STUDY MODULE DESCRIPTION FORM

Name of the module/subject		Code
Adaptive Control		**1010532111010559181**
Field of study: **Automatic Control and Robotics**	Profile of study (general academic, practical): **general academic**	Year /Semester: **1 / 1**
Elective path/specialty: **Smart Aerospace and Autonomous Systems**	Subject offered in: **English**	Course (compulsory, elective): **obligatory**
Cycle of study: **Second-cycle studies**	Form of study (full-time,part-time): **full-time**	
No. of hours: Lecture: **30** Classes: **-** Laboratory: **30** Project/seminars: **-**		No. of credits: **4**
Status of the course in the study program (Basic, major, other): **major**	(university-wide, from another field): **from field**	
Education areas and fields of science and art: **technical sciences** / **Technical sciences**		ECTS distribution (number and %): **4 100%** / **4 100%**

Responsible for subject / lecturer:

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Prerequisites in terms of knowledge, skills and social competencies:

1	**Knowledge**	Before taking this course, each student should poses basic knowledge in mathematical statistics as well as control and systems theory (state-space representation, input-output description in continuous and discrete time-domain, Lyapunov stability analysis, Taylor-approximation).
2	**Skills**	Student should also possess the ability to solve basic problems regarding the feedback control design for linear systems, should possess basic programming skills in Matlab-Simulink environment, as well as the ability to acquire additional information from various sources.
3	**Social competencies**	The prospective student should be ready for team work activities during the course. Additionally, one should present following social skills: honesty, responsibility, persistence, curiosity, creativity, appropriateness of behavior, and respect for other human being.

Assumptions and objectives of the course:

- Extension of students' knowledge in the scope of design and application of mathematical models of plants/processes based on experimental data. Introduction to various techniques of parametric identification (with an emphasis on recursive methods) as well as their implementation and practical utilization.
- Presentation of various adaptive control techniques with their exemplification in automation and robotics.
- Teaching the implementation of selected basic adaptive control algorithms in a simulation environment.
- Development of the ability to work in small teams.

Study outcomes and reference to the educational results for a field of study

Knowledge:

1. Extended knowledge in the scope of parametric identification methods (batch-type and recursive-type estimators) for static and dynamic, linear and nonlinear plants/processes described in continuous-time and discrete-time domains; - [K_W5]

2. Knowledge on selected model structures, basic methods of model validation, basic problems and their solutions related to practical application of identification methods (also in a closed-loop system); - [K_W5]

3. Knowledge how to utilize the empirical models in the schemes of adaptive control; knowledge on basic techniques of adaptive recursive identification for parameter-varying plants/processes; - [K_W5]

4. Knowledge and understanding of such terms as adaptation and adaptive control; - [K_W7, K_W9]

5. Knowledge on objectives of adaptive control and properties of an ideal and a real adaptive control system; knowledge on a decision scheme of application of the adaptive control schemes; - [K_W7, K_W9]

6. Basic theoretical and practical knowledge in the scope of selected adaptive control techniques like: Model-Identification Adaptive Control (self-tuning scheme), Multi-Model Adaptive Control with supervised switching, Model-Reference Adaptive Control, Lyapunov-based Adaptive Control, Parameters Scheduling method, and Active/Adaptive Disturbance Rejection Control; - [K_W7, K_W9]

7. Awareness of necessity of supervision and safety nets application in the practical adaptive control systems; - [K_W7, K_W9]

Skills:

1. Construction and validation of simple empirical models for single-input single-output (SISO) systems, and their practical utilization in adaptive control systems. - [K_U10]

2. Ability to select a proper adaptive control algorithm and then to implement and commission it in a simulation environment. - [K_U9, K_U22]

3. Multi-criteria evaluation of control quality for selected adaptive control methods. - [K_U19]

4. Proper preparation and presentation of the results obtained during exercises. - [K_U8]

Social competencies:

1. Ability to work in a small team taking responsibility for a given task. - [K_K3]

2. Awareness of the necessity to professional approach to the technical problems presented during the course. - [K_K4]

Assessment methods of study outcomes

a) Lectures: Rating is decided upon the exam in the form of a selection test. The test comprise 30 meritorious questions. Four different answers A, B, C, and D are provided for every question, where two of them are correct and other two - incorrect. Selection of two correct answers gives 1 point for a question. Selection of a single correct answer and leaving the second answer unselected gives 0.5 point for a question. Selection of single correct answer and single incorrect one implies zero points for a question. Other possibilities of answers selection (or their lack) imply zero points for a question. Positive rating TR from the test requires collecting at least 15.5 points. A final rating FR from the course is obtained according to the rule: FR = TR*0.7 + LR*0.3, where TR is a rating received from the selection test, and LR is a final rating received from the laboratory exercises (FR < 3.0 implies negative final mark from the course);

b) Laboratory exercises: Final rating results from the overall quality assessment of the tasks realized by the students (assessment concerns technical quality of the obtained results, quality of the implementation details, and a defense of the tasks in the form of answers to detailed questions related to meritorious topics covered by the laboratory exercises).

Course description

The course covers the following topics:

A) introduction to system identification and selected parametric identification techniques: model definition, types of models, identification as an alternative pragmatic approach to system modeling, properties of experimental models, selected structures of static and dynamic input-output models (in continuous-time and discrete-time domains), linearity of models with respect to parameters (linear regression), linearization of models with respect to parameters, simulator vs. one-step ahead predictor, general schemes of parametric identification for continuous-time and discrete-time model structures, selected stochastic estimation methods (Least Squares, Recursive Least Squares, Extended Recursive Least Squares), comments on implementation of recursive estimation methods, adaptive recursive identification for systems with time-varying parameters (forgetting factor, covariance resetting), selected practical issues concerning system identification (the State Variable Filters method, sampling time selection, persistent excitation property of input signals, problems of identification in a closed-loop system);

B) introduction to adaptive control: a concept of adaptation and adaptive control, objectives of adaptive control, properties of an ideal and a real adaptive control system, a general scheme of an adaptive control system, remarks on applicability of adaptive systems, decision-making scheme of adaptive control application;

C) selected schemes of adaptive control systems:

- Model-Identification Adaptive Control - Self-Tuning Regulator (MIAC-STR) in the indirect approach using the certainty equivalence (CE) principle,
- Multi-Model Adaptive Control with supervised switching (MMAC),
- Model-Reference Adaptive Control (MRAC) in the direct approach with the gradient-based adaptation (MIT rule),
- Parameters/Gains Scheduling approach (P/GS),

- Lyapunov-based adaptive control schemes (LbAC),
- Active/Adaptive Disturbance Rejection Control (ADRC),

D) selected issues on practical implementation of adaptive systems,

E) examples of commercial adaptive-control systems;

Lectures are performed using multimedia presentations illustrated with simulation examples and occasional mathematical derivations on the blackboard.

Laboratory exercises are organized in the form of fifteen 2sh-long meetings (1sh = school hour = 45min.). Exercises are conducted by 2-person student groups. Laboratory program covers the following topics (simulation exercises in the Matlab-Simulink environment using synthetic data):
- simple deterministic time-response methods of SISO system identification,
- parametric identification by the batch-type Least Squares method,
- recursive parametric identification by the Least Squares method for the time-invariant and time-varying parameters,
- adaptive control in the MIAC-STR scheme with a pole-placement controller synthesis,
- adaptive control in the MRAC scheme,
- adaptive control in the ADRC scheme.

Basic bibliography:

1. Robust and Adaptive Control with Aerospace Applications, E. Lavretsky, K. A. Wise, Springer-Verlag, London, 2013
2. Adaptive Control. Second Edition, K. J. Aström,, B. Wittenmark, Addison Wesley, 1995
3. System Identification, T. Söderström, P. Stoica, Prentice Hall International, Cambridge, 1989

Additional bibliography:

1. Adaptive Control. Algorithms, Analysis and Applications, I. D. Landau, R. Lozano, M. M'Saad, A. Karimi, Springer, London, 2011
2. Stable Adaptive Systems, K. S. Narendra, A. M. Annaswamy, Dover Publications, New York, 2005
3. Robust adaptive control, P. Ioannou, J. Sun, Dover Publications, New York, 2012
4. Adaptive Control Tutorial, P. Ioannou, B. Fidan, Advances in Design and Control, SIAM, Philadelphia 2006
5. System Identification. Theory for the User. Second Edition, L. Ljung, PTR Prentice Hall, New Jersey, 1999

Result of average student's workload

Activity	Time (working hours)
1. participation in laboratory exercises: 15 x 2 h	30
2. preparation to laboratory exercises: 15 x 1 h	15
3. participation in consultations related with the course	1
4. testing the designed control schemes (outside of laboratory classes)	8
5. participation in lectures	30
6. analysis of course materials and additional literature (10 pages = 1h), 100 pages	10
7. preparation to lectures and to final examination	20
8. participation in final examination	2

Student’s workload

Source of workload	hours	ECTS
Total workload	116	4
Contact hours	63	2
Practical activities	38	1