COURSE OFFERED IN THE DOCTORAL SCHOOL

Code of the course	4606-ES-000000H-0034	Name of the course	Polish	Metody optymalizacji i sterowania optymalnego w zadaniach inżynierskich	
			English	Methods of optimization and optimal control in engineering problems	
Type of the course	Advanced course				
Course coordinator	Elżbieta Jarzębowska, dr hab. inż.,prof. PW				
Implementing unit	MEiL	Scientific discipline / disciplines*	Mechanical engineering		
Level of education	Doctoral level	Semester	Winter or Summer		
Language of the course	Polish or English				
Type of assessment:	pass	Number of hours in a semester	45	ECTS credits	3
Minimum number of participants	10	Maximum number of participants	15	Available for students (BSc, MSc)	yes

Type of classes		Lecture	Auditory classes	Project classes	Laboratory	Seminar
Number of hours	in a week	1	1	1		
	in a semester	15	15	15		

* does not apply to the Researcher's Workshop

1. Prerequisites

PREREQUISITES IN KNOWLEDGE AND SKILLS
1. knowledge:
- quite good knowledge in theoretical mechanics and analytical mechanics
- quite good knowledge in mathematics at the level of ordinary differentia equations and basis in partial differentia equations,
- quite good knowledge in linear control theory.

2. **skills:**
- good command of English in speaking and understanding,
- good skills in scientific reference reviews and scientific data bases searches,
- ability for reasonable selection of information, its assessment and formulation of own conclusions and judgements,
- can use engineering commercial software and other engineering tools for scientific communication,
- can evaluate his/her ideas and their applicability in research.

2. Course objectives

1. Provide the students some portion of knowledge in optimization methods and optimal control applicable in technical problems. The scope of the lecture is: classical optimal control problems, their extensions onto new methods used in engineering.
2. Demonstrate, through the lecture structure and example selections, a kind of universality of some methods and tools, and ways of approaching problems in different research areas.
3. Demonstrate to the Participants and teach them methods of research problem formulations within optimal control.
4. Demonstrate that the path to „scientific novelty" goes through regular engineering activity, taking new challenges and through reading scientific literature.
5. Demonstrate that „difficult areas", like nonlinear control and optimal control can be mastered and you may like it.

3. Course content (separate for each type of classes)

Lecture

1. Introduction – from the brachystochrone problem to Apollo moon landing – birth and development of optimization and optimal control for engineering problems. Roots of optimization and optimal control in calculus of variations, in classical control theory and theory of random processes, linear programming and nonlinear programming (NLP). References and references overview.
2. Performance criteria in classical optimal control.
   - Qualitative and quantitative control performance criteria for linear time-invariant models with single-input-single-output (SISO) – criteria by Nyquist, Bode and Nichols.
   - Kalman theory in applications to linear time varying models with multi-input-multi-output (MIMO). A formal concept of "optimality" in control theory.

   Homework: individual studies on classical control theory – recall what you forgot or missed for some reasons.
3. Methods of linear and nonlinear programming – parameter optimization at the presence of constraints - Khun-Tucker conditions, Trajectory optimization using the NLP method, Advantages and drawbacks of optimization methods of classical control theory and NLP.
4. Modern methods and algorithms of nonlinear control - Kinematic and dynamic control models for nonlinear systems. Feedback linearization conditions for nonlinear control models.
5. Classical problems of optimal control theory - The Pontryagin method for solving optimality problems, theory of Hamilton – Jacobi, dynamic programming by Bellman, formulation of optimal control theory problems for nonlinear time varying models – examples.
6. Modern methods of optimal control theory - Nonlinear optimal feedback control, inverse optimal control for nonlinear affine system models, stability of nonlinear methods and algorithms of optimal control and inverse optimal control, computation challenges in solving optimal control problems and remedies for them.
7. An overview of latest trends in optimal control methods and applications to engineering problems. Summary of the course.

Auditory Classes

- Computation example in optimization using the LQR method.
- Examples of designing nonlinear control models, selections of control strategies and algorithms; what may be optimized?
- Examples of formulation of optimal control theory problems for nonlinear time varying models.
- Presenting individual student examples

Project Classes

1. Generate, for a given mechanical system, a nonlinear control model, design, for a given control goal, a control strategy and algorithm. Formulate an optimization problem.
2. Generate, for a given mechanical system, a nonlinear control model, design, for a given control/optimization goal, a control strategy and an optimization algorithm. Present simulation results.
3. The final project – optional.

4. Learning outcomes			
	Learning outcomes description	Reference to the learning outcomes of the WUT DS	Learning outcomes verification methods*
Knowledge			
K01	Acquisition of knowledge about the current development of optimization methods and optimal control methods for linear system models.	SD_W2	Assessment of activity during classes
K02	Acquisition of knowledge about developments of nonlinear system models and their linearizations.	SD_W2	Assessment of activity during classes

K03	Acquisition of knowledge about the algorithms and optimal control methods.	SD_W2, SD_W5	Assessment of activity during classes. Project grading
Skills			
S01	Ability of formulating optimization problems for: system model, objective function, constraints, decisive variables.	SD_U1	Project grading/presentation grading - optional
S02	Ability of formulating optimization problems for NLP applications.	SD_U1, SD_U2	Project grading/presentation grading - optional
S03	Ability of designing optimal control strategies and algorithms for nonlinear system models.	SD_U1	Project grading/presentation grading - optional
Social competences			
SC01	Understands what she/he does at the doctoral studies.	SD_K2	Assessment of activity during classes.
	Understands the need of constant learning and mastering skills and demonstrates initiatives in doing so.	SD_K1	Assessment of activity during classes.
	Follows scientific researcher good practices roles and researcher ethics.	SD_K5	Assessment of projects/presentations

*Allowed learning outcomes verification methods: exam; oral exam; written test; oral test; project evaluation; report evaluation; presentation evaluation; active participation during classes; homework; tests

5. Assessment criteria

Grading (pass or not) based upon presence on the classes and optionally activity/project submission.

6. Literature

Basic Literature:

1. Agrachev, A. 2001. Introduction to optimal control theory. Lecture notes, Summer school on mathematical control theory, Trieste, Sept. 2001.
2. Anderson, B.D. and J.B. Moore. 1989. Optimal control. Linear quadratic methods. New York: Prentice Hall.
3. Athans, M. 2004. Kalman filtering. Ch. 13 in Control system advanced methods. Boca Raton: CRC Press.
4. Chong, E.K. and S. Żak. 2001. An introduction to optimization. New York: John Wiley & Sons.
5. Gutowski, R. 1972. (Analytical mechanics) Mechanika analityczna. Warszawa: PWN.
6. Kucera, V. 2004. Riccati equations and their solutions. Ch.14 in in Control system advanced methods. Boca Raton: CRC Press.
7. Lew, A. and H. Mauch. 2007. Dynamic programming. A computational approach. Berlin: Springer.
8. Slotine, J. and W. Li. 1996. Applied nonlinear control. Englewood Cliffs, New York: Prentice Hall.

Advanced/Suplementary Literature:

1. Kwatny, H.G. and G.L. Blankenship. 2000. Nonlinear control and analytical mechanics. A computational approach. Boston: Birkhauser.
2. Khalil, H. Nonlinear systems. 2001. Englewood Cliffs, New York: Prentice Hall.
3. Nijmeijer, H. and A. van der Schaft. 1990. Nonlinear dynamical control systems. New York: Springer Verlag.
4. Murray, R.M. Z.X. Li and S.S. Sastry. 1994. A mathematical introduction to robotic manipulation. Boca Raton: CRC Press.

7. PhD student’s workload necessary to achieve the learning outcomes**		
No.	Description	Number of hours
1	Hours of scheduled instruction given by the academic teacher in the classroom	45
2	Hours of consultations with the academic teacher, exams, tests, etc.	10
3	Amount of time devoted to the preparation for classes, preparation of presentations, reports, projects, homework	30
4	Amount of time devoted to the preparation for exams, test, assessments	5
	Total number of hours	**90**
	ECTS credits	**3**

** 1 ECTS = 25-30 hours of the PhD students work (2 ECTS = 60 hours; 4 ECTS = 110 hours, etc.)