MECH-3610: Control Principles Course Syllabus

The Hong Kong University of Science and Technology

UG Course Syllabus

Course Title: Control Principles

Course Code: MECH-3610

Number of Credits: 3

Pre-/co-requisites: N/A

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Course Description

This course introduces the essential principles of feedback control systems, with emphasis on modeling, analysis, stability, and controller design for engineering systems. Students will learn how to describe dynamic systems mathematically, predict their time- and frequency-domain behavior, and design controllers that improve stability, transient response, and steady-state accuracy.

The course begins with motivation and basic concepts, including why control is needed in mechanical, electrical, robotic, aerospace, and manufacturing systems. It then develops the core mathematical tools for control analysis, including dynamical-system modeling, Laplace transforms, linear time-invariant (LTI) systems, transfer functions, and block-diagram representation and reduction. These tools are applied to characterize transient response, steady-state error, and the relationship between system poles, zeros, and performance.

The second half of the course introduces classical methods for stability analysis and controller design. Topics include the Routh-Hurwitz stability criterion, root locus method, frequency-response analysis using Bode plots, Nyquist stability ideas where appropriate, and the design and interpretation of common controllers such as proportional, integral, derivative, PI, PD, and PID controllers. The course also introduces controllability, observability, and state-space representation to connect classical control concepts with modern control-system analysis.

Through lectures, tutorials, homework assignments, and examinations, students will develop the ability to model physical systems, analyze feedback behavior, assess stability and performance, and design basic controllers for practical engineering applications.

Intended Learning Outcomes (ILOs)

By the end of this course, students should be able to:

1. Develop mathematical models of dynamic systems using differential equations, Laplace transforms, transfer functions, block diagrams, and state-space representations.

2. Analyze time-domain responses and steady-state errors of feedback control systems, and relate these responses to poles, zeros, system type, and performance specifications.

3. Determine closed-loop stability and relative stability using classical methods including the Routh-Hurwitz criterion, root locus analysis, and frequency-response tools.

4. Design, tune, and evaluate basic feedback controllers, including PID-type controllers, to meet stability, transient-response, and steady-state performance requirements.

Assessment and Grading

This course will be assessed using criterion-referencing. Grades will not be assigned using a curve. Student performance will be evaluated according to demonstrated achievement of the intended learning outcomes (ILOs) via regular homework assignments, a mid-term examination, and a final examination. Rubrics and grade descriptors are provided below to clarify the criteria used for evaluation.

Assessment Task	**Contribution to Overall Course Grade (%)**	**Due Date**
Regular homework	40%	Throughout the term
Mid-term examination	20%	Around week 7
Final examination	40%	Final examination period

Mapping of Course ILOs to Assessment Tasks

Assessed Task	**Mapped ILOs**	**Explanation**
Regular homework	ILO 1, ILO 2, ILO 3, ILO 4	Homework assignments assess students ability to apply theoretical and analytical tools introduced in lectures and tutorials. Through structured problem sets, students model dynamic systems using transfer functions, block diagrams, and state-space representations (ILO 1), compute and interpret transient response and steady-state errors (ILO 2), assess stability using Routh-Hurwitz, root locus, and frequency-response methods (ILO 3), and design or tune basic feedback controllers to meet performance requirements (ILO 4).
Mid-term examination	ILO 1, ILO 2	The mid-term examination assesses individual achievement of the foundational learning outcomes in the first half of the course. Students are required to formulate mathematical models of engineering systems, apply Laplace-transform and transfer-function methods (ILO 1), and analyze time-domain response, pole-zero behavior, and steady-state error in standard feedback systems (ILO 2).
Final examination	ILO 1, ILO 2, ILO 3, ILO 4	The final examination is cumulative and assesses individual achievement of the core conceptual and analytical outcomes of the course. Students apply modeling and system-representation tools (ILO 1), analyze transient and steady-state behavior (ILO 2), determine stability and relative stability using classical control methods (ILO 3), and design and evaluate controllers for specified performance targets (ILO 4).

Grading Rubrics

The following rubrics describe the general criteria used to assess the major assessment components in this course. More detailed task-specific marking schemes may be provided for individual homework assignments and examination questions.

Rubric for <u>Homework Assignments</u>

Criteria	Excellent	Good	Satisfactory	Marginal	Fail	Map to Course ILOs
Conceptual understanding	Demonstrates clear and accurate understanding of relevant control concepts, feedback mechanisms, assumptions, and limitations.	Shows good understanding of the main concepts with only minor omissions or imprecision.	Shows adequate understanding of basic concepts but may lack depth or contain some conceptual gaps.	Shows limited understanding; explanations are incomplete or partially incorrect.	Shows little or no understanding of relevant control concepts.	ILO 1, ILO 2, ILO 3, ILO 4
Application of control theory	Selects and applies appropriate modeling, response-analysis, stability, and controller-design methods correctly and efficiently.	Applies appropriate methods with mostly correct reasoning and only minor errors.	Applies standard methods to familiar problems but may require clearer justification or contain procedural errors.	Attempts to apply relevant methods but with significant errors or weak justification.	Fails to apply appropriate control methods or uses irrelevant approaches.	ILO 1, ILO 2, ILO 3, ILO 4
Mathematical accuracy and problem solving	Solutions are mathematically sound, logically organized, and lead to correct results with appropriate units and notation.	Solutions are generally correct with minor algebraic, numerical, or unit errors.	Solutions show reasonable effort and partial correctness but include some significant errors.	Solutions are incomplete or contain major mathematical errors.	Solutions are largely absent, incorrect, or not submitted.	ILO 1, ILO 2, ILO 3, ILO 4
Physical interpretation of results	Provides clear interpretation of results, including dynamic behavior, stability margins, limiting cases, model assumptions, and engineering significance.	Provides reasonable interpretation, though some details may be missing.	Provides basic interpretation but may not fully connect results to physical system behavior.	Provides limited or superficial interpretation.	Provides no meaningful interpretation of results.	ILO 1, ILO 2, ILO 3, ILO 4
Clarity of presentation	Work is clear, well structured, legible, and easy to follow, with appropriate equations, diagrams, and explanations.	Work is mostly clear and organized.	Work is understandable but may be disorganized or difficult to follow in places.	Work is poorly organized or hard to follow.	Work is illegible, incoherent, or missing.	ILO 1, ILO 2, ILO 3, ILO 4

Rubric for <u>Mid-term Examination</u>

Criteria	**Excellent**	**Good**	**Satisfactory**	**Marginal**	**Fail**	**Map to Course ILOs**
Modeling and system representation	Correctly formulates models using differential equations, Laplace transforms, transfer functions, block diagrams, and state-space forms where relevant.	Applies modeling tools mostly correctly with minor errors.	Applies standard modeling methods to familiar systems but with some errors or incomplete reasoning.	Shows limited ability to construct or interpret system models.	Fails to construct meaningful system models.	ILO 1
Time-domain response analysis	Accurately analyzes first- and second-order responses, transient specifications, pole-zero effects, and steady-state error.	Performs response analysis correctly with minor errors.	Provides adequate calculations but may miss some interpretation or contain errors.	Shows limited ability to analyze response behavior.	Fails to analyze basic time-domain response.	ILO 2
Use of control-system tools	Uses block-diagram reduction, characteristic equations, and standard feedback relations correctly and efficiently.	Uses tools mostly correctly with minor omissions.	Uses basic tools but may require clearer justification.	Uses tools with significant errors or weak organization.	Fails to use relevant control-system tools.	ILO 1, ILO 2
Mathematical accuracy, organization, and clarity	Work is accurate, logically structured, clearly presented, and uses appropriate notation and units under examination conditions.	Work is generally clear and accurate, with minor errors.	Work is understandable but may contain errors, omissions, or lack organization.	Work is poorly organized or contains major errors.	Work is incoherent, largely incorrect, or missing.	ILO 1, ILO 2

Rubric for Final Examination

Criteria	Excellent	Good	Satisfactory	Marginal	Fail	Map to Course ILOs
Dynamic-system modeling	Correctly and independently develops and interprets transfer-function, block-diagram, and state-space representations of control systems.	Applies modeling methods mostly correctly with minor errors.	Applies modeling methods to familiar systems but with some errors.	Shows limited ability to model control systems.	Fails to apply basic modeling tools.	ILO 1
Transient response and steady-state error	Clearly analyzes transient response, steady-state error, system type, and pole-zero effects, and connects calculations to performance.	Analyzes response behavior mostly correctly with minor omissions.	Demonstrates adequate understanding but may lack depth or make errors.	Demonstrates limited or fragmented understanding.	Demonstrates insufficient understanding of response and error analysis.	ILO 2
Stability analysis	Correctly applies Routh-Hurwitz, root locus, Bode-plot, and related frequency-domain concepts to determine stability and relative stability.	Applies stability-analysis methods mostly correctly with minor errors.	Demonstrates adequate understanding of basic stability tools but may struggle with complex cases.	Shows limited understanding of stability methods.	Fails to determine stability at an acceptable level.	ILO 3
Controller design and evaluation	Designs, tunes, and evaluates basic feedback controllers, including PID-type controllers, to meet stability and performance targets.	Performs controller design mostly correctly with minor errors or omissions.	Provides adequate controller design for familiar problems but may lack depth.	Shows limited ability to design or evaluate controllers.	Fails to design or evaluate a meaningful controller.	ILO 4
Mathematical accuracy, organization, and clarity	Work is accurate, logically structured, clearly presented, and uses appropriate equations, units, notation, and physical reasoning under examination conditions.	Work is generally clear and accurate, with minor errors.	Work is understandable but may contain errors, omissions, or lack organization.	Work is poorly organized or contains major errors.	Work is incoherent, largely incorrect, or missing.	ILO 1, ILO 2, ILO 3, ILO 4

Final Grade Descriptors

Grade	Short Description	Elaboration on Subject Grading Description
A	Excellent Performance	Demonstrates an excellent command of the fundamental principles of feedback control. Applies modeling, transfer-function, block-diagram, time-response, stability-analysis, and controller-design methods accurately and insightfully. Clearly connects mathematical results to physical system behavior and engineering design decisions. Work is accurate, well organized, and shows strong physical insight and engineering judgement.
B	Good Performance	Demonstrates good understanding of the main concepts in control systems. Applies most modeling, response-analysis, stability, and controller-design methods correctly. Solves standard and moderately challenging problems with generally sound reasoning. Homework and examination solutions are clear and technically competent, with only minor weaknesses in depth, precision, or completeness.
C	Satisfactory Performance	Demonstrates adequate understanding of core control concepts and can apply standard methods to familiar problems. Shows satisfactory ability to model systems, analyze transient response and steady-state error, assess stability, and perform basic controller design. Some errors or gaps in reasoning may be present, and physical interpretation may lack depth, but the main learning

		outcomes are achieved at an acceptable level.
D	Marginal Pass	Demonstrates threshold understanding of basic control concepts but has difficulty applying theories consistently or accurately. Can attempt standard calculations involving system modeling, response analysis, stability, and controller design, but work may contain significant errors, incomplete reasoning, or weak physical interpretation. There is sufficient evidence of partial achievement of the course learning outcomes, but performance is limited.
F	Fail	Demonstrates insufficient understanding of fundamental control concepts. Is unable to apply basic modeling tools, does not adequately analyze response or steady-state error, fails to determine stability, or cannot design and evaluate controllers at an acceptable level. Work contains major conceptual and mathematical errors, is incomplete, or does not demonstrate achievement of the intended learning outcomes.

Course AI Policy

The use of artificial intelligence (AI) tools is permitted in this course for learning support, brainstorming, checking understanding, improving writing clarity, and assisting with coding or software-related tasks. However, students remain fully responsible for the accuracy, originality, and integrity of all submitted work.

For homework submissions, students may use AI tools to support their learning, but they must ensure that the final submitted work reflects their own understanding and reasoning. Students should not submit AI-generated solutions without verification, explanation, and independent judgement. Any use of AI that contributes substantively to submitted work should be acknowledged where appropriate.

During the mid-term and final examinations, the use of AI tools is not permitted.

Communication and Feedback

Assessment marks for individual assessed tasks will normally be communicated via Canvas within two weeks of submission. Feedback may include written comments, annotated solutions, marking rubrics, sample solutions, in-class or tutorial discussion, or verbal feedback during course activities.

Homework feedback will focus on the correctness of methods, mathematical execution, physical interpretation, and clarity of presentation. Examination feedback will address the achievement of learning outcomes and common conceptual or procedural issues.

Students who have questions about feedback or marks should contact the instructor or teaching team within two weeks after the feedback is released.

Late Submission Policy

To ensure fairness to students who submit work on time, late submissions for homework components will be subject to a penalty of 10% of the attained mark per day, unless prior approval has been granted by the instructor or valid supporting documentation is provided.

Required Texts and Materials

The main textbook for this course is:

- Modern Control Systems by Richard C. Dorf and Robert H. Bishop, 13th Edition, Pearson. ISBN-13: 9780132270281.

Additional recommended optional references include:

- Feedback Control of Dynamic Systems by Gene F. Franklin, J. David Powell, and Abbas Emami-Naeini.
- Automatic Control Systems by Benjamin C. Kuo and Farid Golnaraghi.

- Control Systems Engineering by Norman S. Nise.

Other materials, including lecture slides, tutorial handouts, homework assignments, example codes, and software-related guidance, will be provided via Canvas.

Academic Integrity

Students are expected to uphold HKUSTs Academic Honor Code and maintain the highest standards of academic integrity. The University has zero tolerance for academic misconduct, including plagiarism, cheating, fabrication of data, and misrepresentation of work.

Students may discuss course concepts and homework strategies with classmates, the instructor, and teaching assistants. However, submitted work must be the students own unless a task is explicitly designated as group work. Students should refer to the HKUST Academic Registry for the Universitys definitions of academic misconduct and guidance on academic integrity.

Course Outline

1. Motivation, Modeling, and Basic Concepts [Week 1]

- Why control is needed in engineering systems
- Open-loop versus closed-loop control
- Examples from mechanical, robotic, electrical, aerospace, and manufacturing systems
- Input, output, disturbance, feedback, performance, and robustness

2. Laplace Transform and Transfer Functions [Weeks 2-3]

- Laplace-transform review and solution of linear differential equations
- Linear time-invariant systems and transfer functions
- Poles, zeros, characteristic equations, and system order
- Block diagrams, signal-flow ideas, and block-diagram reduction

3. Time-Domain Response and Steady-State Error [Weeks 4-5]

- First-order and second-order system responses
- Rise time, settling time, peak time, overshoot, damping ratio, and natural frequency
- Effects of poles and zeros on system response
- System type, error constants, and steady-state error analysis

4. Stability Analysis Using Routh-Hurwitz Criterion [Week 6]

- Closed-loop stability and characteristic equations
- Routh array construction and interpretation
- Special cases in the Routh-Hurwitz criterion
- Parametric stability ranges and design implications

5. Root Locus Analysis and Controller Effects [Weeks 7-8]

- Root locus rules and graphical construction
- Relationship between pole locations and transient performance
- Effects of adding poles, zeros, and controller gains
- Preliminary controller design using root locus

6. Frequency-Domain Analysis and Bode Plots [Weeks 9-10]

- Sinusoidal steady-state response and frequency response
- Magnitude and phase plots

- Gain margin, phase margin, bandwidth, and resonance
- Interpretation of Bode plots for stability and performance

7. Nyquist Stability and Robustness Concepts [Week 11]

- Nyquist stability criterion and closed-loop stability interpretation
- Relationship among Bode plots, Nyquist plots, and stability margins
- Robustness to model uncertainty and parameter variation

8. PID Control and Integrated Controller Design [Week 12]

- Proportional, integral, derivative, PI, PD, and PID control actions
- Controller tuning and trade-offs among speed, overshoot, error, and robustness
- Design examples for common engineering systems
- Implementation considerations and limitations

9. Introduction to State-Space Methods [Week 13]

- State variables and state-space representation
- Conversion between transfer functions and state-space models
- Basic ideas of controllability and observability
- Connection between classical and modern control perspectives