| UČNI NAČRT PREDMETA / COURSE SYLLABUS | |
|---|---|
| **Predmet:** | Matematično modeliranje kompleksnih sistemov |
| **Course title:** | Mathematical Modeling of Complex Systems |

| Študijski program in stopnja<br>Study programme and level | Modul<br>Module | Letnik<br>Academic year | Semester<br>Semester |
|---|---|---|---|
| Informacijske in komunikacijske tehnologije, 2. stopnja | Digitalna transformacija | 1 | 2 |
| Information and Communication Technologies, 2nd cycle | Digital Transformation | 1 | 2 |

**Vrsta predmeta / Course type** Izbirni / Elective

**Univerzitetna koda predmeta / University course code:** IKT-615

| Predavanja<br>Lectures | Seminar<br>Seminar | Sem. vaje<br>Tutorial | Lab. vaje<br>Laboratory work | Druge oblike | Samost. delo<br>Individ. work | ECTS |
|---|---|---|---|---|---|---|
| **15** | **15** | | | **15** | **105** | **5** |

**Navedena porazdelitev ur velja, če je vpisanih vsaj 15 študentov. Drugače se obseg izvedbe kontaktnih ur sorazmerno zmanjša in prenese v samostojno delo. / This distribution of hours is valid if at least 15 students are enrolled. Otherwise the contact hours are linearly reduced and transfered to individual work.*

**Nosilec predmeta / Lecturer:** Prof. dr. Đani Juričić

| **Jeziki / Languages:** | | |
|---|---|---|
| | **Predavanja / Lectures:** | slovenščina, angleščina / Slovenian, English |
| | **Vaje / Tutorial:** | |

| **Pogoji za vključitev v delo oz. za opravljanje študijskih obveznosti:** | **Prerequisites:** |
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| Zaključen študijski program prve stopnje s področja naravoslovja, tehnike ali računalništva. | Student must complete first-cycle study programmes in natural sciences, technical disciplines or computer science. |

| **Vsebina:** | **Content (Syllabus outline):** |
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| **1) Uvod**<br>Faze procesa sinteze modela, osnove nelinearne dinamike.<br><br>**2) Kompleksna dinamika**<br>Modeli kompleksnih in samo-organizirajočih sistemov; determinizem, prediktabilnost in kavzalnost v (kompleksnih) dinamičnih sistemih; stohastični procesi, Fokker-Planckova enačba; sinhronizacija.<br><br>**3) Analiza kompleksnih dinamičnih sistemov**<br>Spektralne metode (Fourierjeva in valčna analiza), Lyapunov eksponent, korelacijska | **1) Uvod**<br>Basic steps of the model synthesis process, basics of nonlinear dynamics<br><br>**2) Complex dynamics**<br>Models of complex and self-organizing systems; determinism, predictability and causality in (complex) dynamic systems; stochastic processes, Fokker- Planck equation; synchronization.<br><br>**3) Analysis of complex dynamic systems**<br>Spectral methods (Fourier and vawelet analysis), Lyapunov exponent, correlation dimension. |

dimenzija.

**4) Sodobni koncepti simulacije**
Osnove numerične integracije; stabilnost, konvergenca, natančnost. Simulacija sistemov diferencialno-algebrajskih enačb. Simulacija modelov s porazdeljenimi parametri; metoda končnih elementov, brezmrežne metode (s primeri iz ekologije, prevajanja toplote, Black-Scholes finančni model).
Simulacija stohastičnih sistemov (Monte Carlo pristopi, Markovske verige). Nekaj orodij za simulacijo: Matlab, Simulink, Femlab.

**5) Sinteza modelov kompleksnih dinamičnih sistemov iz podatkov**
Osnove linearne regresije in metode instrumentalnih spremenljivk. Identifikacija neparametričnih modelov (nevronske mreže, Gaussovi procesi). Bayesov pristop k identifikaciji kompleksnih dinamičnih sistemov. Primeri aplikacij.

**4) Advanced simulation**
Basics of numerical integration. Simulation of differential-algebraic equations. Simulation of models with distributed parameters; method of final elements, offline methods (with examples from ecology, heat conduction, Black-Scholes financial model).
Simulation of stochastic systems (Monte Carlo approaches, Markov chains). Simulation tools: Matlab, Simulink, Femlab.

**5) Data driven modelling of complex dynamic systems**
Basics of linear regression and instrumental variables method. Nonparametric model identification (neural networks, Gaussian processes). Bayesian approach to the identification of complex dynamic systems. Applications.

**Temeljna literatura in viri / Readings:**


- H. Sayama (2015). Introduction to the Modeling and Analysis of Complex Systems, Open SUNY Textbooks, Milne Library, Geneseo, NY.
- Y.W. Kwon (2015). Multiphysics and Multiscale Modeling: Techniques and Applications. CRC Press
- L. Ljung (2016). Modeling & Identification of Dynamic Systems, Studentlitteratur AB;
- J.N. Kutz (2013). Data-Driven Modeling & Scientific Computation: Methods for Complex Systems & Big Data, Oxford University Press, Oxford.
- X. Han, P. E. Kloeden (2017). Random Ordinary Differential Equations and Their Numerical Solution. Springer, Singapore.
- J. Kocijan (2016). Modelling and Control of Dynamic Systems Using Gaussian Process Models, Springer. London.
- S.A. Billings (2013). Nonlinear System Identification NARMAX Methods in the Time, Frequency, and Spatio-Temporal Domains. Wiley, Chichester.
- J. N. Kutz, S.l. Brunton, B.W. Brunton, J.l. Proctor (2016), Dynamic Mode Decomposition: Data-Driven Modeling of Complex Systems. Oxford University Press, Oxford.
- U. Spagnolini (2018). Statistical Signal Processing in Engineering. Wiley, Chichester.


**Cilji in kompetence:**

Matematično modeliranje je izrazito generična in interdisciplinarna znanstvena veja, katere znanja se uporabljajo v domala vseh vejah naravoslovnih, tehničnih in e-znanosti. Namen predmeta je seznaniti slušatelje z izbranimi temami iz problematike sinteze modelov kompleksnih dinamičnih procesov, njihove simulacije in kalibracije. Predstavljene bodo osnovne tehnike in

**Objectives and competences:**

Mathematical modelling is a distinctly generic and interdisciplinary branch of science which is applied in almost all branches of natural, technical and, last but not least, e-science. The purpose of this course is to present selected topics related to the issues of the synthesis of models for complex dynamic processes, their simulations and calibration. The presentation will include basic techniques and ideas,

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| ideje, razpoložljiva orodja za modeliranje in simulacijo ter zgledi praktične uporabe.<br><br>Študent bo sposoben načrtovanja modelov na podlagi osnovnih fizikalnih načel in načrtovanja modelov iz podatkov. | available modelling and simulation tools and examples of their practical use.<br><br>The student will be able to design models based on basic physical principles and design models from data. |

| **Predvideni študijski rezultati:** | **Intended learning outcomes:** |
|---|---|
| Študenti bodo z uspešno opravljenimi obveznostmi tega predmeta pridobili:<br>• razumevanje procesa modeliranja dinamičnih sistemov<br>• sposobnost povezovanja sistemskih znanj in matematičnih orodij pri sintezi modela dinamičnega procesa,<br>• sposobnost uporabe teoretičnih znanj v praksi,<br>• delo v multidisciplinarnih skupinah<br>• dokumentiranje in diseminacija rezultatov dela na mednarodnem nivoju<br>• sposobnost reševanja zahtevnejših problemov modeliranja<br>• razumevanje dinamike kompleksnih sistemov<br>• spoznavanje osnovnih orodij za simulacijo dinamičnih sistemov | Students successfully completing this course will acquire:<br>• understanding of the process modeling cycle<br>• the ability to combine knowledge of systems sciences and mathematical tools in model synthesis<br>• the ability to apply theoretical knowledge in practice<br>• co-operation in multi-disciplinary teams<br>• documentation and dissemination of results on the international level<br>• ability to solve non-trivial modelling problems<br>• understanding the complex systems dynamics<br>• familiarity with modern simulation tools |

| **Metode poučevanja in učenja:** | **Learning and teaching methods:** |
|---|---|
| • predavanja<br>• seminarji<br>• laboratorijsko delo | • lectures<br>• seminar work<br>• laboratory work |

| **Načini ocenjevanja:** | Delež (v %) / Weight (in %) | **Assessment:** |
|---|---|---|
| Seminar | 50 % | Seminar |
| Ustni izpit | 50 % | Oral exam |

**Reference nosilca / Lecturer's references:**


• Mileva-Boshkoska, B., Boškoski, P., Debenjak, A., Juričić, Đ. Dependence among complex random variables as a fuel cell condition indicator. Journal of Power Sources, [in press], 26 str., 2015.

• Debenjak, A., Boškoski, P., Musizza, B., Petrovčič, J., Juričić, Đ. Fast measurement of proton exchange membrane fuel cell impedance based on pseudo-random binary sequence perturbation signals and continuous wavelet transform. Journal of Power Sources, 254, 112-118, 2014.

• Boškoski, P., Gašperin, M., Petelin, D., Juričić, Đ. Bearing fault prognostics using Rényi entropy based features and Gaussian process models. Mechanical Ssystems and Signal Processing, 11 str.,2014

• Moura O. P. B., Vrančić, D., Boaventura C.J., Solteiro P. E.J. Teaching particle swarm optimization through an open-loop system identification project. Computer Applications in Engineering Education, 22(2), 227-237, 2014



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