COURSE DESCRIPTION CARD - SYLLABUS

Course name

Theory and Signal Processing

Course

Field of study	Year/Semester
Automatic Control and Robotics	2/3
Area of study (specialization)	Profile of study
-	general academic
Level of study	Course offered in
First-cycle studies	Polish
Form of study	Requirements
full-time	compulsory

Number of hours

Lecture	Laboratory classes	Other (e.g. online)
45	30	0
Tutorials	Projects/seminars	
30	0	

Number of credit points

8

Lecturers

Responsible for the course/lecturer:

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Prerequisites

The student starting this course should have basic knowledge of mathematics and statistics. Should have computer skills, spreadsheet skills, and be willing to learn to use other computer programs such as Matlab. The student should be able to obtain information from the indicated sources. Should also understand the need to expand his/her competences, be able to search for information sources and be ready to cooperate within the team. In addition, in terms of social competences, the student must present attitudes and features such as: honesty, responsibility, perseverance, cognitive curiosity, creativity, creative thinking, diligence, reliability, personal culture, good upbringing, respect for other people, care for laboratory equipment.

Course objective

1. Provide students with the basics of knowledge about signal processing techniques and teach how to use this knowledge in practice.

2. Developing students' problem-solving skills related to the selection of appropriate signal processing techniques for specific purposes with the use of computer systems.

3. Teaching the correct application of methods of signal analysis and processing.

Course-related learning outcomes

Knowledge

The student acquires knowledge in the field of mathematics including algebra, geometry, analysis, probability and elements of discrete mathematics and logic (K1_W1, K1_W5), including mathematical methods and numerical methods necessary for: description and analysis of the properties of linear and basic nonlinear dynamic and static systems, description and analysis of complex quantities, description of random processes and uncertain quantities, description and analysis of combinational and sequential logic systems, description of algorithms of control and analysis of the stability of dynamic systems, description, analysis and methods of signal processing in the time and frequency domain, numerical simulation of dynamic systems in the domain of continuous time and discrete time. The student also acquires basic knowledge of the operation and use of IT tools for these purposes (K1_W10).

Skills

As a result of the course, the student should demonstrate skills in the use of basic methods of signal processing and analysis in the time and frequency domain and extract information from the analyzed signals (K1_U9).

Social competences

The students are ready to critically assess the acquired knowledge, understands and feels the need for continuous training and improvement of professional, personal and social competences, can inspire and organize the learning process of other people (K1_K1). He is also aware of the need for a professional and responsible approach to technical issues, scrupulous reading of the documentation and environmental conditions of the used devices. Moreover, he is ready to follow the rules of professional ethics and requires it from others, respects the diversity of views (K1_K5).

Methods for verifying learning outcomes and assessment criteria

Learning outcomes presented above are verified as follows:

The learning outcomes presented above are verified as follows:

Formative assessment:

a) in the field of lectures - on the basis of answers to questions about the material discussed in previous lectures,

b) in the field of laboratories / tutorials - on the basis of the assessment of the knowledge and understanding of the current issues presented in the course.

Summative assessment:

a) in the field of lectures, verification of the assumed learning outcomes is carried out by: assessing the knowledge and skills shown in the problem-based written exam (however, the use of auxiliary materials, including electronic devices, is not allowed during the exam), the exam consists of 4 problem tasks; on the exam, the student can get 20 points, a minimum of 10 points must be obtained for a positive mark, for outstanding students the exam may have elements of checking knowledge spread over time in the form of self-performed tasks using a variety of auxiliary materials, the examination results are discussed by providing comprehensive solutions to the problems considered on the Internet at www.dsp.put.poznan.pl

b) in terms of tutorials, verification of the assumed learning outcomes is carried out by: assessing the student's preparation for individual classes, continuous assessment, at each class (oral answers) - rewarding the increase in the ability to use the learned principles and methods, assessment of solving tasks partially solved during classes and partially after their completion, the assessment of knowledge and skills related to solving tasks through a final test

c) in the field of laboratories, verification of the assumed learning outcomes is carried out by: assessing the student's preparation for individual laboratory classes and assessing the skills related to the implementation of laboratory exercises, continuous assessment, during each class (oral answers) - rewarding the increase in the ability to use the learned principles and methods, evaluation of the report partially prepared during the classes, and also after their completion (this evaluation also takes into account the ability to work in a team of 2-3 people).

There is a possibility of obtaining additional points for activity during classes, in particular for: discussing additional aspects of the issue, the effectiveness of applying the acquired knowledge when solving a given problem, the ability to cooperate as part of a team practically implementing a detailed task in the laboratory, comments related to the improvement of teaching materials, indicating perceptual difficulties of students, enabling ongoing improvement of the teaching process.

Programme content

The lecture program includes the following topics:

1. Basic signal parameters (DC and AC components of the signal, energy, signal power and RMS value of signal, orthogonal signals, signal correlation coefficient, standard deviation and signal variance, covariance matrix, signal histogram, energy and power signal normalization, center and length of signal, signal level).

2. Signal energy and power (finite and infinite in time signals, periodic signals, orthogonal signals, signal sum power and orthogonal signals).

3. Fourier series and transformations (the concept of signal transformation, Fourier series, Fourier series in complex form - signal spectrum (DFS), Gibbs effect, Fourier transformation (FT), Parseval-Rayleigh

theorem, examples of Fourier transformation, impulse (Dirac pseudo-function), Discrete Time Fourier Transformation (DtFT), Discrete Fourier Transformation (DFT), Multivariate Fourier Transformation).

4. Representation of continuous signals (Laplace transformation and Fourier transformation, limit theorems, transient and steady state responses in automation systems).

5. Discrete Fourier Transformation (DFT) (variants of DFT, "butterfly" two-point DFT, computational complexity of DFT, fast Forurier transformation (FFT) - "divide and conquer", distribution of DFT samples on the complex plane, signal distribution on harmonics, optical Fourier transformation, computing DFT in Matlab environment, two- and multidimensional DFT, standard and optical 2D DFT transformation, discrete trigonometric transformations (DTTs), discrete cosine transformations (DCTs), discrete sine transformations (DSTs), JPEG image compression standard).

6.Signal sampling (example of digital photography, sampling concept and process, non-ideal sampling, sampled signal spectrum, continuous signal recovery - sampling theorem, signal sampling, perfectly sampled signal spectrum, Fourier representation, two interpretations of the spectrum of a discrete signal, strict formulation of sampling theorem, sampling of band signals, reconstruction of a continuous signal, Kell coefficient).

7. Interpretations of Shannon's theorem (cardinal series, aliasing and strobe effect)

8. Quantization of signals (digital signal - binary stream, quantization noise, compression and expansion, differential PCM representation, delta modulation, pulse width modulation (PWM), sigma-delta modulation).

9. Binary representations of signal samples (can computers be trusted indiscriminately?, binary representations of natural numbers, octal and hexadecimal representations of numbers, "negative" bits - binary representations of integers, CSD code, numbers and calculations in the U2 code, conversion of integers to binary system, maximal digit's complement and positional system base, BCD codes, fractional representations, Qn format, floating point representations).

10. Convolution (continuous convolution, discrete linear and circular convolution, convolution versus correlation, geometric interpretation, linear system response, determination of the convolution by DFT method)

11. Z transformation (continuous-analog world versus discrete-digital world, concept of Z transformation, regions of convergence of Z transformation, uniqueness of right-hand Z transformation, Laurent series, holomorphic functions and Cauchy-Riemann equations, residuum, theorem about residues, properties of Z transformation, limit theorems, Z transform table, signal convolution and convolution transform, inverse Z transformations).

12. Discrete dynamical systems (concept and properties of linear stationary discrete systems, stability of a discrete system, description of linear stationary discrete systems, convolution of discrete signals, structures of digital filters, recursive digital filters - filters with infinite impulse response (IIR), non-recursive digital filters - filters with finite impulse response (FIR), basic implementations of digital filters).

13. Random signals and signal correlations (the concept of a random variable, the concept of a stochastic process, ergodic stochastic process, sequence of autocorrelation, covariance, basics of estimation, estimators of the correlation function).

14. Filtering of discrete signals (description of digital filters, recursive digital filters (IIR filters), non-recursive digital filters (FIR filters), basic (direct) realizations of IIR digital filters, signal flow graphs and Mason's formula, cascade and parallel realizations of IIR filters, description of discrete systems in the state space, implementations of digital FIR filters, FIR filters with linear phase characteristics, advantages and disadvantages of FIR filters compared to IIR filters).

15. Elements of information theory and data coding (formal definition of information - entropy and autoinformation, entropy properties, total entropy, conditional entropy and shared information, data coding, prefix code concept, Kraft's inequality, lossless data compression, Shannon coding theorem, coders and their efficiency, Shannon encoder, Shannon-Fano encoder, Huffman encoder (optimal encoder), arithmetic encoder).

16. Spectrum estimation (periodogram, Welch estimators).

17. Hurwitz polynomial (notion of Hurwitz polynomial and modified Hurwitz polynomial, necessary conditions to be met by the Hurwitz polynomial, Hurwitz stability criterion, Routh stability criterion, test fraction, test fraction realizability criterion as an LC immittance).

18. Filtering of random signals (processing of discrete random signals, noise, white noise and Gaussian noise, adding noise, mutually weakly stationary processes, spectral power density, random signal filtration process, Wiener-Chinczyn theorem, Wiener filter, Kalman filter - description in space states).

19. Conversion of the probability density in automation systems (passage of the probability density function through a linear system, passage of the probability density function through a non-linear system, generation of a random signal using the inverse distribution function).

20. Theory of approximation (polynomial filters: Butterworth filters, Chebyshev filters, rational filters: inverse Chebyshev filters, generalized Chebyshev filters, Cauer-elliptical filters).

21. Designing of digital filters (ideal low-pass filter, stages of designing of digital filters, filter tolerance diagram, brilliant but unfortunate idea for designing FIR filters, the problem of approximating the characteristics of continuous-time (analog) filters, transformation of reference (analog) filters into digital filters, digital filters wave and orthogonal, frequency transforms).

22. Image processing (human eye, three-stimulus theory of vision, Grassmann's laws, basic colors and matching functions, color as a vector in color space, RGB space, chromatic coordinates, luminance and chrominance, CMY and CMYK spaces, HSL (HSI) and HSB (HSV) spaces, multidimensional dynamic operations, multidimensional linear systems, multidimension convolution, linear stationary systems, separable systems).

23. Human-computer interfaces (voice, iris, fingerprints).

The tutorials program includes the following topics:

1. Basic parameters of signals.

2. Fourier series and transformations.

3. Representation of continuous signals (Laplace transform).

4. Discrete Fourier Transformation (DFT).

5. Signal sampling.

6. Quantization of signals.

7. Linear and circular convolution and correlation.

8. Colloquium.

9. Linear dynamic systems. The Z transformation.

10. Random signals and signal correlations. Random signal filtration.

11. Elements of information theory and data coding.

12. Hurwitz polynomials. Analog and digital filters.

13. Convertion of the probability density in automation systems.

14. Image processing.

15. Colloquium.

Laboratory classes are conducted in two cycles (hardware and software), which take place one after another. Laboratory classes are carried out by teams of 2-3 students.

The hardware cycle uses modern teaching stations from National Instruments (USA), which include ELVIS II (Educational Laboratory Virtual Instrumentation Suite) measurement systems with Emona DATEx overlays dedicated to this course. These kits cooperate with PC computers via specialized software - the so-called virtual measuring instruments operating in the LabVIEW environment. During the course, students use a variety of measuring devices for the study and analysis of signals, including from a virtual spectrum analyzer, frequency characteristics analyzer (Bode), as well as from a virtual oscilloscope. They get acquainted in practice with the operation of basic circuits and functional blocks related to signal processing, such as the sampling-memory (S&H) circuit, multiplier, adder with adjustable weights, phase shifter, comparator, white noise generator, tunable filters, PCM encoder/decoder, signal and sequences generators). The hardware cycle consists of the following activities:

1. Introduction to Emona environment.

2. Sampling and reconstruction of signals.

3. Investigation of the phenomenon of aliasing.

4. PCM coding and decoding.

5. Signal noise and SNR parameters determination.

6. Detection of digital signals in the transmission channel.

The program cycle includes classes at computer workstations equipped with the Matlab programming environment. During the course, students carry out the following exercises:

1. Introduction to Matlab.

2. Basic parameters of signals.

3. Estimators of the correlation function - radar simulator.

4. Fourier series - signal analysis and synthesis.

5. Properties of DFT.

6. Convolution and filtration.

7. Test completing the software cycle.

The last, 14th class is planned for the summary of the laboratory and for the performance of exercises by students with excused disability during the earlier classes.

Teaching methods

1. Lecture: multimedia presentation, presentation illustrated with examples given on the board, solving problems, multimedia show, demonstration.

2. Tutorials: task solving, problem solving, case studies.

3. Laboratory classes: practical exercises, carrying out experiments, solving tasks, team work.

Bibliography

Basic

1. Dąbrowski A., "Teoria i przetwarzanie sygnałów", zestaw sfilmowanych wykładów, www.put.poznan.pl, e-learning Moodle, wykłady otwarte, PolitechnikaPoznańska, Poznań 2020 oraz materiały do wykładów wraz z zadaniami egzaminacyjnymi z rozwiązaniami na stronie www.dsp.put.poznan.pl

2. Dąbrowski A. i in., "Przetwarzanie sygnałów przy użyciu procesorów sygnałowych", Wydawnictwo Politechniki Poznańskiej, Poznań 1998.

3. Florek A., Mazurkiewicz P., "Sygnały i systemy dynamiczne. Interpretacje – przykłady – zadania", Wyd. II PP, Poznań 2015.

4. Smith S. W., "Cyfrowe przetwarzanie sygnałów - praktyczny poradnik dla inżynierów i naukowców", BTC, Warszawa 2007.

5. Lyons R.G., "Wprowadzenie do cyfrowego przetwarzania sygnałów", WKŁ, Warszawa 1999.

6. Szabatin J., "Podstawy teorii sygnałów", Wyd. WKŁ, Warszawa 2007.

7. Wojciechowski J., "Sygnały i systemy", Wyd. WKŁ, 2008.

8. Zieliński T.P., "Cyfrowe przetwarzanie sygnałów: od teorii do zastosowań", Wyd. WKŁ, Warszawa 2013.

Additional

1. MitOpenCourseWare, Massachusetts Institute of Technology, http://ocw.mit.edu/ (courses: 6.011 "Introduction to Communication, Control, and Signal Processing", 6.003 "Signals and Systems").

2. Oppenheim A.V., Schafer R.W., "Cyfrowe przetwarzanie sygnałów", Wyd. WKŁ, Warszawa 1979.

3. Oppenheim A.V., Willsky A.S., Nawab S.H., "Signals & Systems", Pearson, 2016.

Breakdown of average student's workload

	Hours	ECTS
Total workload	200	8
Classes requiring direct contact with the teacher	105	4,0
Student's own work (literature studies, preparation for laboratory classes and tutorials, preparation for tests and exam)[1]	95	4,0

[1] delete or add other activities as appropriate