AVTONOMNI SISTEMI PAMETNIH TOVARN

UČNI NAČRT PREDMETA/COURSE SYLLABUS

Predmet:	AVTONOMNI SISTEMI PAMETNIH TOVARN
Course title:	AUTONOMOUS SYSTEMS OF SMART FACTORY
Članica nosilka/UL Member:	UL FS

Študijski programi in stopnja	**Študijska smer**	**Letnik**	**Semestri**	**Izbirnost**
Strojništvo, tretja stopnja, doktorski	Proizvodno inženirske znanosti, kibernetika in mehatronika (smer)	1. letnik, 2. letnik	1. semester, 2. semester	izbirni

Univerzitetna koda predmeta/University course code:	0033472
Koda učne enote na članici/UL Member course code:	7317

Predavanja /Lectures	**Seminar /Seminar**	**Vaje /Tutorials**	**Klinične vaje /Clinical tutorials**	**Druge oblike študija /Other forms of study**	**Samostojno delo /Individual student work**	**ECTS**
90					160	10

Nosilec predmeta/Lecturer:	Niko Herakovič

Izvajalci predavanj:	Niko Herakovič
Izvajalci seminarjev:	
Izvajalci vaj:	
Izvajalci kliničnih vaj:	
Izvajalci drugih oblik:	

Izvajalci praktičnega usposabljanja:	
Vrsta predmeta/Course type:	Izbirni predmet /Elective course

Jeziki/Languages:	Predavanja/Lectures:	Slovenščina
	Vaje/Tutorial:	Slovenščina

Pogoji za vključitev v delo oz. za opravljanje študijskih obveznosti:	**Prerequisites:**
Veljajo splošni pogoji za doktorski študij.	General prerequisites for the third level studies.

Vsebina:	**Content (Syllabus outline):**
1. Definicija in utemeljitev pametne tovarne kot avtonomnega sistema in procesa. Razlogi in potrebni pogoji za uvanaje koncepta avtonomnih pametnih tovarn (APT). Koncepti, sistemi in procesi APT, 2. Vertikalna in horizontalna integracija, mrežna struktura APT, IoT in IIOT, »Top down« in »Bottom-up« pristop. 3. Arhitekturni modeli pametnih tovarn (RAMI 4.0, LASFA) - kdaj, zakaj in kako jih lahko uporabimo. 4. Tehnologije, ki so potrebne za funkcioniranje APT (pregled tehnologij, naloge in osnovni koncepti elemntov APT, načrtovanje in ovrednotenje APT sistemov). 5. Naročila in delovne operacije - avtonomno planiranje zaporedja delovnih operacij in resursov. 6. Oblikovanje in razvoj izdelkov za čim bolj učinkovito delovanje APT. 7. Avtomatizirani in pametni ročni sistemi APT, fleksibilna in agilna avtomatizacija APT, modularna zasnova APT sistemov, uporaba razširjene resničnosti pri pametnih ročnih delovnih mestih. 8. Robotizirani sistemi APT- vključitev avnomno delujočih robotov v sisteme	1. Definition and justification of smart factories as autonomous systems and processes. Reasons and necessary conditions for the introduction of the concept of autonomous smart factories (APT). Concepts, systems, and processes of APT. 2. Vertical and horizontal integration, network structure of APT, IoT and IIoT, "Top-down" and "Bottom-up" approaches. 3. Architectural models of smart factories (RAMI 4.0, LASFA) - when, why, and how they can be used. 4. Technologies required for the functioning of APT (overview of technologies, tasks, and basic concepts of APT elements, planning, and evaluation of APT systems). 5. Orders and work operations - autonomous planning of the sequence of work operations and resources. Design and development of products for the most efficient operation of APT. 6. Automated and smart manual systems APT, flexible and agile automation APT, modular design of APT systems, use of augmented reality in smart manual workstations. 7. Robotic systems APT - integration of autonomous robots into APTR systems, flexible, agile, and self-configurable robotic assembly cells, robotic assembly

APTR, fleksibilne, agilne in predvsem samo-konfigurabilne robotizirane montažne celice, robotizirane montažne linije. 9. Modulani sistemi in povezljivost za postavitev fleksibilnih, adaptabilnih in agilnih konceptov proizvodnih linij v APT. 10. Senzorika in aktorika v sistemih APT, avonomija delovanja APT z vključevanjem sistemov strojnega vida in drugih inteligentnih senzorjev. 11. Ključni pristopi razvoja pametnih tovarn - pametna proizvodnja, sledljivost in ovezljivost preko oblaka, pametna naprave – M2M, 5G in 6G komunikacijske tehnologije in algoritmi, računanje na robu, pametni izdelki, pametna logistika materiala in informacij, velepodatki in prediktivna analitika, dinamično planiranje. 12. Koncept distribuiranih sistemov APT, distribuirani sistemi in njihove značilnosti, omogočitvene tehnologije distribuiranih sistemov, povezljivost med objekti in subjekti, komunikacijski protokoli, delovanje v realnem času, fleksibilnost in agilnost. 13. Pet-dimenzionalno modeliranje digitalnih dvojčkov (DD) vseh proecseov APT in njihove ključne tehnologije. 14. Koncept krmiljenja pametne proizvodnje z digitalnimi agenti - DA (Umetna inteligenca – AI) in digitalnimi dvojčki - ključne tehnologije AI za gradnjo DA. 15. Optimiranje porabe resursov in energije proizvodnih sredstev, kibernetsko-fizična spojitev v proizvodnji, krmiljeni z AD in DD (fizični elementi, modeli, podatki, storitve), prognostika delovanja pametne proizvodnje z AD in DD. 16. DA in DD ter nove tehnologhije – računanje v oblaku, »Edge computing« in hibridni sistemi, velepodatki, storitve, virtualna in razširjena resničnost.	lines. 8. Modular systems and connectivity for setting up flexible, adaptable, and agile concepts of production lines in APT. 9. Sensing and actuation in APT systems, autonomy of operation of APT by incorporating machine vision systems and other intelligent sensors. 10. Key approaches to the development of smart factories - smart manufacturing, traceability and traceability via the cloud, smart devices - M2M, 5G and 6G communication technologies and algorithms, edge computing, smart products, smart material and information logistics, big data, and predictive analytics, dynamic planning. 11. Concept of distributed APT systems, distributed systems and their characteristics, enabling technologies of distributed systems, connectivity between objects and subjects, communication protocols, real-time operation, flexibility, and agility. 12. Five-dimensional modeling of digital twins (DD) of all APT processes and their key technologies. 13. Concept of controlling smart production with digital agents - DA (Artificial Intelligence - AI) and digital twins - key AI technologies for building DA. 14. Optimization of resource and energy consumption of production assets, cyber-physical connection in production, controlled by DA and DD (physical elements, models, data, services), prognostics of smart production operation with DA and DD. 15. DA and DD and new technologies - cloud computing, Edge computing, and hybrid systems, big data, services, virtual and augmented reality.

Temeljna literatura in viri/Readings:

[1] Boothroyd, G.: Assembly Automation and Product Design, 2nd ed., Boca Raton, FL: Taylor & Francis/CRC Press, 2005, COBISS.SI-ID – 26842117
[2] Groover, Mikell P.: Automation, production systems, and computer-integrated manufacturing, 5th ed., New York (NY): Pearson, cop. 2019, COBISS.SI-ID – 146606595
[3] Phanden, Rakesh Kumar | Ajai, Jain | Davim, J. Paulo: Integration of process planning and scheduling: approaches and algorithms, London; New York : CRC Press, Taylor & Francis, 2020, [COBISS.SI-ID – 17409539].
[4] Gao, Vincent: Smart manufacturing principles and applications, knjiga, [S. l.: V. Gao], cop. 2021, [COBISS.SI-ID – 146626819].
[5] Groover, Mikell P.: Fundamentals of modern manufacturing: materials, processes, and systems, 7th ed., Hoboken (NJ): John Wiley & Sons, cop. 2020, [COBISS.SI-ID – 146641667].
[6] NOVAK, Tina, POVH, Janez, ŽEROVNIK, Janez. Izbrana poglavja iz operacijskih raziskav. Ljubljana: Fakulteta za strojništvo, 2020. 227 str., ilustr. ISBN 978-961-6980-73-9. [COBISS.SI-ID 38246915]
[7] Shtub, Avraham ; Cohen, Yuval: Introduction to industrial engineering, 2nd ed., Boca Raton; London; New York: CRC Press, Taylor & Francis, cop. 2016, [COBISS.SI-ID – 38399749].
[8] Hopkinson, N.: Rapid manufacturing: an industrial revolution for the digital age, Chichester, England; Hoboken, NJ: John Wiley, cop. 2006, [COBISS.SI-ID – 11614258].

Cilji in kompetence:	**Objectives and competences:**
Cilji: • Nadgraditi znanja, potrebna za izbiro in snovanje sistemov avtonomnihpametnih tovarn (APT). • Naučiti študente doktorskega študija razvoja in uporabe inteligentnih algoritmov, umetne inteligence in tehnologgije digitalnih dvojčkov za krmiljenje in avtonomno delovanje sisemov APT. **Kompetence:** • Študent osvoji znanja s področja sistemov APT ter pridobi sposobnost odločanja in izbire tehnologij pri njihovem snovanju. • Znanje in sposobnost izbire ustreznih delovnih metod in postopkov z vidika stopnje avtonomije pametne tovarne ter s tehnoloških in ekonomskih vidikov. • Razumevanje delovanja tehnologije digitalnih dvojčkov proizvodnih in logističnih sistemov ter procesov v povezavi z razvojem digitalnih agentov na osnovi umetne	**Goals**: • Enhance the knowledge required for the selection and design of systems for autonomous smart factories (APT). • Teach doctoral students about the development and application of intelligent algorithms, artificial intelligence, and digital twin technology for controlling and autonomously operating APT systems. **Competences**: • The student acquires knowledge in the field of APT systems and gains the ability to make decisions and select technologies in their design. • Understanding and ability to choose appropriate working methods and procedures in terms of the level of autonomy of smart factories, as well as from technological and economic perspectives. • Understanding the operation of digital twin technology for

inteligence.	manufacturing and logistics systems and processes, in connection with the development of digital agents based on artificial intelligence.

Predvideni študijski rezultati:	**Intended learning outcomes:**
• Študent osvoji znanja s področja sitemov in procesov APT ter pridobi sposobnost odločanja in izbire tehnologij pri njihovem snovanju. • Znanje in sposobnost izbire ustreznih tehnologij za doseganje želene stopnje avtonomije pametnih tovarn. • Razumevanje delovanja in razvoja digitalnih dvojčkov APT in digitalnih agentov mna osnovi umetne inteligence za popolnoma avtonomno planiranje procesov in sistemov ter krmiljenje pametne tovarne.	• The student acquires knowledge in the field of APT systems and processes and gains the ability to make decisions and choose technologies for their design. • Knowledge and the ability to choose appropriate technologies to achieve the desired level of autonomy in smart factories. • Understanding the operation and development of APT digital twins and digital agents based on artificial intelligence for fully autonomous planning of processes and systems, as well as controlling smart factories.

Metode poučevanja in učenja:	**Learning and teaching methods:**
Predavanja, laboratorijske vaje, seminarsko delo, e-izobraževanje, konzultacije. Seminarsko delo v čim večji meri navezujoče se na področje doktorskega raziskovanja. Študij z uporabo priporočene literature.	Lectures, laboratory practice & seminar work, e-education, consulting. The seminar work is related, as much as possible, to the student's doctoral research field. Study on a recommended literature basis.

Načini ocenjevanja:	**Delež/Weight**	**Assessment:**
Ustni izpit, poročilo o seminarskem delu. Pogoj za opravljanje ustnega izpita je uspešno izdelano in pozitivno ocenjeno seminarsko delo. Način (ustno izpraševanje, naloge, projektni seminar) • Naloge (30%) • Projektni seminar (40%) • Ustno izpraševanje (30%)	100,00 %	Oral exam, report on seminar work. The condition for admission to oral exam is successful completion of seminar work, rewarded with a passing grade. Method (written exam, oral examination, assignments, project): • assignments (30%) • project seminar (40%) • oral examination (30%)

Ocenjevalna lestvica:	**Grading system:**
5 - 10, pri čemer velja, da je pozitivna	5 - 10, a student passes the exam if he is

ocena od 6 - 10	graded from 6 to 10

Reference nosilca/Lecturer's references:

prof. dr. Niko HERAKOVIČ

HERAKOVIČ, Niko, METLIKOVIČ, Peter, DEBEVEC, Mihael. Motivational lean game to support decision between push and pull production strategy. International journal of simulation modelling. Dec. 2014, vol. 13, nr. 4, str. 433-446, ilustr. ISSN 1726-4529. DOI: 10.2507/IJSIMM13(4)4.275. [COBISS.SI-ID 13828379], [JCR, SNIP, WoS do 12. 11. 2021: št. citatov (TC): 6, čistih citatov (CI): 6, čistih citatov na avtorja (CIAu): 2,00, Scopus do 8. 6. 2021: št. citatov (TC): 9, čistih citatov (CI): 8, čistih citatov na avtorja (CIAu): 2,67]

ŠIMIC, Marko, HERAKOVIČ, Niko. Reduction of the flow forces in a small hydraulic seat valve as alternative approach to improve the valve characteristics. Energy conversion and management. [Print ed.]. 2015, vol. 89, str. 708-718, ilustr. ISSN 0196-8904. https://www.sciencedirect.com/science/article/pii/S0196890414009182?via%3Dihub, DOI: 10.1016/j.enconman.2014.10.037. [COBISS.SI-ID 13766683], [JCR, SNIP, WoS do 18. 1. 2023: št. citatov (TC): 73, čistih citatov (CI): 73, čistih citatov na avtorja (CIAu): 36,50, Scopus do 13. 1. 2023: št. citatov (TC): 79, čistih citatov (CI): 79, čistih citatov na avtorja (CIAu): 39,50]

TURK, Maja, PIPAN, Miha, ŠIMIC, Marko, HERAKOVIČ, Niko. Simulation-based time evaluation of basic manual assembly tasks. Advances in production engineering & management. Sep. 2020, vol. 15, no. 3, str. 331-344, ilustr. ISSN 1854-6250. http://www.apem-journal.org/Archives/2020/Abstract-APEM15-3_331-344.html, DOI: 10.14743/apem2020.3.369. [COBISS.SI-ID 40044035], [JCR, SNIP, WoS do 2. 11. 2022: št. citatov (TC): 6, čistih citatov (CI): 6, čistih citatov na avtorja (CIAu):1,50, Scopus do 12. 11. 2022: št. citatov (TC): 8, čistih citatov (CI): 8, čistih citatov na avtorja (CIAu): 2,00]

RESMAN, Matevž, PIPAN, Miha, ŠIMIC, Marko, HERAKOVIČ, Niko. A new architecture model for smart manufacturing : a performance analysis and comparison with the RAMI 4.0 reference model. Advances in production engineering & management. Jun. 2019, vol. 14, no. 2, str. 153-165, ilustr. ISSN 1854-6250. http://apem-journal.org/Archives/2019/APEM14-2_153-165.pdf, DOI: 10.14743/apem2019.2.318.[COBISS.SI-ID 16766235], [JCR, SNIP, WoS do 4. 12. 2022: št. citatov (TC): 25, čistih citatov (CI): 22, čistih citatov na avtorja (CIAu): 5,50, Scopus do 18. 1. 2023: št. citatov (TC): 35, čistih citatov (CI): 31, čistih citatov na avtorja (CIAu): 7,75]

DEBEVEC, Mihael, ŠIMIC, Marko, JOVANOVIĆ, Vukica, HERAKOVIČ, Niko. Virtual factory as a useful tool for improving production processes. Journal of manufacturing systems. Oct. 2020, vol. 57, str. 379-389, ilustr. ISSN 0278-6125. https://www.sciencedirect.com/science/article/pii/S0278612520301874, DOI: 10.1016/j.jmsy.2020.10.018. [COBISS.SI-ID 39737859], [JCR, SNIP, WoS do 22. 1. 2023: št. citatov (TC): 5, čistih citatov (CI): 4, čistih citatov na avtorja (CIAu): 1,00, Scopus do 3. 1. 2023: št. citatov (TC): 5, čistih citatov (CI): 4, čistih citatov na

avtorja (CIAu): 1,00]