

WROCLAW UNIVERSITY OF TECHNOLOGY – PHD STUDIES

FACULTY OF PURE AND APPLIED MATHEMATICS	
SUBJECT CARD	
Course name in Polish: Kawałkami Gładkie Układy Dynamiczne – Analiza Bifurkacji i Symulacje Numeryczne	
Course name in English: Piecewise-smooth Dynamical Systems – Bifurcation Analysis and Numerical Simulations	
Course language: English	
University-wide general course type: 1) <u>basic course (mathematics, physics, chemistry, other)</u> 2) humanity course 3) managerial skills 4) English language 5) other modern language Departmental course developing professional skills: 1) specialized course 2) interdisciplinary course 3) seminar (interdisciplinary, specialized, departmental)	
Type of course (obligatory, <u>optional</u>)	
Educational effects according to ZW 26/2017 regulations: P8S_WG, P8S_UW, P8S_KK, P8S_KR	
Subject code: MAT1659	

*delete as applicable

	Lecture
Number of hours of organized classes in University (ZZU)	30
Number of hours of total student workload (CNPS)	90
Form of crediting	Exam
Number of ECTS points	3
including number of ECTS points for practical (P) classes	
including number of ECTS points for direct teacher-student contact (BK) classes	2

PREREQUISITES RELATING TO KNOWLEDGE, SKILLS AND OTHER COMPETENCES

1. Student knows real analysis and linear algebra. The knowledge of basic asymptotic and perturbation analysis techniques is useful. Ability to implement numerical methods using Matlab, or other software (e.g. Python) is also expected.
2. Student is able to search for supplementary material in various areas of knowledge.

SUBJECT OBJECTIVES

C1	Students will learn concepts and techniques which will allow local analysis of state space transitions in piecewise-smooth systems (with discontinuous vector fields and reset mappings)
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C2	Students will acquire research ability to investigate novel state space transitions in piecewise-smooth systems, as well as numerically implement analytical results to perform numerical continuation of invariant sets in model equations.
C3	Students will be able to apply piecewise-smooth systems to model system of relevance to applications as well as investigate model equations analytically and numerically in view of determining the existence, stability and qualitative changes of invariant sets under parameter variations.

SUBJECT EDUCATIONAL EFFECTS

Relating to knowledge:

PEK_W01 – Students know the description of piecewise-smooth systems by means of systems with switched vector fields (Filippovs systems) and reset mappings.

PEK_W02 – Students possess knowledge concerning the application of local bifurcation theory to analyse analytically and numerically changes in invariant sets in piecewise-smooth systems.

Relating to skills:

PEK_U01 – Student gains skills needed to perform his/her research.

PEK_U02 – Student is able to conduct his/her research.

Relating to social competences:

PEK_K01 – Student is aware of the role of cooperation, including an international cooperation.

PEK_K02 – Student is aware of the importance of original research activity.

PROGRAM CONTENTS

PROGRAM CONTENTS		
Form of classes – lecture		Number of hours
Lec 1	Canonical examples of piecewise-smooth system of relevance to applications; Introduction	2
Lec 2	Phase space topology of Filippov systems. The definition of <i>sliding flow</i> .	2
Lec 3	Bifurcations of equilibria in Filippov systems. Analysis and classification.	4
Lec 4	Poincare maps and stability analysis of limit cycles in piecewise-smooth systems. Introduction of the monodromy matrix and discontinuity mapping.	4
Lec5	Bifurcations of limit cycles in Filippov systems. Normal form map derivations.	4
Lec6	Analysis of co-dimension two bifurcations of limit cycles in Filippov systems.	4
Lec7	Systems with reset mappings; canonical example.	2
Lec8	Derivation of normal form mapping for <i>grazing bifurcations</i> in systems with reset mappings.	4
Lec9	Numerical techniques for piecewise-smooth systems. Direct numerical integration. Numerical continuation of invariant sets. Discussions and examples.	4

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	Total hours	30
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TEACHING TOOLS USED	
N1	lecture
N2	consultation
N3	homework: solving problems and exercises

EVALUATION OF ACHIEVED SUBJECT EDUCATIONAL EFFECTS		
Evaluation: F – forming (partial) C – concluding	Educational effect number	Way of evaluating achievement of educational effects
F1	PEK_U01, PEK_U02, PEK_W01, PEK_W02	attendance of lectures
F2	PEK_W01, PEK_W02, PEK_U01, PEK_U02, PEK_K01, PEK_K02	solving problems and exercises
$C = 0.5 \cdot F1 + 0.5 \cdot F2$		

PRIMARY AND SECONDARY LITERATURE
<u>PRIMARY LITERATURE:</u> [1] M. di Bernardo, C. Budd, A. R. Champneys, P. Kowalczyk, <i>Piecewise-smooth Dynamical Systems: Theory and Applications</i> (2008), Springer [2] Yu. A. Kuznetsov, S. Rinaldi, and A. Gragnani, <i>One-Parameter Bifurcations in Planar Filippov Systems</i>, Int. J. Bifurcation Chaos 13, 2157 (2003) [3] R. Seydel, <i>From Equilibrium to Chaos: Practical Bifurcation and Stability Analysis</i>, Elsevier, 1989 <u>SECONDARY LITERATURE:</u> [1] B. Nordmark and P. Kowalczyk, <i>A codimension-two scenario of sliding solutions in grazing-sliding bifurcations</i>, Nonlinearity 19(1), pp. 1-26, 2006 [2] P. Kowalczyk, M. di Bernardo, A. R. Champneys, S. J. Hogan, M. Homer, Yu. A. Kuznetsov, A. B. Nordmark and P. T. Piiroinen, <i>Two-parameter nonsmooth bifurcations of limit cycles: classification and open problems</i>, International Journal of bifurcation and chaos, Vol. 16 No. 3, pp.601-629, 2006 [3] P. T. Piiroinen and Yu. A. Kuznetsov <i>An Event-Driven Method to Simulate Filippov Systems with Accurate Computing of Sliding Motions</i>, in ACM Transactions on Mathematical Software 34(3), May 2008

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[4] F. Dercole and Yu. A. Kuznetsov, *SlideCont: An Auto97 Driver for Bifurcation Analysis of Filippov Systems*

SUBJECT SUPERVISOR (NAME AND SURNAME, E-MAIL ADDRESS)
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**MATRIX OF CORRELATION BETWEEN EDUCATIONAL EFFECTS
FOR SUBJECT
PIECEWISE-SMOOTH DYNAMICAL SYSTEMS – BIFURCATION ANALYSIS AND
NUMERICAL SIMULATIONS
AND EDUCATIONAL EFFECTS FOR MAIN FIELD OF STUDY
Doctoral studies at Faculty of Pure and Applied Mathematics**

Subject educational effect	Correlation between subject educational effect and educational effects defined for main field of study and specialization (if applicable)**	Subject objectives** *	Programme content***	Teaching tool number***
(knowledge) PEK_W01	P8S_WG	C1,C2	Lec1-10	N1, N2, N3
PEK_W02	P8S_WG	C1,C2	Lec1-10	N1, N2, N3
(skills) PEK_U01	P8S_UW	C2	Lec1-10	N2, N3
PEK_U02	P8S_UW	C2,C3	Lec1-10	N2, N3
(competences) PEK_K01	P8S_KK	C3	Lec1-10	N1, N2
PEK_K02	P8S_KR	C3	Lec1-10	N1, N2

** - enter symbols for main-field-of-study/specialization educational effects

*** - from table above