AGH University of Science and Technology

Module name:	Control theory
Academic year:	2013/2014
Code:	RMS-1-404-s
ECTS credits:	10
Faculty of:	Mechanical Engineering and Robotics
Field of study:	Mechatronics with English as instruction languagege
Specialty:	—
Study level:	First-cycle studies
Form and type of study:	Full-time studies
Lecture language:	English
Profile of education:	Academic (A)
Semester:	4
Course homepage:	—
Responsible teacher:	dr hab. inż, prof. AGH Dao Phong (phongdao@agh.edu.pl)
Academic teachers:	dr hab. inż, prof. AGH Dao Phong (phongdao@agh.edu.pl)

Description of learning outcomes for module

MLO code	Student after module completion has the knowledge/ knows how to/is able to	Connections with FLO	Method of learning outcomes verification (form of completion)
Social competence			
M_K001	- apply knowledge of basic science and engineering fundamentals through applications of knowledge and skills related to control theory on the living standards and society structure at a global scale; - use a system approach to design and manufacturing process in order to meet the client's demands and needs.	MS1A_K04, MS1A_K07, MS1A_K06, MS1A_K05, MS1A_K02	Activity during classes, Execution of laboratory classes, Involvement in teamwork
Skills			

M_U001	- use the basic principles and techniques for designing, analysing, implementing and evaluating controllers for linear systems in both continuous-time and discrete-time frameworks; - use of the feedback and feed-forward control structures to improve the dynamic behaviour of a controlled system and to make it less sensitive for disturbances and parameter variations and simultaneously understand the limitations of these measures with respect to stability; explain the stability of the control systems and apply stability criteria to analyse stability of control systems; - integrate the knowledge from other courses, in particular knowledge on modelling and identification of physical systems and various representations of dynamical systems, to analyse and synthesise control systems.	MS1A_U07, MS1A_U11, MS1A_U20, MS1A_U16, MS1A_U05, MS1A_U10	Activity during classes, Examination, Execution of exercises, Execution of laboratory classes, Report, Test
M_U002	use MATLAB, Simulink and the Control Systems Toolbox for computer-assisted design, analysis, simulation and implementation of control systems.	MS1A_U07, MS1A_U08	Activity during classes, Execution of laboratory classes, Report
M_U003	- perform a survey and literature search to find materials relevant to the subject being explored; - briefly summarize, present and defend the work in an oral presentation; - prepare clear and concise reports of the work that was done in the laboratory and project; - work effectively with other students in a collaborative group to be able to obtain the overall goal assigned to the team.	MS1A_U01, MS1A_U04, MS1A_U03, MS1A_U05, MS1A_U02	Activity during classes, Execution of laboratory classes, Involvement in teamwork, Presentation, Report
Knowledge			
M_W001	- model real-world dynamical systems in terms of differential equations, Laplace Transform and state-space models such that they can be used for the design and simulation of control systems; - use flexibly system representations in the time domain (i.e. step response, state-space description), frequency domain (e.g. Bode, Nyquist and Nichols plots) and s-domain and understand the transformations between these systems and their mutual relations.	MS1A_W08, MS1A_W09, MS1A_W04, MS1A_W01	Activity during classes, Examination, Execution of exercises, Execution of laboratory classes, Report, Test

M_W002	- design PID controllers, lead-lag compensators and feed-forward controllers for improving dynamic performances of systems by using classical control techniques such as frequency domain design using Bode plots and s-plane design using root-locus; analyse the stability of feedback systems in Bode and Nyquist plots in the frequency domain and with root-loci in the s-domain; - apply modern control principles: state-space control (e.g. state variable feedback, state observers, Integral control), optimal control (Linear Quadratic Regulator), optimal estimation (Kalman filter), robust control (e.g. robust PID controllers, Internal Model Control), intelligent control (e.g. Fuzzy logic control, Neural Network) and adaptive control (Model Reference Adaptive Control); understand the basic concepts of agents, multi-agent systems and agent-based control.	MS1A_W08, MS1A_W09, MS1A_W04, MS1A_W12	Activity during classes, Examination, Execution of exercises, Execution of laboratory classes, Report, Test
M_W003	understand discrete-time systems (i.e. sampling, the z-transform, analysis of stability, observability) and design sampled-data control systems (e.g. lead-lag compensators, PID controllers) using three different approaches to discrete-time controller design: (1) indirect design by translating a continuous-time controller to a discrete-time controller using various approximations (or emulations); (2) direct design in z-plane using the root-locus method, or the Bode and Nyquist diagrams, and (3) direct design in discrete-time domain using state-space approach.	MS1A_W08, MS1A_W09, MS1A_W12, MS1A_W10	Activity during classes, Examination, Execution of exercises, Execution of laboratory classes, Report, Test

FLO matrix in relation to forms of classes

MLO code	Student after module completion has the knowledge/ knows how to/is able to	Form of classes										
		Lectures	Auditorium classes	Laboratory classes	Project classes	Conversation seminar	Seminar classes	Practical classes	Others	Fieldwork classes	Workshops	E-learning
Social competence												

M_K001	- apply knowledge of basic science and engineering fundamentals through applications of knowledge and skills related to control theory on the living standards and society structure at a global scale; - use a system approach to design and manufacturing process in order to meet the client’s demands and needs.	+	+	+	-	-	-	-	-	-	-	-
Skills												
M_U001	- use the basic principles and techniques for designing, analysing, implementing and evaluating controllers for linear systems in both continuous-time and discrete-time frameworks; - use of the feedback and feed-forward control structures to improve the dynamic behaviour of a controlled system and to make it less sensitive for disturbances and parameter variations and simultaneously understand the limitations of these measures with respect to stability; explain the stability of the control systems and apply stability criteria to analyse stability of control systems; - integrate the knowledge from other courses, in particular knowledge on modelling and identification of physical systems and various representations of dynamical systems, to analyse and synthesise control systems.	+	+	+	-	-	-	-	-	-	-	-
M_U002	use MATLAB, Simulink and the Control Systems Toolbox for computer-assisted design, analysis, simulation and implementation of control systems.	+	-	+	-	-	-	-	-	-	-	-

M_U003	- perform a survey and literature search to find materials relevant to the subject being explored; - briefly summarize, present and defend the work in an oral presentation; - prepare clear and concise reports of the work that was done in the laboratory and project; - work effectively with other students in a collaborative group to be able to obtain the overall goal assigned to the team.	+	-	+	-	-	-	-	-	-	-	-
Knowledge												
M_W001	- model real-world dynamical systems in terms of differential equations, Laplace Transform and state-space models such that they can be used for the design and simulation of control systems; - use flexibly system representations in the time domain (i.e. step response, state-space description), frequency domain (e.g. Bode, Nyquist and Nichols plots) and s-domain and understand the transformations between these systems and their mutual relations.	+	+	+	-	-	-	-	-	-	-	-

M_W002	- design PID controllers, lead-lag compensators and feed-forward controllers for improving dynamic performances of systems by using classical control techniques such as frequency domain design using Bode plots and s-plane design using root-locus; analyse the stability of feedback systems in Bode and Nyquist plots in the frequency domain and with root-loci in the s-domain; - apply modern control principles: state-space control (e.g. state variable feedback, state observers, Integral control), optimal control (Linear Quadratic Regulator), optimal estimation (Kalman filter), robust control (e.g. robust PID controllers, Internal Model Control), intelligent control (e.g. Fuzzy logic control, Neural Network) and adaptive control (Model Reference Adaptive Control); understand the basic concepts of agents, multi-agent systems and agent-based control.	+	+	+	-	-	-	-	-	-	-	-
M_W003	understand discrete-time systems (i.e. sampling, the z-transform, analysis of stability, observability) and design sampled-data control systems (e.g. lead-lag compensators, PID controllers) using three different approaches to discrete-time controller design: (1) indirect design by translating a continuous-time controller to a discrete-time controller using various approximations (or emulations); (2) direct design in z-plane using the root-locus method, or the Bode and Nyquist diagrams, and (3) direct design in discrete-time domain using state-space approach.	+	+	+	-	-	-	-	-	-	-	-

Module content

Lectures

1. Introduction to control systems

1.1. Course organisation
1.2. History of automatic control
1.3. Control system fundamentals

1.4. Examples of control systems
1.5. Steps in the design of a control system

<u>2. System modelling and descriptions</u>
2.1. Physical modelling, black-box and grey-box modelling
2.2. Modelling of (real-world) dynamical systems: examples with mechatronic systems
2.3. Multiple views in modelling of a system
2.4. Nonlinearities
2.5. Linearization of nonlinear systems

<u>3. Time domain analysis (revision)</u>
3.1. Laplace transforms
3.2. Transfer functions
3.3. Time domain response of first-order systems
3.4. Time domain response of second-order systems
3.5. Step response analysis and performance specification
3.6. Response of higher-order systems

<u>4. Closed-loop control systems (revision)</u>
4.1. Closed-loop transfer function
4.2. Block diagram reduction
4.3. Systems with multiple inputs
4.4. PID controllers
4.5. Low-pass filters
4.6. Feed-forward control

<u>5. Classical design in the s-plane (revision)</u>
5.1. Stability of dynamic systems
5.2. The Routh-Hurwitz stability criterion
5.3. Root-locus analysis
5.4. Design in the s-plane

<u>6. Classical design in the frequency domain (revision)</u>
6.1. The complex frequency approach
6.2. The Bode diagram
6.3. Stability in the frequency domain
6.4. Compensator design in the frequency domain
6.5. Relationship between frequency response and time response for closed-loop systems

<u>7. Digital control system design</u>
7.1. Shannon’s sampling theorem
7.2. Ideal sampling
7.3. The z-transform
7.4. Digital control systems
7.5. Stability in the z-plane
7.6. Discrete-time controller design approaches

<u>8. State-space methods for control system design</u>
8.1. The state-space approach
8.2. Solution of the state vector differential equation
8.3. Discrete-time solution of the state vector differential equation
8.4. Controllability and observability
8.5. State variable feedback design
8.6. State observer design
8.7. Effect of a full-order state observer on a closed-loop system

8.8. Reduced-order state observers
8.9. Steady-state error design using Integral control

9. Optimal control system design
9.1. Introduction to optimal control
9.2. The Linear Quadratic Regulator (LQR)
9.3. The linear quadratic tracking problem
9.4. The Kalman filter
9.5. The Linear Quadratic Gaussian (LQG) control system design

10. Robust control system design
10.1. Introduction to robust control
10.2. Robust control systems and system sensitivity
10.3. Analysis of robustness
10.4. Systems with uncertain parameters
10.5. The design of robust control systems
10.6. Control systems with a prefilter
10.7. The design of robust PID controlled systems
10.8. The robust internal model control (IMC) system

11. Intelligent control system design
11.1. Introduction to intelligent control
11.2. Fuzzy logic control systems
11.3. Neural network control systems
11.4. Learning and adaptive control systems

12. Agent-based control
12.1. Agents and Multi-Agent Systems (MAS)
12.2. Applicability of Agent and MAS Technology
12.3. Applications of MAS in Control Engineering
12.4. Multi-Agent Control Systems (MACS)

Lecture schedule
Lectures 1 & 2: Introduction to control systems, system modelling and descriptions.
Lecture 3: Time domain analysis and closed-loop control systems.
Lecture 4: Classical design in the s-plane and frequency domain.
Lecture 5: Digital control system design.
Lecture 6: State-space methods for control system design.
Lecture 7: Optimal control system design.
Lecture 8: Robust control system design.
Lecture 9: Intelligent control system design.
Lecture 10: Agent-based control.

Auditorium classes

During these classes, students are required to solve exercises through applying knowledge learned from the lectures without using MATLAB/Simulink. These exercises cover the following topics:
1. Construct mathematical models for mechatronic systems;
2. Design control systems in the s-plane using the root-locus method and in the frequency domain using the Bode diagram;
3. Design sampled-data control systems using three different approaches to discrete-time controller design: (1) indirect design by translating a continuous-time controller to a discrete-time controller using various approximations (or emulations); (2) direct design in z-plane using the root-locus method, or the Bode and Nyquist diagrams, and

(3) direct design in discrete-time domain using state-space approach;
4. Design state variable feedback controllers and state observers;
5. Design robust PID controllers using the ITAE method.

Laboratory classes

There are five laboratory assignments assigned periodically during the course. Students will need to use MATLAB including Simulink and the Control Systems Toolbox to aid in solving these assignments.
Laboratory no. 1 – Classical Feedback Control
Laboratory no. 2 – Discrete-Time Control
Laboratory no. 3 – State-Space and Optimal Control
Laboratory no. 4 – Robust Control
Laboratory no. 5 – Adaptive Control

Method of calculating the final grade

The final grade will be based on exercises, laboratory assignments and a final exam.
- Exercises: 30%
- Laboratory: 40%
- Final exam: 30%

Prerequisites and additional requirements

A good background on basic automatic control theory – obtained form the Control Theory Fundamentals course (RMS-1-302-s) – is a definite prerequisite for this module.
Knowledge of basic linear algebra and complex number arithmetic is desirable.
Prior experience with MATLAB/Simulink is required.

Recommended literature and teaching resources

[1] Roland S. Burns, Advanced Control Engineering, Butterworth-Heinemann, 2001, ISBN 978-0-7506-5100-4.
[2] Richard C. Dorf and Robert H. Bishop, Modern Control Systems, 8th edition, Addison-Welley, Boston, MA, 1997, ISBN: 978-0-2013-0864-8.
[3] Norman S. Nise, Control Systems Engineering, 4th edition, John Wiley and Sons Inc., 2004.
[4] Matlab, Simulink and Control Systems Toolbox, http://www.mathworks.com/.

Scientific publications of module course instructors related to the topic of the module

Additional scientific publications not specified

Additional information

Class attendance policy
Students are required to attend at least 70% of the lectures, auditorium and laboratory classes.
Exercise and laboratory policy
Homework exercises and laboratory assignments are performed in groups of two students.
Exercises and laboratory assignments will be handed out every two or three weeks. Students should solve all exercises and assignments and submit reports within the prescribed time (due two or three weeks after they are assigned). No late report will be accepted except for exceptional circumstances. Exercise and laboratory reports must be typed on a word-processor and submitted in person as printed documents or via email as PDF attachments.
Final exam
The final exam will test the student’s comprehension and ability to apply knowledge learned in classes and through assignments. This is an OPEN NOTE/BOOK examination.
Lecture schedule is subject to change as we move through the semester.

Student workload (ECTS credits balance)

Student activity form	Student workload
Participation in lectures	60 h
Realization of independently performed tasks	50 h
Participation in auditorium classes	30 h
Preparation for classes	90 h
Participation in laboratory classes	30 h
Preparation of a report, presentation, written work, etc.	30 h
Examination or Final test	3 h
Summary student workload	293 h
Module ECTS credits	10 ECTS