6)</td>
<td></td>
<td>Unclassified (2)</td>
<td>Valve, Damper, Louver (13)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>V Vibration, Mechanical Analysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>W Weight, Force</td>
<td>X Axis</td>
<td>Unclassified (2)</td>
<td>Unclassified (2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X Unclassified (2)</td>
<td>Y Axis</td>
<td></td>
<td>Relay, Compute, Convert (13, 14, 18)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Y Event, State or Presence (20)</td>
<td>Z Axis</td>
<td></td>
<td>Driver, Actuator, Unclassified Final Control Element</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Z Position Dimension</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Schematic diagram of a temperature feedback control system for a stirred-tank heater. 

--- Electrical instrument line; TT, temperature transmitter; TC, temperature controller.
Control process diagram – Example 4
Applications of control systems
Applications of control theory

Feedback control can be found in many applications:

- Production system: cement plants, sugar mills, ....
- Industrial processes: temperature, flow, pressure, speed, ...
- Mechatronics: robot arms, computer numerical control (CNC), ...
- Information systems
- Power generation and transmission
- Transportation systems: cars, trains, aircraft, spacecraft, ...
- Military equipments
- Measurement
- Home appliances: air conditioners, televisions, refrigerators, washing machines, cameras, rice cookers, ...
- Medical equipments

© H. T. Hoang - www4.hcmut.edu.vn/~hthoang/
Temperature control

Temperature control plays an important role in many manufacturing systems: production of cement, ceramic tiles, pulp and paper, rubber and plastic, oil and gas, food and beverage,…

Cement factory

Paper factory
Examples of temperature control

- Agricultural product drying system (coffee, cashew nut, black pepper, ...)

Agricultural product drying system
Block diagram of a temperature control system

- Differential amplifier
- Controller
- Power amplifier
- Heater
- Measurement
Temperature controller and user interface
Temperature measurement using thermocouple

The circuit diagram shows a thermocouple connected to an amplifier (OP07) and followed by a voltage follower (OP07) and an op-amp (OP07) to increase the output voltage. The LM35 temperature sensor is used to measure temperature. The circuit includes capacitors (C1, C2, C3) and resistors (R1, R2, R3, R4, R5, R6) to filter and stabilize the output signal. The circuit is designed to measure temperature accurately and provide a stable output voltage for further processing.
Power circuit

+12V

PORTC<2>

Q1

Q2SC1815

R1 47k

R2 330

U15 MOC3020

Q2 BTA16

FUSE

Heater

220Vac 0Vdc

R3 470
An industrial temperature control system

Temperature controller

Furnace

Thermocouple
Motor control

- Motors (DC, AC) are one of the most common actuators used in machinery and manufacturing factories.
- Three basic control problems: speed control, position control, torque control.
Antenna position control

Desired azimuth angle input

$\theta_i(t)$

Potentiometer

Differential amplifier and power amplifier

Motor

$\theta_o(t)$

Azimuth angle output

Potentiometer

Antenna

Desired azimuth angle input

$\theta_i(t)$

Potentiometer

Differential amplifier and power amplifier

Motor

$\theta_o(t)$

Azimuth angle output

Potentiometer

Antenna
Analog PID control of DC motor
An industrial DC motor control system

DC Motor

DC Driver

Encoder
Level control

- Level control can be found in industrial processes such as food and beverage, waste water treatment, ...

- Level control, flow control

- Sensor:
  - Level sensor: pressure sensor, capacitor sensor, ultrasonic
  - Flow sensor: ultrasonic
Level control system in industry

LC: Level Controller
LT: Level Transmitter
LV: Level Valve
Pulp concentration control

Diagram showing a control system for pulp concentration with a mixer, control valve, controller, and consistency measuring device leading to drying and rolling stations.
Pitch angle control
Block diagram of pitch angle control system

Desired Angle (deg) → Input Angular Sensor → Error Signal

(V) + (V) → Controller

Control Signal (V) → Servo-valve

Fluid Flow-rate (m³/s) → Hydraulic Cylinder

Hydraulic Force (N) → Elevator

Actual Angle (deg)

Output Angular Sensor

6 December 2013 © H. T. Hoang - www4.hcmut.edu.vn/~hthoang/
CNC diagram

Computer Controller

Computer Program

Digital Controller

Power Amplifier

DC-Servomotor

Lead-Screw

Machine Table Movement

Shaft Encoder

Bearing

Tachogenerator

Digital Positional Feedback

Analogue Velocity Feedback
Block diagram of CNC control system

- **Computer Program**
- **Digital Controller**
- **Power Amplifier**
- **DC Servo Motor**
- **Machine Table**
- **Integrator**
- **Tacho-generator**
- **Shaft Encoder**
- **Actual Position (m)**

**Feedback Loops:**
- **Digital Positional Feedback**
- **Velocity Feedback**

**Signals:**
- **Digital Desired Position**
- **Digital Error**
- **Control Signal (V)**
- **Torque (Nm)**
- **Actual Velocity (m/s)**
Distillation Process

FC = flow control loop
TC = temperature control loop
PC = pressure control loop
LC = level control loop
= automatic control valve
CW = cooling water
= pneumatic or electronic control signal

6 December 2013 © H. T. Hoang - www4.hcmut.edu.vn/∼hthoang/
Steam Power Generator

Water → Valves → Boiler → Turbine → Shaft → Actual power
Air
Liquid fuel

Turbine

Generator

Speed governor

Computer

Desired pressure, temperature, oxygen and electric power

Oxygen, pressure and temperature measurements
## Course learning outcomes

- Explain the concepts of open-loop and closed-loop control systems
- Describe continuous and discrete control systems using transfer function and state space model
- Calculate the equivalent transfer function of control systems using block diagram and signal flow graph
- Analyze the dynamics of control systems in time domain and frequency domain
- Analyze the stability of control systems
- Analyze the transient and steady-state performances of control systems
- Analyze the controllability and observerbility of control systems
- Design lead-lag compensator using root locus and frequency response
- Design PID controller using frequency response, Zeigler-Nichols method
- Design state feedback controller using pole placement method
- Use teamwork and communication skills in collaborating course design projects
- Use modern software in analysis and design control systems
Review of complex variables and matrix theory
Review
