ROBOTIZIRANA PROIZVODNJA

UČNI NAČRT PREDMETA/COURSE SYLLABUS

Predmet:	Robotizirana proizvodnja
Course title:	Robotized production
Članica nosilka/UL Member:	UL FS

Študijski programi in stopnja	**Študijska smer**	**Letnik**	**Semestri**	**Izbirnost**
Strojništvo - projektno aplikativni program, prva stopnja, visokošolski strokovni	Industrijsko inženirstvo (smer)	3. letnik	1. semester	obvezni

Univerzitetna koda predmeta/University course code:	0563552
Koda učne enote na članici/UL Member course code:	3067-V

Predavanja /Lectures	**Seminar /Seminar**	**Vaje /Tutorials**	**Klinične vaje /Clinical tutorials**	**Druge oblike študija /Other forms of study**	**Samostojno delo /Individual student work**	**ECTS**
30		30			40	4

Nosilec predmeta/Lecturer:	Marko Šimic, Miha Pipan, Niko Herakovič

Izvajalci predavanj:	
Izvajalci seminarjev:	
Izvajalci vaj:	
Izvajalci kliničnih vaj:	
Izvajalci drugih oblik:	
Izvajalci praktičnega usposabljanja:	

Vrsta predmeta/Course type:	Izbirni strokovni predmet/Elective specialised course

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

Pogoji za vključitev v delo oz. za opravljanje študijskih obveznosti:	**Prerequisites:**
Izpolnjevanje pogojev za vpis v Visokošolski strokovni študijski program I. stopnje Strojništvo - Projektno aplikativni program.	Meeting the enrollment conditions for the MECHANICAL ENGINEERING - Project Oriented Applied Programme.

Vsebina:	**Content (Syllabus outline):**
1. Uvod, avtomatizirana in robotizirana proizvodnja - Avtomatizacija, robotizacija in proizvodni sistemi - Človek in stroj v proizvodnih sistemih - Principi in strategije avtomatizacije in robotizacije proizvodnje - Osnovni elementi avtomatizirane proizvodnje 2. Krmilni sistemi v proizvodnih procesih - Kosovna in procesna proizvodnja, stopnja avtomatizacije in robotizacije v obeh tipih proizvodnje - Spremenljivke in parametri v obeh tipih proizvodnje - Diskretno in kontinuirano krmiljenje 3. Robotika v proizvodnji - Fleksibilna avtomatizacija z roboti - Definicije področja robotika, definicija industrijskega robota, osnovni zakoni robotike, cilji robotizacije, zgodovinski pregled - Vloga robotov v avtomatizirani proizvodnji in področja implementacije, pozitivni in negativni aspekti - Tipi in vrste robotov 4. Anatomija in atributi industrijskih robotov (IR) - Osnovne komponente IR - Industrijski robot kot sistem po McKerrow-u - Povezave in členki, prostostne	1. Introduction, automated and robotic production - Automation, robotization and production systems - Man and machine in production systems - Principles and strategies of automation and robotization of production - The basic elements of automated production 2. Control systems in production processes - Parts manufacturing and process production, degree of automation and robotization in both types of production - Variables and parameters in both types of production - Discrete and continuous control 3. Robotics in production - Flexible automation with robots - Definitions of robotics, definition of industrial robot, basic laws of robotics, goals of robotization, historical overview - The role of robots in automated manufacturing and implementation areas, positive and negative aspects - Types of robots 4. Anatomy and attributes of industrial robots (IR) - Basic components of IR - Industrial robot as a system according to McKerrow

stopnje - Konfiguracije robotov, klasifikacija in specifikacije IR 5. Krmiljenje IR robotov v proizvodnih procesih - Blokovna shema povezave robotskih podsistemov - Regulacija položaja robotske roke - Aktuacijski in pozicijski senzorski sistemi, notranji in zunanji senzorji - Robotski vid 6. Krmiljenje in programiranje IR - Vrste in načini gibanj robotske roke - Programiranje robotov, načini in principi - Simulacije in off-line programiranje 7. Linearni robotski manipulatorji - Primi in odloži (pick and place) enote, razlike med povratnozačnimi in odprtozančnimi robotskimi manipulatorji - Osnovni koncepti linearnih robotskih manipulatorjev, modulna gradnja in fleksibilnost ter cenenost - Zgradba in krmiljenje pnevmatičnega linearnega in rotacijskega modula - Kriteriji izbire linearnih in rotacijskih modulov 8. Medsebojno sodelujoči roboti in sodelovanje človek-robot - Razlogi za sodelovanje robotov, povečanje fleksibilnosti in skrajšanje pretočnega časa delovnega procesa - Tipi robotskih konfiguracij - Simulacije trajektorij gibanja več sodelujočih robotov, izogibanje koliziji - Sodelovanje človek-robot (kolaborativni roboti) - Tipi kolaborativnih robotov in prijemal - Kriteriji izbire mesta in upravičenosti implementacije kolaborativnega robota v proizvodni proces 9. Robotska prijemala - Naloge prijemal in mesto namestitve na robotu, tipi in vrste prijemal - Prijemalne sile in dimenzioniranje prijemala glede na potrebno prijemalno silo - Pametna prijemala, primer zgradbe čeljustnega prijemala - Mehanska, magnetna in vakuumska	- Links and segments, degrees of freedom - Robot configurations, classification and specifications of IR 5. Control of IR robots in production processes - Block diagram of connection of robotic subsystems - Regulation of position of the robotic arm - Actuation and positional sensor systems, internal and external sensors - Robot vision 6. IR control and programming - Types and modes of robot arm movement - Programming of robots, modes and principles - Simulation and off-line programming 7. Linear robotic manipulators - Pick and place units, differences between feedback and open loop robotic manipulators - Basic concepts of linear robotic manipulators, modular construction and flexibility and affordability - Pneumatic linear and rotary module construction and control - Selection criteria for linear and rotary modules 8. Collaborative robots and human-robot collaboration - Reasons for robot collaboration, increased flexibility, and shorter workflow time of a work process - Types of robotic configurations - Simulation of motion trajectories of multiple collaborating robots, collision avoidance - Human robot collaboration (collaborative robots) - Types of collaborative robots and grippers - Criteria for work site selection and the justification for the implementation of a collaborative robot in the production process 9. Robotic grippers - Goals of grippers and mounting locations on the robot, types of grippers - Gripping forces and dimensioning of

prijemala, prilagodljiva prijemala in prijemala z dodatnimi gibi 10. Kriteriji izbire industrijskega robota (IR) - Vplivni parametri izbire IR - Natančnost in ponovljivost robota - Specifikacije robota in testiranje dejanskih parametrov - Modeliranje in simulacija gibanja robotske roke in izbor na osnovi rezultatov simulacije - Ekomonomičnost in evalvacijske strategije robotizacije proizvodnje, vpliv na proizvodnjo in družbo 11. Inštalacije robotov in načrtovanje robotizacije proizvodnje - Vpliv lastnosti izdelka in strukture izdelka - Analiza proizvodnega procesa, simulacija gibanja robotske roke, določitev dejanskih časov gibanja robotske roke na delovnem mestu za konkreten izdelek in trajektorije gibov - Digitalna tovarna, modeliranje in simulacije diskretnih dogodkov robotiziranega proizvodnega procesa, kaj-če scenariji in strategija odločitev o načinu robotizacije in o tipu robotov - Odločitveni kriteriji 12. Koncepti in pogoji implementacije IR v proizvodni proces - Oblikovanje izdelkov in delovnih mest za delo z roboti - Prilagoditev transportnega sistema - Prilagoditev logistike materiala in sredstev - Prilagoditev vmesnih zalogovnikov - Oblikovanje robotiziranih delovnih mest in periferije v virtualnem okolju in simulacija delovanja 13. Aplikacije IR in kolaborativnih robotov ter varnost - Pregled možnih aplikacij - Primeri aplikacij IR: logistika, nalaganje in razkladanje, paletiziranje, montažne in strežne operacije, barvanje, varjenje, strega izdelovalnih strojev, lepljenje in doziranje materialov - Primeri aplikacij kolaborativnih robotov, kot delavčevih pomočnikov 14. Simulacija IR	the gripper according to the required gripping forces - Smart grippers, an example of a jaw gripper structure - Mechanical, magnetic and vacuum grippers, adjustable grippers and grippers with additional movements 10. Industrial robot (IR) selection criteria - Influential parameters of IR selection - The accuracy and repeatability of the robot - Robot specifications and testing of actual parameters - Modeling and simulation of robot arm movement and selection based on simulation results - Economics and evaluation strategies for production robotization, impact on production and society 11. Robot installation and planning of robotization of production - The impact of product properties and product structure - Analysis of the production process, simulation of the motion of the robotic arm, determining the actual times of movement of the robotic arm at the workplace for a specific product and motion trajectories - Digital factory, modeling and simulations of discrete events of a robotic manufacturing process, what-if scenarios and a strategy of decision making about method of robotization and the type of robots - Decision criteria 12. Concepts and conditions of implementation of IR in the production process - Designing products and workplaces for robots - Adaptation of the transport system - Adaptation of logistics of materials and assets - Adaptation of buffers - Designing robotic workplaces and peripherals in a virtual environment and simulating operation 13. Applications of IR and collaborative robots and safety

- Proizvodni proces - Uvoz robota in povezave - Analiza proizvodnega procesa z IR - Simulacija in analiza delovnega cikla, zasedenosti, kolizij itd. 15. Varna uporaba IR - Varnost robotov in okolice, strategije in koncepti varnosti - Varnostna cona - Zaznave prisotnosti človeka - Varnostne zaustavitve	- Overview of possible applications - Examples of IR applications: logistics, loading and unloading, palletizing, assembly and handling operations, painting, welding, handling of manufacturing machines, gluing and dosing of materials - Examples of collaborative robot applications as worker assistants 14. Simulation of IR - Production process - The import of robots and connections - An analysis of the manufacturing process with IR - Simulation and analysis of duty cycle, occupancy, collisions, etc. 15. Safe use of IR - Robot and environment safety, safety strategies and concepts - Safety zone - Detection of human presence - Safety stops

Temeljna literatura in viri/Readings:

Miller, R., Miller, M.R.: Robotics – Principles, Systems and Industrial Applications, McGraw Hill, 2017

Groover, M.,R: Automation Production Systems and Computer Integrated Manufacturing, (3rd Edition) Prentice-Hall Int. Ed. 2008

Todd, D.J.: Fundamentals of Robot Technology, Kogan Page, 1986

Angeles, J.: Fundametntals of Robotic Mechanical Systems, Second Edition, Springer, 2003

Tao, F., Zhang, M., Nee, A.Y.C.: Digital Twin Driven Smart Manufacturing, Elsevier, 2019

Siciliano, B., Khatib, O.: Springer Handbook of Robotics, 2nd Edition, Springer, 2016

Bajd, T., Mihelj, M.: Robotika, Ljubljana 2008, Univerza v Ljubljani, Založba FE

Cilji in kompetence:	**Objectives and competences:**
Cilji: Usvojiti znanja o pogojih, namenu in tehnikah robotizirane proizvodnje Spoznati tipe robotov, njihovo anatomijo in primernost njihove uporabe po tipih proizvodnje, glede na postavljene kriterije	Objectives: To gain knowledge of the conditions, purpose and techniques of robotic production To know the types of robots, their anatomy and the suitability of their use by production type, according to the set

Usvojiti osnove in pogoje, kriterije ter načine uporabe kolaborativnih robotov v proizvodnji Usvojiti koncepte krmiljenja industrijskih in kolaborativnih robotov ter njihovo programiranje Spoznati robotska prijemala, njihove značilnosti ter kriterije izbire za posamezne aplikacije Kompetence: Sposobnost prepoznavanja pogojev in smislenosti robotizacije proizvodnje ter sposobnost uporabe tehnik robotizacije Sposobnost izbire ustreznih robotov za robotizacijo posameznih tipov proizvodnje Sposobnost učinkovite implementacije robotov v proizvodnji Sposobnost programiranja robotov Sposobnost izbire in načrtovanja robotskih prijemal za različne aplikacije	criteria To gain knowledge of the basics and conditions, criteria and ways of using collaborative robots in production To gain the concepts of control of industrial and collaborative robots and their programming To know the robotic grippers, their characteristics and selection criteria for individual applications Competencies: Ability to recognize the conditions and reasonableness of production robotization and the ability to use robotization techniques Ability to select appropriate robots to robotize individual production types Ability to effectively implement robots in production Ability to program robots Ability to select and design robotic grippers for various applications

Predvideni študijski rezultati:	**Intended learning outcomes:**
Znanja: Poznavanje in razumevanje osnov robotizacije proizvodnje, izbire in programiranja robotov industrijskih ter kolaborativnih robotov in robotskih prijemal za različne aplikacije in tipe proizvodnje. Spretnosti: Uporaba programskih jezikov za programiranje robotov Uporaba programskih orodij za simulacijo gibanja robotske roke Izbira ustreznih tipov in vrste robota ter robotskih prijemal za različne aplikacije	Knowledge: Knowledge and understanding of the basics of production robotization, selection and programming of industrial robots and collaborative robots and robotic grippers for various applications and types of production. Skills: The use of programming languages for robot programming The use of software tools to simulate the motion of a robotic arm The choice of the right type of robot and robotic grippers for various applications

Metode poučevanja in učenja:	**Learning and teaching methods:**
P1, P2 Avditorna predavanja podprta z interaktivnim prikazom praktičnih primerov	P1, P2 Lectures supported by interactive presentation of practical examples

P3 Avditorne vaje z reševanjem praktičnih primerov P4 Laboratorijske vaje s timskim reševanjem aplikativnih problemov in uporabo programske opreme ter njihova predstavitev z razpravo. P5 Uporaba študijskega gradiva v e-obliki, skripta in e-verzija predavanj. P6 Interaktivna predavanja	P3 Tutorials solving practical examples P4 Laboratory exercises with team solving of application problems, using software and presenting them with discussion. P5 Use of study material in e-form, lecture notes and e-version of lectures. P6 Interactive lectures

Načini ocenjevanja:	**Delež/ Weight**	**Assessment:**
- Teoretične vsebine (predavanja): Kolokviji, pisni in/ali ustni izpit	50,00 %	-Theoretical contents (lectures): Clloquium, writing and/or oral exam
- Samostojno delo na avditornih in laboratorijskih vajah (vključno s poročili):	50,00 %	- Individual work in exercises, individual laboratory work (including reports):

Reference nosilca/Lecturer's references:

Niko Herakovič:

1. HERAKOVIČ, Niko, ŠIMIC, Marko, TRDIČ, Francelj, SKVARČ, Jure. A machine-vision system for automated quality control of welded rings. *Machine vision and applications*, ISSN 0932-8092. [Print ed.], 2011, vol. 22, no. 6, str. 967-981, doi: 10.1007/s00138-010-0293-9. [COBISS.SI-ID 11512091], [JCR, SNIP, WoS, Scopus]
2. DEBEVEC, Mihael, PIPAN, Miha, ZUPAN, Hugo, HERAKOVIČ, Niko. An innovative training of production planners through virtual production performing. *Tehnički vjesnik : znanstveno-stručni časopis tehničkih fakulteta Sveučilišta u Osijeku*, ISSN 1330-3651, Apr. 2016, vol. 23, nr. 2, str. 363-369, ilustr., doi: 10.17559/TV-20150130124330. [COBISS.SI-ID 14633499], [JCR, SNIP, WoS, Scopus]
3. HERAKOVIČ, Niko, NOE, Dragica. Analiza delovanja pnevmatičnega ventila s predkrmilnim piezoventilom = Analysis of the operation of pilot-stage piezo-actuator valves. *Strojniški vestnik*, ISSN 0039-2480, 2006, letn. 52, št. 12, str. 835-851. [COBISS.SI-ID 9821723], [JCR, SNIP, WoS, Scopus]
4. MERWE, Jacob D. van der, MINARIK, Martin, BEROVIČ, Marin, HERAKOVIČ, Niko. Heat transfer in citric acid production with axial and radial flow impellers. *Acta chimica slovenica*, ISSN 1318-0207. [Tiskana izd.], 2010, vol. 57, no. 1, str. 150-156. http://acta.chem-soc.si/57/57-1-150.pdf. [COBISS.SI-ID 33809925], [JCR, SNIP, WoS, Scopus]
5. HERAKOVIČ, Niko. Development trends in assembly automation and fluid power. V: GOLUBOVIĆ BUGARSKI, Valentina (ur.). *Proceedings = Zbornik radova*, 11th International conference on accomplishments in electrical and mechanical engineering and information technology DEMI 2013, Banja Luka, 30th May - 1st June 2013. Banja Luka: University of Banja Luka, Faculty of

Mechanical Engineering. 2013, str. 35-48. [COBISS.SI-ID 12932123]
6. JEJČIČ, Viktor, HOČEVAR, Marko, GODEŠA, Tone, HERAKOVIČ, Niko. *Sprayer for targeted application of phytopharmaceutical preparations in permanent crops = Zerstäuber zur gezielten Auftragung von phytophatmazeutischen Zubereitungen bei Dauerkulturen = Pulvérisateur pour une application ciblée de préparations phytopharmaceutiques dans des cultures permanentes : European patent specification : EP 2 277 376 B1, 2014-08-13*. Paris: Europäisches Patentamt: = European Patent Office: = Office européen des brevets, 2013. 7 str., ilustr. [COBISS.SI-ID 4530024]
patentna družina: SI 22903 (A), 2010-05-31; Št. prijave P-200900203, 2009-07-20; EP 2277376 (A1), 2011-01-26

Marko Šimic:

1. DEBEVEC, Mihael, ŠIMIC, Marko, HERAKOVIČ, Niko. Virtual factory as an advanced approach for production process optimization. *International journal of simulation modelling*. Mar. 2014, vol. 13, no. 1, str. 66-78, ilustr. ISSN 1726-4529. DOI: 10.2507/IJSIMM13(1)6.260. [COBISS.SI-ID 13367835], [JCR, SNIP, WoS, Scopus]
2. HERAKOVIČ, Niko, ŠIMIC, Marko, TRDIČ, Francelj, SKVARČ, Jure. A machine-vision system for automated quality control of welded rings. *Machine vision and applications*. [Print ed.]. 2011, vol. 22, no. 6, str. 967-981. ISSN 0932-8092. DOI: 10.1007/s00138-010-0293-9. [COBISS.SI-ID 11512091], [JCR, SNIP, WoS, Scopus]
3. HERAKOVIČ, Niko, DUHOVNIK, Jože, ŠIMIC, Marko. CFD simulation of flow force reduction in hydraulic valves. *Tehnički vjesnik : znanstveno-stručni časopis tehničkih fakulteta Sveučilišta u Osijeku*. 2015, god. 22, br. 2, str. 453-463, ilustr. ISSN 1330-3651. DOI: 10.17559/TV-20141128090939. [COBISS.SI-ID 13974811], [JCR, SNIP, WoS, Scopus]
4. ŠIMIC, Marko. *Smart factories of the future : lectures at the 2. ICT Society Forum : robots are coming, Kappa center, Ericsson Nikola Tesla, Osijek, 10. 5. 2019*. [COBISS.SI-ID 16606491]
5. HERAKOVIČ, Niko, ŠIMIC, Marko, BEVK, Tomaž, DEBEVEC, Mihael, ADROVIĆ, Edo. *Zasnova dvižnega prijemalnega pripomočka za lamelni paket elektromotorja*. Ljubljana: Fakulteta za strojništvo, 2009. 1 zv., ilustr. [COBISS.SI-ID 11518747]

Miha Pipan:

1. **PIPAN, Miha**, HERAKOVIČ, Niko. Closed-loop volume flow control algorithm for fast switching pneumatic valves with PWM signal. *Control engineering practice*. [Print ed.]. Jan. 2018, vol. 70, str. 114-120. ISSN 0967-0661. https://www.sciencedirect.com/science/article/pii/S096706611730240X, DOI: 10.1016/j.conengprac.2017.10.008. [COBISS.SI-ID 15981083], [JCR, SNIP, WoS do 3. 11. 2022: št. citatov (TC): 10, čistih citatov (CI): 10, čistih citatov na avtorja (CIAu): 5,00, Scopus do 13. 10. 2022: št. citatov (TC): 11, čistih citatov (CI): 11, čistih citatov na avtorja (CIAu): 5,50]
2. **PIPAN, Miha**, HERAKOVIČ, Niko. Volume flow characterization of PWM-controlled fast-switching pneumatic valves. *Strojniški vestnik*. Sep. 2016, vol. 62, no. 9, str. 543-550, si 89, ilustr. ISSN 0039-2480. DOI: 10.5545/sv-jme.2016.3531. [COBISS.SI-ID 14802715], [JCR, SNIP, WoS do 8. 11. 2022: št. citatov (TC): 11, čistih citatov (CI): 10, čistih citatov na avtorja (CIAu): 5,00, Scopus do 14. 2. 2023: št. citatov (TC): 12, čistih citatov (CI): 11, čistih citatov na avtorja (CIAu): 5,50]

3. TURK, Maja, **PIPAN, Miha**, ŠIMIC, Marko, HERAKOVIČ, Niko. A smart algorithm for personalizing the workstation in the assembly process. *Applied sciences*. Dec. 2020, vol. 10, iss. 23, f. 1-19, ilustr. ISSN 2076-3417. https://www.mdpi.com/2076-3417/10/23/8624/htm, DOI: 10.3390/app10238624. [COBISS.SI-ID 40663299], [JCR, SNIP, WoS do 12. 1. 2023: št. citatov (TC): 5, čistih citatov (CI): 4, čistih citatov na avtorja (CIAu): 1,00, Scopus do 14. 2. 2023: št. citatov (TC): 5, čistih citatov (CI): 4, čistih citatov na avtorja (CIAu): 1,00]
4. ŠIMIC, Marko, **PIPAN, Miha**, PROTNER, Jernej, KOS, Andrej, ADROVIĆ, Edo, HERAKOVIČ, Niko. *Eksperimentalna analiza sile ob trku kolaborativnega robota v predmet : zaključno poročilo o rezultatih raziskovalno razvojnega dela*. Ljubljana: Fakulteta za strojništvo, Laboratorij za strego, montažo in pnevmatiko, 2019. 48 str., graf. prikazi. [COBISS.SI-ID 16770331]
5. **PIPAN, Miha**, ADROVIĆ, Edo, HERAKOVIČ, Niko. Machine vision control of industrial robot assembly via serial interface. V: JUNKAR, Mihael (ur.), et al. *MIT & SLIM 2013 : proceedings of the 12th International Conference on Management of Innovative Technologies & 4th International Conference on Sustainable Life in Manufacturing, Fiesa, Slovenia, 22th-24th September 2013*. Ljubljana: TAVO - Slovene Society for Abrasive Water Jet Technology: LAT - Laboratory for Alternative Technologies, Faculty of Mechanical Engineering: LABOD - Laboratory for Cutting, 2013. Str. 218-221, ilustr. ISBN 978-961-6536-67-7. [COBISS.SI-ID 13139483]