MEHATRONIKA IN LASERSKE TEHNOLOGIJE

UČNI NAČRT PREDMETA/COURSE SYLLABUS

Predmet:	Mehatronika in laserske tehnologije
Course title:	MECHATRONICS AND LASER TECHNOLOGIES
Članica nosilka/UL Member:	UL FS

Študijski programi in stopnja	Študijska smer	Letnik	Semestri	Izbirnost
Strojništvo - razvojno raziskovalni program, prva stopnja, univerzitetni (od študijskega leta 2024/2025 dalje)	Ni členitve (študijski program)	3. letnik	2. semester	obvezni

Univerzitetna koda predmeta/University course code:	0577610
Koda učne enote na članici/UL Member course code:	2034-U

Predavanja /Lectures	Seminar /Seminar	Vaje /Tutorials	Klinične vaje /Clinical tutorials	Druge oblike študija /Other forms of study	Samostojno delo /Individual student work	ECTS
45		30			50	5

Nosilec predmeta/Lecturer:	Dominik Kozjek, Gašper Škulj, Matija Jezeršek

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

Vrsta predmeta/Course type:	Obvezni splošni predmet /Compulsory general 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 Univerzitetni študijski program I. stopnje Strojništvo - Razvojno raziskovalni program.	Meeting the enrollment conditions for the Academic study programme of Mechanical Engineering - Research and Development program.

Vsebina:	**Content (Syllabus outline):**
1. Predavanje: Uvod, predstavitev predmeta 2. Predavanje: Številski sistemi in kodiranje • Številski sistemi (desetiški, dvojiški, šestnajstiški) • Kodiranje podatkov (BCD koda, Kodiranje celih števil, Kodiranje števil s plavajočo vejico, Grayev kod, Komunikacijski kodi) 3. Predavanje: Mikrokrmilniki • Zgradba in delovanje mikrokrmilnikov • Arduino strojna oprema in programska orodja • Osnovne funkcije knjižnice Arduino 4. Predavanje: Vezja z mikrokrmilniki • Konfiguracije digitalnih vhodov/izhodov • Vezave tipk, stikal, preklopnih senzorjev na vhodne priključke mikrokrmilnika • Vezave relejev, kontaktorjev, motorjev na izhodne priključke mikrokrmilnika • Galvanska ločitev mikrokrmilnika od perifernih enot 5. Predavanje: Programiranje mikrokrmilnikov	Lecture 1: Introduction, course outline Lecture 2: Numerical systems and coding - Numerical systems (decimal, binary, hexadecimal) - Data encoding (BCD code, Integer encoding, Floating point number encoding, Gray code, Commun. codes) Lecture 3: Microcontrollers - Structure and operation of microcontrollers - Arduino hardware and software tools - Basic functions of the Arduino library Lecture 4: Circuits with microcontrollers - Digital I / O configuration. - Connecting buttons, switches, switching sensors to the input terminals of a microcontroller. - Connecting relays, contactors, motors to the outputs of a microcontroller. - Galvanic isloaltion of a microcontroller from the peripheral units. Lecture 5: Microcontroller programming - Standard C language building blocks 1 (Terms, statements, blocks, Data types, Constants, Variables, Operators) - Standard C language building blocks 2 (Decision structures, Repetition structures, Functions)

- Standardni gradniki jezika C 1 (Izrazi, stavki, bloki, Podatkovni tipi, Konstante, Spremenljivke, Operatorji)
- Standardni gradniki jezika C 2 (Odločitvene strukture, Ponavljalne strukture, Funkcije)

6. Predavanje: Vmesniki

- Števniki, časovniki kot periferne enote, Merjenje frekvence, periode, faze,

Generiranje preklopnih signalov (PWM...)

- A/D in D/A pretvorniki, dostop preko knjižnice Arduino, uporaba v krmilnih programih
- Močnostni vmesniki (H mostič, variante in izvedbe)
- Uporabniški vmesniki

7. Predavanje: Krmiljenje elektromotorjev

- Krmiljenje DC elektromotorjev (s permanentnimi magneti, z elektromagneti, krtačni in brezkrtačni)
- Izbira in preračun DC motorja Modeliranje (opis z diferencialno enačbo)

Statične karakteristike, parametri

Merjenje statičnih karakteristik

Dinamične karakteristike

Termalni preračun

- Krmiljenje AC motorjev (sinhroni, asinhroni)
- Krmiljenje koračnih motorjev
- Krmiljenje servomotorjev

8. Predavanje: Implementacija krmilnih sistemov

- Implementacija preklopnih krmilij z mikrokrmilnikom

sekvenčni avtomati

koračna krmilja

- Implementacija proporcionalnih krmilij z mikrokrmilnikom

Lecture 6: Interfaces
- Counters, timers as peripherals, Frequency, period, phase measurement, Switching signal generation (PWM ...)
- A / D and D / A converters, access via Arduino library, use in control programs
- Power interfaces (H bridge, types and implementations)
- User interfaces

Lecture 7: Control of electric motors
- Control of DC electric motors (with permanent magnets, with electromagnets, brushed and brushless)
- DC motor selection and sizing Modeling (differential equation description) Static characteristics, parameters Measurement of static characteristics Dynamic characteristics Thermal consideration
- Control of AC motors (synchronous, asynchronous) - Stepper motor control
- Servomotor control

Lecture 8: Implementation of control systems
- Implementation of switching controls with microcontrollers, Sequential automata, SFC language
- Implementation of proportional controls with microcontroller

Lecture 9: Motion control
- Numerical control (CNC machine architecture, CNC controller architecture)
- G code (basic commands, interpolation, challenges)
- Interpolation (curve segmentation, curve interpolation, examples)

Lecture 10: Mechatronic systems
- Specifications
- Design methodology
- Selected Design Case: Robot-Sumo mobile robot

Lecture 11: Operation of lasers
- Laser source building blocks
- Stimulated emission, amplification,

9. Predavanje: Krmiljenje gibanj

- Numerično krmiljenje (arhitektura CNC stroja, arhitektura CNC krmilnika)
- G koda (osnovni ukazi, interpolacija, izzivi)
- Interpolacija (segmentacija krivulj, interpolacija krivulj, primeri)

10. Predavanje: Mehatronski sistemi

- Specifikacije
- Metodologija razvoja
- Izbrani primer razvoja: mobilni robot za tekmovanje Robot-Sumo

11. Predavanje: Delovanje laserjev

- Gradniki laserskih izvorov
- Stimulirana emisija, ojačanje, inverzna populacija
- Črpanje, tri-nivojski in štirinivojski sistem
- Resonator, laserski rodovi

12. Predavanje: Značilnosti laserske svetlobe

- Usmerjenost, enobarvnost, koherenca, intenziteta
- Gaussov model
- Kvaliteta
- Fokusiranje

13. Predavanje: Vrste laserskih izvorov

- Plinski laserji (He-Ne, CO2)
- Trdninski laserji (Nd:YAG, Rubin, diskovni, vlakenski)
- Polprevodniški laserji

14. Predavanje: Izbrani laserski merilni sistemi

- Osnovni merilni principi (triangulacija, interferometrija, čas preleta)
- 3D merilni sistemi
- Merilniki hitrosti
- Merilniki deformacij

15. Predavanje: Izbrani laserski obdelovalni sistemi

- Osnovne obdelovalne interakcije
- Sistemi za lasersko vrtanje in rezanje
- Sistemi za lasersko varjenje

inverse population

- Pumping, three-level and four-level systems
- Resonator, laser modes

Lecture 12: Laser light properties
- Directionality, monochromaticity, coherence, intensity
- Gaussian model
- Quality
- Focusing

Lecture 13: Laser types
- Gas lasers (He-Ne, CO2)
- Solid-state lasers (Nd:YAG, Ruby, Disc, Fiber)
- Semiconductor lasers

Lecture 14: Selected laser measuring systems
- Basic measurement principles (triangulation, interferometry, time-of-flight)
- 3D measuring systems
- Speed measurement
- Deformation measurement

Lecture 15: Selected laser processing systems
- Basic machining interactions
- Drilling and cutting laser systems
- Welding laser systems
- Marking and engraving laser systems

• Označevalni in gravirni sistemi	

Temeljna literatura in viri/Readings:

1. W. Bolton, Mechatronics: Electronic Control Systems in Mechanical and Electrical Engineering 6th Ed. Pearson, 2015 [COBISS.SI-ID 17768499].
2. E. Kannatey-Asibu, Principles of Laser Materials Processing, Wiley, 2009. [COBISS.SI-ID 11303451]

Cilji in kompetence:	**Objectives and competences:**
Cilji: 1. Spoznati zgradbo in delovanje mehatronskih in laserskih sistemov, njihovo razčlenitev na osnovne gradnike, osvojiti načine opisa takih sistemov, razumeti njihove karakteristike in specifikacije. 2. Spoznati metode razvoja takih sistemov s posebnim poudarkom na interdisciplinarnem pristopu, fizikalnem, matematičnem in numeričnem modeliranju. 3. Spoznati metode in postopke eksperimentalne evaluacije mehatronskih in laserskih sistemov. Kompetence: 1. S1-RRP + P2-RRP: Sposobnost uporabe pridobljenega strokovnega znanja za reševanje manj zahtevnih nalog s področja mehatronike in laserske tehnologije. 2. P4-RRP: Sposobnost osnovnega fizikalnega, matematičnega in numeričnega modeliranja problemov na področju mehatronike in laserskih sistemov z razvito sposobnostjo kritične analize dobljenih rezultatov. 3. S8-RRP: Usposobljenost za interdisciplinar-no povezovanje s strokovnjaki drugih strok na področju mehatronike in laserskih tehnologij.	Objectives: 1. To learn the structure and operation of mechatronic and laser systems, their breakdown into basic building blocks, to learn ways to describe such systems, to understand their characteristics and specifications. 2. To learn the methods of development of such systems, with particular emphasis on interdisciplinary approach, physical, mathematical and numerical modeling. 3. To acquire the methods and procedures of experimental evaluation of mechatronic and laser systems. Competences: 1. S1-RRP + P2-RRP: Ability to use acquired expertise to solve less demanding tasks in the field of mechatronics and laser technology. 2. P4-RRP: Ability to perform basic physical, mathematical and numerical modeling of problems in the field of mechatronics and laser systems with developed ability to critically analyze the results obtained. 3. S8-RRP: Ability to interdisciplinary collaborate with experts in other disciplines in mechatronics and laser technologies.

Predvideni študijski rezultati:	**Intended learning outcomes:**
Znanja: Z1: Strokovno teoretično in praktično znanje na področju mehatronike in	Knowledge: Z1: Expert theoretical and practical knowledge in the field of mechatronics

laserskih tehnologij podprto s širšo teoretično in metodološko osnovo, ki omogočata vključevanje v interdisciplinarne razvojne skupine na teh področjih. Spretnosti: S1.3: Diagnosticiranje in reševanje problemov na področju mehatronike in laserskih tehnologij v različnih specifičnih delovnih okoljih. S2.2 Načrtovanje in vodenje delovnega procesa na podlagi ustvarjalnega reševanja problemov, povezanih z mehatroniko in laserskimi tehnologijami.	and laser technologies, supported by a broader theoretical and methodological basis, enabling integration into interdisciplinary development teams in these fields. Skills: S1.3: Diagnosis and problem solving in the field of mechatronics and laser technologies in various specific work environments. S2.2 Design and guide workflows based on creative problem solving related to mechatronics and laser technologies.

Metode poučevanja in učenja:	**Learning and teaching methods:**
P1 Avditorna predavanja z reševanjem izbranih - za področje značilnih - teoretičnih in praktično uporabnih primerov. P2 Obravnava snovi po urejeni in vnaprej razloženi sistematiki. P3 Avditorne vaje, kjer se teoretično znanje s predavanj podkrepi z računskimi primeri. P4 Laboratorijske vaje z namenskimi didaktičnimi pripomočki (preklopno krmiljenje zapornice, tekočega traku, PID krmiljenje procesa, laserski merilni sistem, laserski obdelovalni sistem). P5 Uporaba študijskega gradiva v obliki e-verzij: predstavitve predavanj, zbirke nalog z vaj, navodil za izvedbo laboratorijskih vaj P14 Virtualni eksperimenti P15 Uporaba video vsebin kot priprava na vaje	P1 Lectures by solving selected - typical for eng. disciplines - theoretical and practical examples. P2 Treatment of the substance in an orderly and pre-interpreted systematic manner. P3 Practical classes where theoretical knowledge from lectures is supported by computed examples. P4 Laboratory exercises with dedicated didactic aids (switching gate control, conveyor belt, PID process control, laser measuring system, laser processing system). P5 Use of electronic study materials: presentation of lectures, workbooks, instructions for laboratory work P14 Virtual experiments P15 Use video content to prepare for tutorials

Načini ocenjevanja:	**Delež/ Weight**	**Assessment:**
Teoretična snov (predavanja).	50,00 %	Theoretical exam (lectures).
Samostojno delo na vajah.	25,00 %	Independent classwork.

Laboratorijsko delo na vajah (vključno s poročili).	25,00 %	Laboratory work (including reports).

Ocenjevalna lestvica:	**Grading system:**
5 - 10, pri čemer velja, da je pozitivna ocena od 6 - 10	5 - 10, a student passes the exam if he is graded from 6 to 10

Reference nosilca/Lecturer's references:

Matija Jezeršek:

1. **JEZERŠEK, Matija**, KRIEGL, Raphael, KRAVANJA, Gaia, HRIBAR, Luka, DREVENŠEK OLENIK, Irena, UNOLD, Heiko, SHAMONIN, Mikhail. Control of droplet impact through magnetic actuation of surface microstructures. Advanced materials interfaces. Apr. 2023, vol. 10, art. no. 2202471, 10 str., ilustr. ISSN 2196-7350. DOI: 10.1002/admi.20220247 [COBISS.SI-ID 145255427]
2. STRAUS, Izidor, KOKOT, Gašper, KRAVANJA, Gaia, HRIBAR, Luka, KRIEGL, Raphael, SHAMONIN, Mikhail, **JEZERŠEK, Matija**, DREVENŠEK OLENIK, Irena. Dynamically tunable lamellar surface structures from magnetoactive elastomers driven by a uniform magnetic field. Soft matter. 2023, vol. 19, iss. 18, str. 3357-3365, ilustr. ISSN 1744-683X. DOI: 10.1039/D3SM00012E. [COBISS.SI-ID 149684995]
3. KRIEGL, Raphael, KRAVANJA, Gaia, HRIBAR, Luka, ČOGA, Lucija, DREVENŠEK OLENIK, Irena, **JEZERŠEK, Matija**, KALIN, Mitjan, SHAMONIN, Mikhail. Microstructured magnetoactive elastomers for switchable wettability. Polymers. Sep. 2022, vol. 14, art. no. 3883, 22 str., ilustr. ISSN 2073-4360. DOI: 10.3390/polym1418388 [COBISS.SI-ID 121827843]
4. TAŠIČ MUC, Blaž, VELLA, Daniele, LUKAČ, Nejc, KOS, Matjaž, **JEZERŠEK, Matija**. Generation of a focused pressure wave and localized cavitation clouds using a metal-semiconductor Ti/black-TiOx optoacoustic lens. Results in physics. Jan. 2021, vol. 20, f. 1-9 + [8], ilustr. ISSN 2211-3797. https://www.sciencedirect.com/science/article/pii/S2211379720321379?via%3Dihub, https://repozitorij.uni-lj.si/IzpisGradiva.php?id=138453, DOI: 10.1016/j.rinp.2020.103721. [COBISS.SI-ID 43842819]
5. LUKAČ, Nejc, LUKAČ, Matjaž, **JEZERŠEK, Matija**, GREGORČIČ, Peter. Cleaning system = Reinigungssystem = Systéme de nettoyage : European patent specification EP 3 510 961 B1, 2021-06-09. Munich: European Patent Office, 2021. 32 f., ilustr. https://worldwide.espacenet.com/patent/search/family/053776282/publication/EP3510961B1?q=EP3510961%20B1. [COBISS.SI-ID 16243483]

Dominik Kozjek:

1. **KOZJEK, Dominik**, PORTER, Conor, CARTER, Fred M., MOGONYE, Jon-Erik, CAO, Jian. Data-driven prediction of inter-layer process condition variations in laser powder bed fusion. Additive manufacturing. [Spletna izd.]. May 2024, vol. 88, [article no.] 104230, str. 1-15, ilustr. ISSN 2214-7810. https://www.sciencedirect.com/science/article/pii/S2214860424002768?dgcid=coauthor, DOI: 10.1016/j.addma.2024.104230. [COBISS.SI-ID

198409987].

2. CARTER, Fred M., PORTER, Conor, **KOZJEK, Dominik**, SHIMOYOSHI, Kento, FUJISHIMA, Makoto, IRINO, Naruhiro, CAO, Jian. Machine learning guided adaptive laser power control in selective laser melting for pore reduction. CIRP annals. Apr. 2024, str. 1-4, ilustr. ISSN 0007-8506. https://www.sciencedirect.com/science/article/pii/S000785062400057X, DOI: 10.1016/j.cirp.2024.04.043. [COBISS.SI-ID 198424067].
3. PORTER, Conor, CARTER, Fred M., **KOZJEK, Dominik**, CARDONA, Andrea, MOGONYE, Jon-Erik, EHMANN, Kornel F., CAO, Jian. Generation and analysis of AlSi10Mg L-PBF single track data set enabling deeper process insights. V: Solid Freeform Fabrication 2022 : proceedings of the 33rd Annual International Solid Freeform Fabrication Symposium 2022 : an additive manufacturing conference : July 25-27, 2022, [Austin, Texas]. Austin (Texas): University of Texas at Austin, Laboratory for Freeform Fabrication, cop. 2022. Str. 1542-1550, ilustr. https://utw10945.utweb.utexas.edu/sites/default/files/2022/Generation%20and%20Analysis%20of%20AlSi10Mg%20L-PBF%20Single%20T.pdf. [COBISS.SI-ID 170067971].
4. **KOZJEK, Dominik**, VRABIČ, Rok, RIHTARŠIČ, Borut, BUTALA, Peter. Big data analytics for operations management in engineer-to-order manufacturing. V: WANG, Lihui (ur.). 51st CIRP Conference on Manufacturing Systems, 16-18 May, 2018, Stockholm, Sweden. 51st CIRP Conference on Manufacturing Systems, 16-18 May, 2018, Stockholm, Sweden. [Amsterdam etc.]: Elsevier, 2018. Vol. 72, f. 209-214, ilustr. Procedia CIRP, Vol. 72. ISSN 2212-8271. https://www.sciencedirect.com/science/article/pii/S2212827118302531?via%3Dihub, Repozitorij Univerze v Ljubljani – RUL, DOI: 10.1016/j.procir.2018.03.098. [COBISS.SI-ID 16190235].
5. **KOZJEK, Dominik**, PAVLOVČIČ, Urban, KRYŽANOWSKI, Andrej, ŠUŠTERŠIČ, Jakob, JEZERŠEK, Matija. Three-dimensional characterization of concrete's abrasion resistance using laser profilometry. Strojniški vestnik. May 2015, vol. 61, no. 5, str. 311-318, si 58, ilustr. ISSN 0039-2480. Digitalna knjižnica Slovenije - dLib.si, DOI: 10.5545/sv-jme.2015.2430. [COBISS.SI-ID 13986331].

Gašper Škulj:

1. **ŠKULJ, Gašper**, VRABIČ, Rok, PODRŽAJ, Primož. A wearable IMU system for flexible teleoperation of a collaborative industrial robot. Sensors. Sep. 2021, vol. 21, iss. 17, str. 1-19, ilustr. ISSN 1424-8220. https://www.mdpi.com/1424-8220/21/17/5871, Repozitorij Univerze v Ljubljani – RUL, DOI: 10.3390/s21175871. [COBISS.SI-ID 76739587].
2. **ŠKULJ, Gašper**, SLUGA, Alojzij, BRAČUN, Drago, BUTALA, Peter, VRABIČ, Rok. Energy efficient communication based on self-organisation of IoT devices for material flow tracking. CIRP annals. 2019, vol. 68, iss. 1, str. 495-498, ilustr. ISSN 0007-8506. https://www.sciencedirect.com/science/article/pii/S0007850619300137?via%3Dihub, Repozitorij Univerze v Ljubljani – RUL, DOI: 10.1016/j.cirp.2019.03.012. [COBISS.SI-ID 16704539].
3. **ŠKULJ, Gašper**, VRABIČ, Rok, BUTALA, Peter, SLUGA, Alojzij. Decentralised network architecture for cloud manufacturing. International journal of computer integrated manufacturing. [Print ed.]. 2017, vol. 30, nr. 4/5, str. 395-408, ilustr. ISSN 0951-192X.

http://www.tandfonline.com/doi/pdf/10.1080/0951192X.2015.1066861, DOI: 10.1080/0951192X.2015.1066861. [COBISS.SI-ID 14075675].

4. PLETERSKI, Jan, **ŠKULJ, Gašper**, ESNAULT, Corentin, PUC, Jernej, VRABIČ, Rok, PODRŽAJ, Primož. Miniature mobile robot detection using an ultra-low resolution time-of-flight sensor. IEEE transactions on instrumentation and measurement. [Print ed.]. Sep. 2023, vol. 72, str. 1-9, ilustr. ISSN 0018-9456. https://ieeexplore.ieee.org/document/10262176, Repozitorij Univerze v Ljubljani – RUL, DOI: 10.1109/TIM.2023.3318710. [COBISS.SI-ID 166014211].
5. ŽUŽEK, Tena, VRABIČ, Rok, ZDEŠAR, Andrej, **ŠKULJ, Gašper**, BANFI, Igor, BOŠNAK, Matevž, ZALETELJ, Viktor, KLANČAR, Gregor. Simulation-based approach for automatic roadmap design in multi-AGV systems. IEEE transactions on automation science and engineering. [Print ed.]. Oct. 2023, str. 1-12, ilustr. ISSN 1545-5955. https://ieeexplore.ieee.org/document/10287275, DOI: 10.1109/TASE.2023.3323099. [COBISS.SI-ID 169026819].