

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 (od študijskega leta 2026/2027 dalje)	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: prof. dr. Niko Herakovič, doc. dr. Miha Pipan, izr. prof. dr. Marko Šimic

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:

Izpolnjevanje pogojev za vpis v Visokošolski strokovni študijski program I. stopnje Strojništvo - Projektno aplikativni program.

Prerequisites:

Meeting the enrollment conditions for the MECHANICAL ENGINEERING - Project Oriented Applied Programme.

Vsebina:

1. Uvod, avtomatizirana in robotizirana proizvodnja
- Avtomatizacija, robotizacija in proizvodni sistemi
- Človek in stroj v proizvodnih sistemih

Content (Syllabus outline):

1. Introduction, automated and robotic production
- Automation, robotization and production systems
- Man and machine in production systems
- Principles and strategies of automation and

<ul style="list-style-type: none"> - Principi in strategije avtomatizacije in robotizacije proizvodnje - Osnovni elementi avtomatizirane proizvodnje 2. Krmilni sistemi v proizvodnih procesih <ul style="list-style-type: none"> - 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 <ul style="list-style-type: none"> - 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) <ul style="list-style-type: none"> - Osnovne komponente IR - Industrijski robot kot sistem po McKerrow-u - Povezave in členki, prostostne stopnje - Konfiguracije robotov, klasifikacija in specifikacije IR 5. Krmiljenje IR robotov v proizvodnih procesih <ul style="list-style-type: none"> - 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 <ul style="list-style-type: none"> - Vrste in načini gibanj robotske roke - Programiranje robotov, načini in principi - Simulacije in off-line programiranje 7. Linearni robotski manipulatorji <ul style="list-style-type: none"> - Primi in odloži (pick and place) enote, razlike med povratnozačnimi in odprtozačnimi 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 <ul style="list-style-type: none"> - 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 	<ul style="list-style-type: none"> robotization of production <ul style="list-style-type: none"> - The basic elements of automated production 2. Control systems in production processes <ul style="list-style-type: none"> - 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 <ul style="list-style-type: none"> - 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) <ul style="list-style-type: none"> - Basic components of IR - Industrial robot as a system according to McKerrow - Links and segments, degrees of freedom - Robot configurations, classification and specifications of IR 5. Control of IR robots in production processes <ul style="list-style-type: none"> - 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 <ul style="list-style-type: none"> - Types and modes of robot arm movement - Programming of robots, modes and principles - Simulation and off-line programming 7. Linear robotic manipulators <ul style="list-style-type: none"> - 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 <ul style="list-style-type: none"> - 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
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<p>9. Robotska prijemala</p> <ul style="list-style-type: none"> - 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 prijemala, prilagodljiva prijemala in prijemala z dodatnimi gibi <p>10. Kriteriji izbire industrijskega robota (IR)</p> <ul style="list-style-type: none"> - 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 - Ekonomičnost in evalvacijske strategije robotizacije proizvodnje, vpliv na proizvodnjo in družbo <p>11. Inštalacije robotov in načrtovanje robotizacije proizvodnje</p> <ul style="list-style-type: none"> - 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 <p>12. Koncepti in pogoji implementacije IR v proizvodni proces</p> <ul style="list-style-type: none"> - 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 <p>13. Aplikacije IR in kolaborativnih robotov ter varnost</p> <ul style="list-style-type: none"> - 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 <p>14. Simulacija IR</p> <ul style="list-style-type: none"> - Proizvodni proces - Uvoz robota in povezave - Analiza proizvodnega procesa z IR - Simulacija in analiza delovnega cikla, zasedenosti, kolizij itd. <p>15. Varna uporaba IR</p> <ul style="list-style-type: none"> - Varnost robotov in okolice, strategije in koncepti varnosti 	<ul style="list-style-type: none"> - Goals of grippers and mounting locations on the robot, types of grippers - Gripping forces and dimensioning of 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 <p>10. Industrial robot (IR) selection criteria</p> <ul style="list-style-type: none"> - 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 <p>11. Robot installation and planning of robotization of production</p> <ul style="list-style-type: none"> - 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 <p>12. Concepts and conditions of implementation of IR in the production process</p> <ul style="list-style-type: none"> - 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 <p>13. Applications of IR and collaborative robots and safety</p> <ul style="list-style-type: none"> - 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 <p>14. Simulation of IR</p> <ul style="list-style-type: none"> - 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. <p>15. Safe use of IR</p>
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<ul style="list-style-type: none"> - Varnostna cona - Zaznave prisotnosti človeka - Varnostne zaustavitve 	<ul style="list-style-type: none"> - Robot and environment safety, safety strategies and concepts - Safety zone - Detection of human presence - Safety stops
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Temeljna literatura in viri/Readings:

<ol style="list-style-type: none"> 1. Bajd, T., Mihelj, M.: Robotika, Ljubljana 2008, Univerza v Ljubljani, Založba FE, [COBISS.SI-ID 240724736]. 2. Fu, King Sun; Gonzalez, Rafael C.; Lee, C. S. George: Robotics: control, sensing, vision, and intelligence, knjiga, New York [etc.]: McGraw-Hill, 1987, [COBISS.SI-ID 115474]. 3. Hodges, Bernard ; Hallam, Paul, Industrial robotics, knjiga, Oxford [etc.] : Heinemann Newnes, 1990, [COBISS.SI-ID 2342171]. 4. Bonney, Maurice C. Yong, Y. F.: Robot safety, priročnik, Springer, cop. 1985, [COBISS.SI-ID 3361285]. 5. Siciliano, Bruno ...: Robotics: modelling, planning and control, knjiga, London : Springer, cop. 2009, [COBISS.SI-ID 8748628]. 6. Schütz, Daniel Wahl, Friedrich M.: Robotic systems for handling and assembly, 1st ed., softcover reprint, Berlin ; Heidelberg : Springer, 2011, [COBISS.SI-ID 146728195].

Cilji in kompetence:

<p>Cilji:</p> <p>Usvojiti znanja o pogojih, namenu in tehnikah robotizirane proizvodnje</p> <p>Spoznati tipe robotov, njihovo anatomijo in primernost njihove uporabe po tipih proizvodnje, glede na postavljene kriterije</p> <p>Usvojiti osnove in pogoje, kriterije ter načine uporabe kolaborativnih robotov v proizvodnji</p> <p>Usvojiti koncepte krmiljenja industrijskih in kolaborativnih robotov ter njihovo programiranje</p> <p>Spoznati robotska prijemala, njihove značilnosti ter kriterije izbire za posamezne aplikacije</p> <p>Kompetence:</p> <p>Sposobnost prepoznavanja pogojev in smislenosti robotizacije proizvodnje ter sposobnost uporabe tehnik robotizacije</p> <p>Sposobnost izbire ustreznih robotov za robotizacijo posameznih tipov proizvodnje</p> <p>Sposobnost učinkovite implementacije robotov v proizvodnji</p> <p>Sposobnost programiranja robotov</p> <p>Sposobnost izbire in načrtovanja robotskih prijemal za različne aplikacije</p>	<p>Objectives and competences:</p> <p>Objectives:</p> <p>To gain knowledge of the conditions, purpose and techniques of robotic production</p> <p>To know the types of robots, their anatomy and the suitability of their use by production type, according to the set criteria</p> <p>To gain knowledge of the basics and conditions, criteria and ways of using collaborative robots in production</p> <p>To gain the concepts of control of industrial and collaborative robots and their programming</p> <p>To know the robotic grippers, their characteristics and selection criteria for individual applications</p> <p>Competencies:</p> <p>Ability to recognize the conditions and reasonableness of production robotization and the ability to use robotization techniques</p> <p>Ability to select appropriate robots to robotize individual production types</p> <p>Ability to effectively implement robots in production</p> <p>Ability to program robots</p> <p>Ability to select and design robotic grippers for various applications</p>
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Predvideni študijski rezultati:

<p>Znanja:</p> <p>Poznavanje in razumevanje osnov robotizacije proizvodnje, izbire in programiranja robotov industrijskih ter kolaborativnih robotov in robotskih prijemal za različne aplikacije in tipe proizvodnje.</p> <p>Spretnosti:</p> <p>Uporaba programskih jezikov za programiranje robotov</p> <p>Uporaba programskih orodij za simulacijo gibanja robotske roke</p>	<p>Intended learning outcomes:</p> <p>Knowledge:</p> <p>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.</p> <p>Skills:</p> <p>The use of programming languages for robot programming</p> <p>The use of software tools to simulate the motion of a robotic arm</p>
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Izbira ustreznih tipov in vrste robota ter robotskih prijemal za različne aplikacije	The choice of the right type of robot and robotic grippers for various applications
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Metode poučevanja in učenja:

P1, P2 Avditorna predavanja podprta z interaktivnim prikazom praktičnih primerov
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

Learning and teaching methods:

P1, P2 Lectures supported by interactive presentation of practical examples
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.	60,00 %	Theoretical contents (lectures): partial exams, written and/or oral exam.
Samostojno delo na avditornih in laboratorijskih vajah (vključno s poročili).	40,00 %	Individual work in exercises, individual laboratory work (including reports).

Ocenjevalna lestvica:

5 - 10, pri čemer velja, da je pozitivna ocena od 6 - 10

Grading system:

5 - 10, a student passes the exam if he is graded from 6 to 10

Reference nosilca/Lecturer's references:

Niko Herakovič:

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](#)].
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](#)].
3. 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. Apr. 2016, vol. 23, nr. 2, str. 363-369, ilustr. ISSN 1330-3651. DOI: 10.17559/TV-20150130124330. [COBISS.SI-ID [14633499](#)].
4. PIPAN, Miha, PROTNER, Jernej, **HERAKOVIČ, Niko**. Integration of distributed manufacturing nodes in smart factory. V: BORANGIU, Theodor (ur.), et al. Service orientation in holonic and multi-agent manufacturing : proceedings of SOHOMA 2018. Cham: Springer, 2018. F. 424-435, ilustr. Studies in computational intelligence, Vol. 803. ISBN 978-3-030-03003-2. ISSN 1860-949X. https://link.springer.com/chapter/10.1007/978-3-030-03003-2_33, DOI: 10.1007/978-3-030-03003-2_33. [COBISS.SI-ID [16393755](#)].
5. PROTNER, Jernej, **HERAKOVIČ, Niko**, PIPAN, Miha. Position control algorithm for antagonistically driven pneumatic muscle actuators. V: Scientific proceedings of the Scientific-technical Union of Mechanical Engineering : Technical Sciences, Industrial Management. [S. l.]: Scientific-technical Union of Mechanical Engineering, 2018. Vol. 12, iss. 3, f. 94-97, ilustr. International Conference for Young Researchers Technical Sciences and Industrial Management (Online), Vol. 1. ISSN 2535-020X. <http://stumejournals.com/journals/mtm/2018/3/94>. [COBISS.SI-ID [16356379](#)].

Marko Šimic:

1. **ŠIMIC, Marko**, HERAKOVIČ, Niko. Experimental analysis of tribological behaviour of advanced composite spools used in commercial pneumatic spool valves. Tribology international. May 2016, vol. 97, str. 151-162, ilustr. ISSN 0301-679X. DOI: 10.1016/j.triboint.2016.01.012. [COBISS.SI-ID [14459675](#)]
2. RESMAN, Matevž, PROTNER, Jernej, **ŠIMIC, Marko**, HERAKOVIČ, Niko. A five-step approach to planning data-driven digital twins for discrete manufacturing systems. Applied sciences. Apr. 2021, vol. 11,

iss. 8, str. 1-25, ilustr. ISSN 2076-3417. <https://www.mdpi.com/2076-3417/11/8/3639>, DOI: 10.3390/app11083639. [COBISS.SI-ID [61630723](#)]

3. 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](#)]
4. HERAKOVIČ, Niko, ZUPAN, Hugo, PIPAN, Miha, PROTNER, Jernej, **ŠIMIC, Marko**. Distributed manufacturing systems with digital agents. *Strojniški vestnik*. Nov.-Dec. 2019, vol. 65, no. 11/12, str. 650-657, si 84, ilustr. ISSN 0039-2480. <https://www.sv-jme.eu/sl/article/distributed-manufacturing-systems-with-digital-agents/>, DOI: 10.5545/sv-jme.2019.6331. [COBISS.SI-ID [16942875](#)]
5. **ŠIMIC, Marko**, PIPAN, Miha, PROTNER, Jernej, KOS, Andrej, ADROVIČ, 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](#)]

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](#)].
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. Digitalna knjižnica Slovenije - dLib.si, DOI: [10.5545/sv-jme.2016.3531](#). [COBISS.SI-ID [14802715](#)].
3. JANKOVIČ, Denis, **PIPAN, Miha**, ŠIMIC, Marko, HERAKOVIČ, Niko. Polynomial regression-based predictive expert system for enhancing hydraulic press performance over a 5g network. *Applied sciences*. 2024, vol. 14, iss. 24, [art. no.] 12016, 24 str., ilustr. ISSN 2076-3417. <https://www.mdpi.com/2076-3417/14/24/12016>, [Repozitorij Univerze v Ljubljani – RUL](#), DOI: [10.3390/app142412016](#). [COBISS.SI-ID [220374019](#)].
4. ŠIMIC, Marko, **PIPAN, Miha**, PROTNER, Jernej, KOS, Andrej, ADROVIČ, 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**, ŠIMIC, Marko, VONČINA, Leon, HERAKOVIČ, Niko. Use of 5G technology in manufacturing processes and systems. *Ventil : revija za fluidno tehniko in avtomatizacijo*. jun. 2024, letn. 30, št. 3, str. 144-150, ilustr. ISSN 1318-7279. Digitalna knjižnica Slovenije - dLib.si, [Repozitorij Univerze v Ljubljani – RUL](#). [COBISS.SI-ID [200884739](#)].