



COURSE DESCRIPTION CARD - SYLLABUS

Course name

DIAGNOSTICS OF TECHNICAL DEVICES WITH MACHINE LEARNING METHODS [S5AEEITK>DUT]

Course

Proposed by Discipline

—

Year/Semester

2/4

Level of study

Doctoral School

Course offered in

English

Form of study

full-time

Requirements

elective

Number of hours

Lecture

8

Laboratory classes

0

Other

0

Tutorials

0

Projects/seminars

0

Number of credit points

2,00

Coordinators

dr hab. inż. Wojciech Pietrowski prof. PP
wojciech.pietrowski@put.poznan.pl

Lecturers

dr hab. inż. Wojciech Pietrowski prof. PP
wojciech.pietrowski@put.poznan.pl

Prerequisites

The course is intended for doctoral candidates representing various scientific and engineering disciplines who are interested in the diagnosis, monitoring and analysis of technical systems. A general understanding of the operation of technical devices and systems, as well as an ability to interpret measurement data, is recommended. Doctoral candidates should possess basic knowledge of mathematics relevant to engineering and scientific research, including elementary statistics, data representation and graphical interpretation of results. Familiarity with the general principles of experimental research, measurement systems, data acquisition and basic signal analysis will be helpful. Basic ability to use scientific-computing, data-analysis or programming environments, such as MATLAB, Python or equivalent software, is an advantage. However, advanced programming skills, prior practical experience in technical diagnostics, or previous experience with machine-learning algorithms are not required. All machine-learning concepts and their application to fault detection and classification are introduced during the course. The course requires readiness for independent work, critical analysis of scientific literature and technical data, and preparation of an individual report in English on a selected diagnostic problem.

Course objective

The objective of the course is to provide doctoral candidates with an advanced and interdisciplinary understanding of technical equipment diagnostics, with particular emphasis on the application of signal-processing and machine-learning methods to fault detection, identification and classification. The course aims to develop the ability to formulate diagnostic problems, identify relationships between fault mechanisms and measurable diagnostic symptoms, and select appropriate measurement signals and analytical methods. Doctoral candidates will become familiar with selected methods of diagnostic signal processing, including spectral analysis based on the Fast Fourier Transform (FFT), wavelet transform and correlation analysis, used to extract and interpret features related to the technical condition of equipment. A further objective is to introduce a complete data-driven diagnostic workflow, including the acquisition and preparation of measurement data, selection of diagnostic features, construction of datasets, choice of machine-learning methods, validation of classification results and critical assessment of their reliability and limitations. The course also aims to develop the doctoral candidates' ability to independently design and critically evaluate a diagnostic methodology for a selected technical system. Particular attention is given to the responsible use of measurement data, scientific evidence and machine-learning methods, taking into account such issues as data quality, uncertainty, limited availability of fault data, class imbalance, overfitting, interpretability and the practical applicability of diagnostic results.

Course-related learning outcomes

Knowledge

Knows and understands global achievements, including theoretical foundations and selected specific issues relevant to technical equipment diagnostics, signal processing and machine-learning-based fault classification. (P8S_WG/SzD_W01)

Knows and understands key development trends in technical diagnostics, condition monitoring and data-driven methods applied to the assessment of technical equipment condition. (P8S_WG / SzD_W02)

Knows and understands scientific research methodology in the field of technical diagnostics, including the formulation of a diagnostic problem, selection of research methods and tools, diagnostic-signal analysis, feature extraction, classification and interpretation of results. (P8S_WG / SzD_W03)

Skills

Can use knowledge from different branches of science to creatively identify and formulate a complex diagnostic problem related to technical equipment, define the aim and subject of analysis, propose a research hypothesis, develop a diagnostic methodology and draw conclusions on the basis of analysis results. (P8S_UW / SzD_U01)

Can critically analyse and assess the results of diagnostic-signal processing and machine-learning-based fault classification, including their reliability, limitations and contribution to the development of knowledge in technical diagnostics. (P8S_UW / SzD_U02)

Can communicate on specialist issues related to technical equipment diagnostics, signal processing and machine learning at a level enabling active participation in the international scientific community. (P8S_UK / SzD_U04)

Social competencies

Is ready to critically assess achievements within the field of technical diagnostics, including methods and results related to signal analysis and machine-learning-based fault classification. (P8S_KK / SzD_K01)

Is ready to maintain and develop the ethos of research and creative communities by conducting independent scientific activity and respecting the principles of intellectual property protection when using diagnostic data, methods and scientific sources. (P8S_KR / SzD_K07)

Methods for verifying learning outcomes and assessment criteria

Learning outcomes presented above are verified as follows:

Learning outcomes are verified through an individual diagnostic case study prepared independently by each doctoral candidate. The assessment is based on a written report in English and an individual oral presentation or technical discussion with the course instructor.

The doctoral candidate selects, or is assigned, a diagnostic problem concerning an electrical machine, transformer, electromechanical converter or another technical device. The topic may be related to the doctoral candidate's research area, provided that the selected problem enables the application and critical assessment of diagnostic signal-processing and machine-learning methods.

The final report shall be prepared in English and should have a recommended length of 6–10 pages,

excluding references and appendices. It shall contain:

1. formulation of the technical and research problem,
2. description of the diagnosed object, selected fault mechanism or degradation process, and expected diagnostic symptoms,
3. selection and justification of diagnostic signals, measurement quantities, sensors or available datasets,
4. proposal of a signal-processing procedure, including at least one selected method: Fast Fourier Transform, wavelet transform or correlation analysis,
5. identification and justification of fault-related diagnostic features,
6. proposal of a machine-learning-based classification procedure, including fault classes, feature vector, selected classifier, data-division method and validation strategy,
7. critical evaluation of the reliability, limitations and practical applicability of the proposed methodology, including data quality, limited dataset size, class imbalance, overfitting, data leakage and uncertainty,
8. conclusions and a bibliography based on relevant scientific literature.

The report may be based on the doctoral candidate's own measurement, simulation or experimental data. If such data are not available, the doctoral candidate may prepare a literature-based case study or use an openly available dataset. Programming implementation is not mandatory; the assessment concerns the scientific correctness, methodological justification and critical evaluation of the proposed diagnostic procedure.

Programme content

The course covers the fundamentals of technical equipment diagnostics, condition monitoring and predictive maintenance, including key terminology such as technical condition, degradation, fault, failure, diagnostic symptom, diagnostic parameter and diagnostic signal. The diagnostic process is discussed as a sequence of activities involving the selection of the technical object and measurement signals, data acquisition, preprocessing, feature extraction, diagnostic decision-making and interpretation of results. Particular attention is given to the relationship between physical fault mechanisms and measurable diagnostic symptoms, as well as to current challenges in technical diagnostics, including measurement noise, uncertainty, variable operating conditions, non-stationary signals and limited availability of fault data. The course addresses diagnostic problems in electromechanical converters, electric motors and transformers. It includes typical mechanical, electrical, magnetic and thermal fault mechanisms, as well as selected examples of stator-winding faults, rotor faults, bearing faults, air-gap eccentricity, permanent-magnet demagnetisation, insulation degradation, magnetic-core faults and transformer-winding faults. The selection of diagnostic signals, measurement quantities, sensors and measurement locations is considered together with the influence of load, supply conditions, operating point and environmental factors on the reliability of diagnostic decisions.

The course also presents methods for the acquisition, preparation and processing of diagnostic signals. The topics include sampling, filtering, normalization, segmentation and disturbance reduction; time-domain analysis and statistical descriptors; frequency-domain analysis using the Fast Fourier Transform; interpretation of spectral components and fault-related frequency patterns; wavelet transform for the time-frequency analysis of non-stationary signals and transient phenomena; and correlation analysis for identifying relationships between diagnostic signals, operating conditions and fault symptoms. Methods for extracting, selecting and interpreting diagnostic features are discussed, with emphasis on the influence of signal quality and operating-condition variability on feature reliability.

Finally, the course introduces the use of machine-learning methods for technical fault classification. This includes the preparation of diagnostic datasets, definition of diagnostic classes and labels, construction of feature vectors, and division of data into training, validation and test sets. Selected supervised learning methods, including k-nearest neighbours, support vector machines, decision trees, random forests and artificial neural networks, are discussed. The course covers classifier selection, validation and assessment using a confusion matrix, accuracy, precision, recall, specificity and F1-score. Particular emphasis is placed on critical evaluation of the practical applicability and limitations of machine-learning methods, including overfitting, underfitting, class imbalance, data leakage, uncertainty, interpretability and transferability of diagnostic models.

Course topics

Lecture 1. Fundamentals of technical equipment diagnostics

Purpose, scope and terminology of technical diagnostics, condition monitoring and predictive maintenance. Technical condition, degradation mechanism, fault, failure, diagnostic symptom, diagnostic parameter and diagnostic signal.

General structure of a diagnostic system: technical object, sensors, measurement system, data acquisition, signal preprocessing, feature extraction, decision-making and interpretation.

Sources of diagnostic information, including electrical, magnetic, vibration, acoustic, thermal and operational signals.

Relationship between physical fault mechanisms and measurable diagnostic symptoms.

Fundamental challenges of modern technical diagnostics: noise, interference, variable operating conditions, non-stationary signals, measurement uncertainty and limited access to fault data.

Overview of current trends in technical diagnostics, including data-driven diagnostics, condition monitoring, predictive maintenance and the integration of signal-processing and machine-learning methods.

Lecture 2. Diagnostics of electromechanical converters, electric motors and transformers

Diagnostic problems in electromechanical converters, electric motors and power transformers.

Typical mechanical, electrical, magnetic and thermal fault mechanisms.

Examples of faults in induction motors, permanent-magnet machines and transformers.

Selected diagnostic symptoms of stator-winding faults, rotor faults, bearing faults, eccentricity, demagnetisation, insulation degradation, core faults and transformer winding or magnetic-circuit faults.

Measurement quantities used in diagnostics: current, voltage, magnetic flux, vibration, acoustic emission, temperature, speed and torque.

Selection of sensors and measurement locations.

Influence of load, supply conditions, operating point and environmental conditions on diagnostic signals and the reliability of diagnostic decisions.

Examples of research and industrial applications of condition monitoring in electrical equipment.

Lecture 3. Signal processing for fault-feature extraction

Acquisition and preparation of diagnostic signals: sampling, filtering, segmentation, normalization and removal of trends and disturbances.

Time-domain analysis and selected statistical parameters of diagnostic signals.

Frequency-domain analysis using the Fast Fourier Transform.

Interpretation of spectral components and fault-related frequency patterns in diagnostic signals.

Time-frequency analysis using wavelet transform, with particular emphasis on non-stationary signals and transient phenomena.

Correlation analysis for identifying relationships between diagnostic signals, operating conditions and fault symptoms.

Extraction, selection and interpretation of diagnostic features.

Influence of data quality, measurement uncertainty and operating-condition variability on the reliability of extracted features.

Lecture 4. Machine learning for fault classification

Role and scope of machine learning in technical diagnostics and condition monitoring.

Construction of a diagnostic dataset: diagnostic classes, labels, feature vectors, data quality and representativeness.

Division of datasets into training, validation and test sets.

Selected supervised machine-learning methods for fault classification: k-nearest neighbours, support vector machines, decision trees, random forests and artificial neural networks.

Principles of classifier selection and hyperparameter tuning.

Evaluation of classification performance: confusion matrix, accuracy, precision, recall, specificity and F1-score.

Causes and consequences of overfitting, underfitting, class imbalance and data leakage.

Interpretability, uncertainty and transferability of machine-learning models.

Critical assessment of the applicability of machine-learning methods in research and industrial diagnostic systems.

Teaching methods

The course is delivered through interactive lectures supported by multimedia presentations, practical diagnostic examples and discussion of selected research and industrial case studies. The teaching process combines the presentation of theoretical foundations with the critical analysis of diagnostic problems related to technical equipment, electromechanical converters, electric motors and transformers.

The lectures include guided interpretation of diagnostic signals and examples of signal-processing procedures, including spectral analysis, wavelet analysis and correlation analysis. Selected examples of

machine-learning-based fault classification are used to illustrate the complete diagnostic workflow, from data acquisition and feature extraction to classifier selection, validation and critical interpretation of results. Doctoral candidates are encouraged to actively participate in discussions, analyse selected scientific publications and relate the presented methods to their own research interests. The teaching process is supplemented by individual self-study and preparation of an independent diagnostic case study, in which the doctoral candidate proposes and critically evaluates a signal-processing and machine-learning-based diagnostic procedure for a selected technical problem.

Bibliography

Basic

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Randall, R. B., Vibration-based Condition Monitoring: Industrial, Automotive and Aerospace Applications, 2nd ed., Wiley, Chichester, 2021.

Lei, Y., Intelligent Fault Diagnosis and Remaining Useful Life Prediction of Rotating Machinery, Butterworth-Heinemann, Oxford, 2016.

Bishop, C. M., Pattern Recognition and Machine Learning, Springer, New York, 2006.

Mallat, S., A Wavelet Tour of Signal Processing: The Sparse Way, 3rd ed., Academic Press, 2008.

Additional

Jardine, A. K. S., Lin, D., Banjevic, D., "A review on machinery diagnostics and prognostics implementing condition-based maintenance," Mechanical Systems and Signal Processing, 20(7), 1483–1510, 2006.

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Frosini, L., "Novel Diagnostic Techniques for Rotating Electrical Machines—A Review," Energies, 13(19), 5066, 2020. <https://doi.org/10.3390/en13195066>

Lei, Y., Li, N., Guo, L., Li, N., Yan, T., Lin, J., "Machinery health prognostics: A systematic review from data acquisition to RUL prediction," Mechanical Systems and Signal Processing, 104, 799–834, 2018. <https://doi.org/10.1016/j.ymssp.2017.11.016>

Zhao, R., Yan, R., Chen, Z., Mao, K., Wang, P., Gao, R. X., "Deep learning and its applications to machine health monitoring," Mechanical Systems and Signal Processing, 115, 213–237, 2019.

Breakdown of average student's workload

	Hours	ECTS
Total workload	50	2,00
Classes requiring direct contact with the teacher	8	0,50
Doctoral student's own work (literature studies, preparation for laboratory classes/tutorials, preparation for tests/exam, project preparation)	42	1,50