Національний технічний університет України
«КИЇВСЬКИЙ ПОЛІТЕХНІЧНИЙ ІНСТИТУТ
імені ІГОРЯ СІКОРСЬКОГО»

MMCA

Department of Mathematical Methods of System Analysis

Analysis of Complex Systems by Machine Learning Methods Work program of the discipline (Syllabus)

Details of the discipline	
Level of higher education	***Third (educational and scientific)***
Field of knowledge	*12 Information Technology*
Speciality	*124 System Analysis*
Educational program	*System Analysis*
Discipline status	*Custom*
Form of study	*full-time (daytime)/full-time (evening)/part-time/remote/mixed*
Year of preparation, semester	*2nd year, autumn/spring semester*
Scope of discipline	*4 ECTS credits*
Semester control / control measures	*Passed*
Timetable	
Language of instruction	*Ukrainian/English*
Information about Course Leader / Instructors	Lecturer: *Doctor of Physical and Mathematical Sciences, Professor, Corresponding Member of the National Academy of Sciences of Ukraine Kasyanov Pavlo Olehovych, kasyanov.pavlo@lll.kpi.ua https://www.facebook.com/pkasyanov https://www.linkedin.com/in/pavlokasyanov/ https://www.researchgate.net/profile/Pavlo_Kasyanov* Practical / Seminar: *Doctor of Physical and Mathematical Sciences, Professor, Corresponding Member of the National Academy of Sciences of Ukraine Kasyanov Pavlo Olehovych*, kasyanov.pavlo@lll.kpi.ua https://www.facebook.com/pkasyanov https://www.linkedin.com/in/pavlokasyanov/ https://www.researchgate.net/profile/Pavlo_Kasyanov
Course Placement	https://piazza.com/national_technical_university_of_ukraine_igor_sikorsky_kyiv_polytechnic_institute/spring2022/mlcs/resources

The program of the discipline

1. Description of the discipline, its purpose, subject of study and learning outcomes

The purpose *of the credit module is to form the abilities of applicants for the third level of higher education (PhD) to formulate, analyze and synthesize scientific tasks in the field of information technology and system analysis at an abstract level, to critically analyze the positive and negative qualities of existing methods of system analysis, as well as to assess their possibilities for further use in solving specific scientific and practical problems, to accept scientifically based solutions in conditions of uncertainty, which requires the development of new methods, and the conduct of research and innovation activities, deep analysis and creation of new methods of data and knowledge analysis, research of weakly structured problems, development of new methods for their further use. In particular, to assimilate existing and create new methods and algorithms for approximating generalized solutions of complex nonlinear systems in special classes of spaces with nonlinear and multivalued Volterra-type mappings using recurrent neural networks using open software libraries for machine learning TensorFlow and Keras with applications to problems of approximate solution of classes of nonlinear partial derivatives with admissibly nonlinear non-monotonic* *differential operators of divergent type and nonlinear boundary value problems. The advantages lie in the ability to make effective approximations of solutions for problems with acceptably multivalued nonlinearities, in particular, without the uniqueness of solutions of the corresponding Cauchy problems, which is important for applications to nonlinear DRFP, nonlinear boundary value problems and control and optimization problems in infinite-dimensional spaces, and PhD students should master the following* ***competencies****:*

general - *GC 4 Ability to independently conduct research activities, including analysis of problems, setting goals and objectives, selection of means and methods of research, as well as assessment of its quality; GC 5 Ability to initiate, plan, implement and adjust a sequential process of thorough scientific research; GC 6 Ability to critically analyze, evaluate, and synthesize new and complex ideas; GC 7 Ability for continuous self-development and self-improvement;*

professional *– FC 1 Ability to initiate complex projects using a systematic approach and implement them independently; FC 2 Ability to comply with moral and ethical rules of conduct, research ethics, characteristics for participants in the academic environment, as well as the rules of academic integrity in scientific research; FC 3 Ability to critically analyze the positive and negative qualities of existing methods of system analysis, as well as to assess their capabilities for further use in solving specific scientific and practical problems; FC 4 Ability to make scientifically sound decisions in conditions of uncertainty, which requires the development of new methods and the conduct of research and innovation activities; FC 5 Ability to carry out research and professional activities at an interdisciplinary level; FC 6 Ability to deeply analyze and create new methods for analyzing data and knowledge; FC 7 Ability to perform research on loosely structured problems, develop new methods, and then solve them; FC 8 Ability to plan and conduct scientific research, prepare, present and publish the results of research activities.*

Upon completion of the course, applicants for the third level of higher education should ***acquire the following program learning outcomes:*** *PRN 4 Know the advantages and disadvantages of existing methods of system analysis and the possibility of their use to solve specific scientific and applied problems in intelligent decision support systems; PRN 5 Know the basics of the organization of the research scientific process to solve significant problems in the field of system analysis, be able to apply knowledge of the basics of analysis and synthesis in various subject areas, critical comprehension and solution of research problems; PRN 10 Be able to create new methods of system analysis and mathematical models of complex systems of various nature; PRN 11 Be able to develop and use new methods for analyzing complex systems and new methods of decision-making under uncertainty; PRN 12 Be able to critically analyze the advantages and disadvantages of known methods of system analysis, as well as be able to assess the possibilities of their use to solve specific scientific and practical problems; PRN 13 Be able to develop scientific projects in the field of system analysis; PRN 14 Be able to implement the results of scientific research based on the methods of system analysis; PRN 15 Be able to solve complex problems in the field of system analysis or as a result of research and innovation activities, which involves a deep rethinking of existing and the creation of new holistic knowledge; PRN 17 Read and understand foreign texts in the specialty; freely present and discuss with specialists and non-specialists the results of research, scientific and applied problems of the industry in the state and foreign languages, competently reflect the results of research in scientific publications in leading international scientific journals; PRN 18 Adhere to the rules of academic integrity; know and adhere to the basic principles of academic integrity in scientific and educational (pedagogical) activities.*

Subject of study.

Complex Nonlinear Systems in Special Classes of Infinite-Dimensional Distribution Spaces.

The main tasks of the credit module.

According to the requirements of the program of the discipline, postgraduate students after mastering the credit module must demonstrate the following learning outcomes:

***Knowledge**:*

methods and tools of machine learning for the analysis of complex systems.

***Skills**:*

regularization of non-smooth and multivalued nonlinearities of differential-operator equations and inclusions in special classes of distribution spaces using Yohida and Bertsekas methods. With the help of the method of artificial control, learn to justify new a priori estimates, prove new theorems on regularity and convergence for generalized solutions. For regularized tasks, investigate the topology of approximating neural networks. Develop an algorithm for the implementation of approximate solution methods using TensorFlow and Keras software libraries for machine learning. The results are to be implemented on specific test and applied problems with partial derivatives with permissible nonlinear non-monotonic differential operators of divergent type and nonlinear boundary value problems

***Experience**:*

creation of a research laboratory for the analysis of complex systems (a paradigm of organized cooperation based on the experience of leading national laboratories in the United States), where the role of each team member is to specialize in a particular task in order to become the best in it, while having a holistic view of the entire process.

2. Prerequisites and post-requisites of the discipline (place in the structural and logical scheme of training in the relevant educational program)

Basic level of English, higher mathematics, programming.

3. The content of the discipline

Credit module 1.

1. *Topology of an approximating neural network for classes of differential-operator equations and inclusions of Volterra type;*
2. *Methods and algorithms for approximate solution of classes of differential-operator equations and inclusions using open software libraries for machine learning TensorFlow and Keras;*
3. *Approximate solution of classes of partial derivative nonlinear problems with admissibly nonlinear non-monotone differential operators of divergent type and nonlinear boundary value problems using recurrent neural networks using open software libraries for machine learning TensorFlow and Keras.*

Recommended topics of practical (seminar) classes

The purpose of conducting practical classes is to consolidate the knowledge acquired at lectures, to acquire the ability to solve real problems of qualitative and quantitative analysis of complex systems using methods and tools of machine learning.

1. *study of the topology of an approximating neural network for classes of differential-operator equations and inclusions of the Volterra type;*
2. *machine learning of stable approximating dynamical systems;*
3. *study of stability and substantiation of new a priori estimates for solutions of differential-operator equations and inclusions in special classes of infinite-dimensional spaces with Volterra-type mappings;*

4. *proving the main theorems on the convergence of algorithms for the approximate solution of differential-operator equations and inclusions in special classes of distribution spaces with nonlinear and multivalued Volterra-type mappings using recurrent neural networks;*
5. *development of methods and algorithms for approximate solution of classes of differential-operator equations and inclusions using open software libraries for machine learning TensorFlow and Keras;*
6. *approximate solution of classes of partial derivative nonlinear problems with admissibly nonlinear non-monotonic differential operators of divergent type and nonlinear boundary value problems using recurrent neural networks using open software libraries for machine learning TensorFlow and Keras.*

4. Training Materials & Resources

All the necessary materials are contained on the Piazza platform

https://piazza.com/national_technical_university_of_ukraine_igor_sikorsky_kyiv_polytechnic_institute/spring2022/mlcs/resources

Basic literature:

1. *Zgurovsky, Michael Z., and Pavlo O. Kasyanov. Qualitative and Quantitative Analysis of Nonlinear Systems. Springer, Cham, 2018.*
2. https://www.tensorflow.org/
3. https://keras.io/
4. *Maria Laura Piscopo, Michael Spannowsky, and Philip Waite Solving differential equations with neural networks: Applications to the calculation of cosmological phase transitions // Phys. Rev. D 100, 016002 – Published 9 July 2019*
5. *MohamadAli Torkamani, Phillip Wallis, Shiv Shankar, Amirmohammad Rooshenas Learning Compact Neural Networks Using Ordinary Differential Equations as Activation Functions // 2019, arXiv:1905.07685*

Further reading:

6. *Isaac Elias Lagaris, Aristidis Likas, and Dimitrios I. Fotiadis Artificial Neural Networks for Solving Ordinary and Partial Differential Equations // IEEE Transactions On Neural Networks, Vol. 9, No. 5, 1998*
7. *Ken-ichi Funahashi, Yuichi Nakamura Approximation of dynamical systems by continuous time recurrent neural networks // Neural Networks Volume 6, Issue 6, 1993, Pages 801-806*

Educational content

5. Methods of mastering the discipline (educational component)

5.1. Lectures

Salary No.	Title of the topic of the lecture and a list of the main questions (list of didactic aids, references to literature and tasks for the SRS)
1	Topology of an approximating neural network for classes of differential-operator equations and inclusions of Volterra type [1-7];
2	Methods and algorithms for approximate solution of classes of differential-operator equations and inclusions using open software libraries for machine learning TensorFlow and Keras [1-7];

3	*Approximate solution of classes of nonlinear partial derivatives problems with admissibly nonlinear non-monotonic differential operators of divergent type and nonlinear boundary value problems using recurrent neural networks using open software libraries for machine learning TensorFlow and Keras [1-7];*

5.2. Practical exercises

The purpose of conducting practical classes is to consolidate the knowledge gained in lectures, to acquire the ability to solve real problems using methods and tools of machine learning

Salary No.	*Name of the topic of the lesson (list of didactic support, links to literature and tasks for the SRS)*
1	*study of the topology of an approximating neural network for classes of differential-operator equations and inclusions of the Volterra type [1-7];*
2	*machine learning of stable approximating dynamical systems [1-7];*
3	*study of stability and substantiation of new a priori estimates for solutions of differential-operator equations and inclusions in special classes of infinite-dimensional spaces with Volterra-type mappings [1-7];*
4	*proving the main theorems on the convergence of algorithms for the approximate solution of differential-operator equations and inclusions in special classes of distribution spaces with nonlinear and multivalued Volterra-type mappings using recurrent neural networks [1-7];*
5	*development of methods and algorithms for approximate solution of classes of differential-operator equations and inclusions using open software libraries for machine learning TensorFlow and Keras [1-7];*
6	*approximate solution of classes of partial derivative nonlinear problems with admissibly nonlinear non-monotonic differential operators of divergent type and nonlinear boundary value problems using recurrent neural networks using open software libraries for machine learning TensorFlow and Keras [1-7];*

6. Independent work of a student/graduate student

Students' independent work consists in processing materials and completing tasks on the Piazza distance learning platform https://piazza.com/national_technical_university_of_ukraine_igor_sikorsky_kyiv_polytechnic_institute/spring2022/mlcs/resources *; preparation for the test.*

Policy & Control

7. Academic discipline policy (educational component)

Proper completion of all tasks on the Piazza distance learning platform is required https://piazza.com/national_technical_university_of_ukraine_igor_sikorsky_kyiv_polytechnic_institute/spring2022/mlcs/resources *according to the requirements and individual strategy, which is determined by the graduate student independently or, if necessary, under the scientific guidance of the teacher / supervisor.*

8. Types of control and rating system for assessing learning outcomes (CRO)

Current control: *each student determines the strategy for completing tasks (independently or, if necessary, under the scientific guidance of the teacher / supervisor), aiming to receive 100 points at the end of the semester.*

Types of control:

1) two answers (each student on average) in practical classes (provided that an average of 8 students are interviewed in one lesson with a maximum group size of 30 people);

2) performance of one test (remotely – tests and tasks).

RATING POINTS SYSTEM

1. Practical lesson

The maximum number of points in all practical classes is 20 points X 2 = 40 points.

Evaluation criteria:

0-8 points – the problem is not solved, while the student has certain theoretical information about the topic of the practical lesson;

9-14 points – the problem is not fully solved or the solution contains gross technical shortcomings, while the student is fluent in theoretical information about the topic of the practical lesson;

15-20 points – the problem is solved as a whole, while the student is fluent in theoretical information about the topic of the practical lesson.

2. Modular control.

The maximum number of points for a test (project) is 60 points.

Evaluation criteria:

0-20 points – the problem as a whole has not been solved or the solution contains gross technical shortcomings, there is no answer to the theoretical question;

21-50 points – the problem is solved as a whole, the theoretical issue is disclosed;

51-60 points – the problem is solved, the answer to the theoretical question is exhaustive.

Penalty and incentive points for:

- performance of tasks to improve didactic materials in disciplines is given from 15 to 30 incentive points.

According to the results of academic work in the first 7 weeks, the "ideal student" should score 20 points. At the first attestation (8th week), a student receives an "enrolled" if his current rating is not less than 10 points. According to the results of 13 weeks of study, the "ideal student" should score 40 points. At the second attestation (14th week), the student receives "passed" if his current rating is not less than 20 points. The maximum amount of points is 100. A prerequisite for admission to the test is a positive mark on the test. To receive credit from the credit module "automatically", you need to have a rating of at least 60 points, as well as a credited test (more than 30 points). Students who have a rating of less than 60 points at the end of the semester, as well as those who want to improve their grade in the ECTS system, complete the test work. At the same time, the points for the test are added to the points for the test work, and this rating score is final. The control task of this work consists of two questions of the work program from the list provided in the methodological recommendations for mastering the credit module. An additional question on the topics of practical classes is given to students who did not take part in the work of a particular practical lesson. An unsatisfactory answer to an additional question lowers the overall score by 4 points.

Each question is scored out of 20 points according to the grading system:

– "excellent", full answer (at least 90% of the required information) – 20... 18 points;

– "good", a fairly complete answer (at least 75% of the required information, or minor inaccuracies) – 17... 14 points;

– "satisfactory", incomplete answer (at least 60% of the required information and some errors) – 13... 11 points;
– "unsatisfactory", unsatisfactory answer – 0 points.
Sum of points: for each of the two questions of the test and the test, it is transferred to the credit grade according to the table.

Points Score
100… 95 Excellent
94… 85 Very Good
84… 75 Good
74… 65 Satisfactory
64… 60 Enough
Less than 60 Unsatisfactory
R&D Not Credited Not Allowed

9. Additional information on the discipline (educational component)

All the necessary materials are contained on the Piazza learning platform
https://piazza.com/national_technical_university_of_ukraine_igor_sikorsky_kyiv_polytechnic_institute/spring2022/cscphd/resources

Work program of the discipline (syllabus):

Compiled by Director of IASA, Doctor of Physical and Mathematical Sciences, Professor, Kasyanov Pavel Olegovich

Academician of the National Academy of Sciences of Ukraine, Doctor of Technical Sciences, Prof. Mikhail Zakharovich Zgurovsky

Approved by the Department of Mathematical Methods of System Analysis (Minutes No. 13 dated 05.06.2024)

Approved by the Methodological Commission of the Faculty (Minutes No. 10 dated 24.06.2024)