Syllabus
Course Program

Ill-posed problems of data processing

Specialty
113 Applied mathematics

Institute
Educational and Scientific Institute of Computer Science and Information Technology

Educational program
Intelligent Data Analysis

Department
Computer Mathematics and Data Analysis

Level of education
Master's level

Course type
Special (professional), Mandatory

Semester
2

Language of instruction
English

Lecturers and course developers

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General information

Summary

The discipline is aimed at studying methods of solving inverse problems of data analysis under conditions of uncertainty. The main uncertainty models, concepts and properties of inverse problems of data analysis are considered. The main method of solving inverse ill-posed problems under conditions of uncertainty is described, namely, the regularization method, the most common methods of regularization in the statistical and non-statistical description of problems are considered. General methods are illustrated by examples of solving typical incorrect data processing problems, assessing the state of static and dynamic systems

Course objectives and goals

The purpose of studying the discipline is to study the theory and methods of solving inverse problems of the analysis of uncertain data, methods of regularization of ill-posed problems, estimation of parameters and state of static and dynamic systems by indirect measurements under conditions of uncertainty.

Format of classes

Lectures, laboratory classes, consultations, self-study. Final control in the form of an exam.

Competencies

GC 4. Ability to identify, pose and solve problems in professional activities.

GC 7. Ability to work with information: find and use information from various sources, necessary for solving professional tasks.
GC 10. Ability to carry out professional scientific and project-production activities in an international environment.
SC 1. The ability to formulate a mathematical formulation of a problem, relying on the formulation in the language of the subject field, to check the correctness of the formulation under conditions of uncertainty.
SC 5. Ability to conduct mathematical and computer modeling and computing experiments, collection, visualization, analysis and processing of received data, solving formalized problems with the help of specialized software tools.
SC 10. The ability to choose, develop, research and apply mathematical models and methods for intellectual analysis of data in conditions of uncertainty.
SC 11. Ability to develop, research and apply mathematical methods and algorithms of machine learning, soft computing and computational intelligence for analysis of uncertain data, forecasting and decision-making

Learning outcomes

LO 5. Build effective algorithms for numerical research of mathematical models and data analysis, decision-making that are effective in terms of calculation accuracy, stability, speed, and consumption of system and computing resources.
LO 8. To be able to apply in practical work specialized software products and software systems of computer mathematics, big data analysis, etc.
LO 12. Know and understand modern methods of solving mathematical problems of statistical and intellectual data analysis, forecasting, etc.
LO 14. Be able to apply existing and develop new algorithms and software tools for statistical and intellectual analysis of uncertain data.

Student workload

The total volume of the course is 150 hours (5 ECTS credits): lectures - 32 hours, laboratory classes - 32 hours, self-study - 86 hours.

Course prerequisites

"Mathematical methods of machine learning", "Nonlinear processes and models".

Features of the course, teaching and learning methods, and technologies

Lectures are conducted interactively using multimedia technologies. Laboratory work is carried out using free software - Python libraries Pandas, SkiPy, SkyLab, machine learning library Scikit-Learn.

Program of the course

Topics of the lectures

Topic 1. Uncertain data evaluation
Uncertain data of measurements and observations.
Mathematical models of uncertain data - interval, statistical, fuzzy data. Statistical and robust evaluation.
Topic 2. Inverse problems of data analysis
Inverse problems. Restoration of functions and fields, processing of signals and images. Properties of the inverse operator.
Topic 3. Ill-posed problems
Well-posed and ill-posed problems. Well-posed according to Hadamard. Solution noise sensitivity.
Ill-conditioned systems of linear matrix equations. Matrix conditioning number.
Singular value decomposition. Eigen and singular numbers and eigen vectors.
Diagonalization of matrices. Singular value decomposition of square and rectangular matrices.
Topic 4. Regularization of ill-posed problems
Regularization according to A.N. Tikhonov. Selection of the regularization parameter.
Regularization by truncated SVM.

Regression recovery problem, multicollinearity. Least squares method.
Regularized regression. Ridge and Lasso regression.
Regression under uncertainty.
Classes of distributions as models of uncertain data. Choice of loss function, Vapnik-Huber loss function.
Topic 5. Regularization under uncertainty.
Regularization under statistical description of uncertain data.
Regularization under interval description of uncertain data.
Ellipsoidal approximations of uncertainty.
Topic 6. Systems state and input estimation
Statistical estimation of the state of static systems.
Recurrent statistical estimation of the state of dynamic systems.
The "prognosis - recovery" scheme, Kalman filter.
Restoration of input signals of dynamic systems. Inverse dynamic systems design.
Synthesis based on the theory of unknown input observer.

Topics of the workshops

Absent

Topics of the laboratory classes

Topic 1. Uncertain data statistical evaluation
Lab. 1. Study of models of uncertain data.
Lab. 2. Research of statistical and robust estimation.
Topic 2. Numerical methods and algorithms studying
Lab. 3. Study of numerical methods of solving the system of linear matrix equations
Lab. 4. Study of numerical methods of diagonalization and singular decomposition of matrices.
Topic 3. Numerical optimization methods studying
Lab. 5. Study of numerical methods of minimization of the quadratic functional.
Lab. 6. Study of numerical methods for solving ill-posed regression recovery problems.
Topic 4. System state estimation studying
Lab. 7. Study of numerical methods of statistical estimation of the state of static systems.
Lab. 8. Study of numerical methods of statistical estimation of the state of dynamic systems.

Self-study

Topic 1. Studying methods of describing uncertainty in data. Studying methods of robust statistics.
Work on examples of ill-conditioned systems of equations. Study of the theory of singular decomposition
Topic 2. Study of the theory of optimization under constraints of the type of inequalities.
Lagrange multiplier method, penalty function method.
Topic 3. Study of the theory of regularization according to the method of A.N. Tikhonov. Learning the least squares method for linear models with uncertain data. Study of the theory of regularized MNC.
Topic 4. Study of methods of statistical assessment of the state of static systems. Study of the Kalman filter algorithm. Study of the theory of inverse dynamic models.
Control and assessment of self-training is carried out in the form of performance of control tasks, seminars, etc.

Course materials and recommended reading

1. Guillaume Bal. Introduction to Inverse Problems. University of Chicago, Chicago. 2019. https://www.stat.uchicago.edu/~guillaumebal/PAPERS/IntroductionInversePro blems.pdf.
2. Yury Korolev, Jonas Latz. Inverse Problems. Lecture notes. University of Cambridge, 2020. 96 p. https://www.damtp.cam.ac.uk/research/cia/files/teaching/Inverse_Problems_2020/LectureNotes2020.pdf
3. Christian Clason. Regularization of inverse problems. Lecture notes. Graz Uni. 2020. https://imsc.uni-graz.at/clason/skripte/InverseNotes.pdf
4. David Di Ruscio. State estimation and Kalman filter. University of South-Eastern Norway. 2019. http://www.davidr.no/iia2217/pensum/main_estim_e2.pdf
5. Shuyang Ling. SVD and Principal Component Analysis. New York University Shanghai. 2020.

https://cims.nyu.edu/~sling/MATH-SHU-236-2020-SPRING/MATH-SHU-236-Lecture-1-2-3-PCASVD.pdf
6. Lectures on Inverse Problems and Imaging. GitHub Pages. 2024.
https://tristanvanleeuwen.github.io/IP_and_Im_Lectures/intro.html

Assessment and grading

Criteria for assessment of student performance, and the final score structure

Description of the final score structure, course requirements, and necessary steps to earn points, especially paying attention to self-study and individual assignments.

Grading scale

Total points	National	ECTS
90–100	Excellent	A
82–89	Good	B
75–81	Good	C
64–74	Satisfactory	D
60–63	Satisfactory	E
35–59	Unsatisfactory (requires additional learning)	FX
1–34	Unsatisfactory (requires repetition of the course)	F

Norms of academic integrity and course policy

The student must adhere to the Code of Ethics of Academic Relations and Integrity of NTU "KhPI": to demonstrate discipline, good manners, kindness, honesty, and responsibility. Conflict situations should be openly discussed in academic groups with a lecturer, and if it is impossible to resolve the conflict, they should be brought to the attention of the Institute's management.
Regulatory and legal documents related to the implementation of the principles of academic integrity at NTU "KhPI" are available on the website: http://blogs.kpi.kharkov.ua/v2/nv/akademichna-dobrochesnist/

Approval

Approved by

Date, signature
31.08.2023

Head of the department
Olena AHIEZER

Date, signature
31.08.2023

Guarantor of the educational program
Leonid LYUBCHYK