STUDY MODULE DESCRIPTION FORM

Name of the module/subject **Adaptive Control**			Code **1010532111010539181**
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**			ECTS distribution (number and %) **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, model linearization, optimal control).
2	**Skills**	Student should also poses the ability to solve basic problems regarding the feedback control design of linear systems, should possess basic programming skills in Matlab environment and in C language (low level programming), as well as the ability to acquire additional information from various sources. The prospective student should be ready for team work activities during the course.
3	**Social competencies**	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:

1. Extension of students? knowledge in the scope of design and application of mathematical models of plants/processes based on experimental methods. Introduction to various techniques of parametric identification (with an emphasis on recursive methods) as well as their implementation and practical utilization.
2. Presentation of various adaptive control techniques with their exemplification in automatics and robotics.
3. Teaching the implementation of selected basic adaptive control algorithms in a simulation environment and in a rapid prototyping environment with the use of real plants.
4. Development of the ability to work in small teams.

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

Knowledge:

1. have an 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; knows selected model structures, knows basic methods of model validation; - [K_W5]

2. knows basic problems and their solutions related to practical application of identification methods (also in a closed-loop system); knows how to utilize the empirical models in the schemes of adaptive control; knows basic techniques of adaptive recursive identification for parameter-varying plants/processes; - [K_W5]

3. know and understand such terms as adaptation and adaptive control; know objectives of adaptive control and properties of an ideal and a real adaptive control system; know a decision scheme of application of the adaptive control schemes; - [K_W7]

4. have a basic theoretical and practical knowledge in the scope of selected adaptive control techniques: 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, Active/Adaptive Disturbance Rejection Control, Extremum-Seeking control; - [K_W8]

5. have an awareness of necessity of supervision and safety nets application in the practical adaptive control systems; know exemplary practical applications of adaptive control systems; - [K_W9]

Skills:

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

2. to select a proper adaptive control algorithm and then to implement and commission it both in simulation environment and in the selected rapid prototyping environment (for a real physical plant) - [K_U9]

3. to select a proper adaptive control algorithm and then to implement and commission it both in simulation environment and in the selected rapid prototyping environment (for a real physical plant) - [K_U22]

4. to make a multi-criteria evaluation of control quality for selected adaptive control methods   - [K_U19]

5. to properly prepare and present the results obtained during exercises - [K_U8]

Social competencies:

1. ability to work in a small team (with responsibility for a given task) - [K_K3]

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

Assessment methods of study outcomes

Total assessment:

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 OW 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 (OK < 3.0 implies negative final mark from the course);

b) Laboratory exercises: Final rating results from the overall quality assessment of the task realized by students in Part II (assessment concerns technical quality of a final written report prepared by student teams, quality of the obtained results, and a defense of the task 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:

1. 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 (State Variable Filter method, sampling time selection, persistent excitation property of input signals, problems of identification in a closed-loop system);

2. 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, general scheme of adaptive control, remarks on applicability of adaptive systems, decision-making scheme of adaptive control application;

3. selected schemes of adaptive control systems:

a. Model-Identification Adaptive Control - Self-Tuning Regulator (MIAC-STR) in the indirect approach using the certainty equivalence (CE) principle,

b. Multi-Model Adaptive Control with supervised switching (MMAC),

c. Model-Reference Adaptive Control (MRAC) in the direct approach with gradient-based adaptation (MIT rule),

d. Parameter Scheduling approach (PS),

e. Lyapunov-based adaptive control schemes (LbAC),

f. Active/Adaptive Disturbance Rejection Control (ADRC),

g. Extremum-Seeking Control (ESC) ? on-line optimization approach under uncertainty conditions;

4. selected issues on practical implementation of adaptive systems;

5. examples of practical applications of adaptive control systems.

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:

Part I (simulation exercises using synthetic data):

1. simple deterministic time-response methods of SISO system identification,
2. parametric identification by the batch-type Least Squares and Weighted Least Squares methods,
3. recursive parametric identification by the Least Squares and Extended Least Squares methods,
4. adaptive control in the MIAC-STR scheme with a pole-placement controller synthesis,
5. adaptive control in the MRAC scheme with a gradient-based adaptation rule;

Part II: design-programming tasks requiring implementation, commissioning, and testing of an adaptive control system using a selected rapid prototyping testbed equipped with a real plant.

Learning methods:

1. lectures ? multimedia presentations illustrated with simulation examples and occasional mathematical derivations on the blackboard;
2. laboratory exercises ? part I: a set of simulation exercises conducted by all students, part II: a programming/computational task performed with utilization of a physical plant (work in teams of two students; each team selects and conducts one of the predefined tasks);

Basic bibliography:

1. Adaptive Control. Second Edition, K. J. Aström,, B. Wittenmark, Addison Wesley, 1995

2. Adaptive control tutorial, P. Ioannou, B. Fidan, Advances in Design and Control, SIAM, Philadelphia 2006

3. System identification, T. Söderström, P. Stoica, Prentice Hall International, Cambridge, 1989,

Additional bibliography:

1. Adaptive control. Algorithms, analysis and applications, Second Ed., I. D. Landau, R. Lozano, M. MSaad, A. Karimi, Springer, Londyn, 2011

2. Stable adaptive systems, K. S. Narendra, A. M. Annaswamy, Dover Publications, Nowy York, 2005

3. Advanced PID control, K. J. ?ström, T. Hägglund, ISA 2006

4. Adaptive Control Design and Analysis, Gang Tao, John Wiley and Sons, Inc., 2003

5. System Identification. Theory for the User. Second Edition, L. Ljung, PTR Prentice Hall, New Jersey, 1999

6. Real-time optimization by extremum-seeking control, K. B. Ariyur, M. Krstić, Wiley-Interscience, New Jersey, 2003

Result of average student's workload

Activity	Time (working hours)

1. participation in laboratory exercises	30
2. preparation for laboratory exercises	15
3. participation in consultations related with the course	1
4. testing the designed control framework (in addition to laboratory classes)	8
5. final report preparation	5
6. participation in lectures	30
7. analysis of course materials and additional literature (10 pages = 1h),	10
8. preparation to lectures and exercises final examination:	11

Student's workload

Source of workload	hours	ECTS
Total workload	110	4
Contact hours	62	2
Practical activities	53	2