

MIKROPROCESORSKA KRMILJA

UČNI NAČRT PREDMETA/COURSE SYLLABUS

Predmet:	Mikroprocesorska krmilja
Course title:	Digital Control Technology
Članica nosilka/UL Member:	UL FS

Študijski programi in stopnja	Študijska smer	Letnik	Semestri	Izbirnost
Strojništvo - Razvojno raziskovalni program, druga stopnja, magistrski	Mehatronika in laserska tehnika (smer)	1. letnik	1. semester	obvezni

Univerzitetna koda predmeta/University course code:	0566808
Koda učne enote na članici/UL Member course code:	6054-M

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			65	5

Nosilec predmeta/Lecturer:	doc. dr. Dominik Kozjek, doc. dr. Gašper Škulj
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Izvajalci predavanj:	
Izvajalci seminarjev:	
Izvajalci vaj:	
Izvajalci kliničnih vaj:	
Izvajalci drugih oblik:	
Izvajalci praktičnega usposabljanja:	

Vrsta predmeta/Course type:	Obvezni strokovni predmet na smeri Mehatronika in laserska tehnika, ki je izbirni strokovni predmet na ostalih smereh./Compulsory specialised course in the study of Mechatronics and laser technology, which is an elective specialised course in other fields of study.
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Jeziki/Languages:	Predavanja/Lectures:	Slovenščina
	Vaje/Tutorial:	Slovenščina

Pogoji za vključitev v delo oz. za opravljanje študijskih obveznosti:

Prerequisites:

Izpolnjevanje pogojev za vpis v Magistrski študijski program II. stopnje Strojništvo - Razvojno raziskovalni program.	Meeting the enrollment conditions for the Master's study programme of Mechanical Engineering - Research and Development program.
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Vsebina:

Content (Syllabus outline):

1. Predavanje: Uvod, predstavitev predmeta 2. Predavanje: Digitalna integrirana vezja - Specifikacije - Izhodi z odprtim kolektorjem/ ponorom - Vodila 3. Predavanje: Razvoj vezij z mikrokrmilniki - Demo in razvojne ploščice – hitra izdelava prototipov - Orodja za načrtovanje vezij (strojne opreme) - Tehnologije izdelave vezij - Testiranje strojne opreme 4. Predavanje: Arhitekture mikrokrmilnikov - 8-bitni mikrokrmilniki (Atmel AVR) - 16-bitni mikrokrmilniki (TI MSP430 ali STM ST10) - 32-bitni mikrokrmilniki (ARM Cortex-M) - Primerjava aplikacije različnih arhitektur v isti krmilni aplikaciji 5. Predavanje: Direktni dostop do perifernih enot mikrokrmilnika 1 - Digitalni I/O (s primeri) - Števniki, časovniki (s primeri) 6. Predavanje: Direktni dostop do perifernih enot mikrokrmilnika 2 - A/D in D/A pretvorniki (s primeri) - Komunikacijski vmesniki (s primeri) 7. Predavanje: Prekinitevni sistem - Viri prekinitev (zunanji, notranji), njihovi vektorji - Programiranje prekinitvenih podprogramov - Prednostni sistem procesov 8. Predavanje: Serijske komunikacije z mikrokrmilniki - RS232, RS422, RS485 - SPI 9. Predavanje: Standardna vodila z mikrokrmilniki - I2C - CAN, LIN 10. Predavanje: Aplikacije mikrokrmilnikov z nizko porabo - baterijsko napajanje: značilnosti, parametri, tipi - značilnosti stanj z zmanjšano porabo - ukrepi s strojno opremo za zmanjšanje porabe - programski ukrepi za zmanjšanje porabe 11. Predavanje: Operacijski sistemi za procesiranje v realnem času - Realno-časovno delovanje in večopravilnost v vgradnih sistemih - Primer: FreeRTOS ◦ Opravila, razporejevalni algoritmi ◦ Upravljanje: pomnilnika, čakalnih vrst, programskih časovnikov, prekinitev, resursov ◦ Storitve komunikacije med opravili 12. Predavanje: Primer razvoja krmilne aplikacije z FreeRTOS - Dispozicija aplikacije - Klici funkcij FreeRTOS - Implementacija - Orodja za odpravljanje napak	1. Lecture: Introduction, course overview 2. Lecture: Digital integrated circuits - Specifications - Open collector/drain outputs - Buses 3. Lecture: Development of Microcontroller Circuit Boards - Demo and development boards - rapid prototyping - PCB design tools (hardware) - PCB manuf. technologies - Hardware testing methods 4. Lecture: Microcontroller architectures - 8-bit MCUs (Atmel AVR) - 16-bit MCUs (TI MSP430 or STM ST10) - 32-bit MCUs (ARM Cortex-M) - Comparing applications of different architectures in the same control application 5. Lecture Direct access to MCU peripherals 1 - Digital I/O (with examples) - Counters, timers (with examples) 6. Lecture: Direct access to MCU peripherals 2 - A/D and D/A converters (with examples) - Communication interfaces (with examples) 7. Lecture: MCU interrupt system - Interrupt sources (external, internal), their vectors - Programming interrupt routines - Interrupt priority 8. Lecture: Serial communications with MCUs - RS232, RS422, RS485 - SPI 9. Lecture: Standard MCU buses - I2C - CAN, LIN 10. Lecture: Low power microcontroller applications - Battery power: characteristics, parameters, types - Characteristics of states with reduced power consumption - Hardware measures to reduce power consumption - Software measures to reduce consumption 11. Lecture: Operating systems for real-time processing - Real-time operation and multitasking in embedded systems - Example: FreeRTOS --Tasks, scheduling algorithms -- Management: memory, queues, program timers, interrupts, resources -- Task communication services 12. Lecture: Developing a control application with FreeRTOS (by example) - Application layout - FreeRTOS function calls - Implementation - Using debugging tools 13. Lecture: Linux for Embedded Systems - Features, distributions - Setting up a selected distribution on a microcomputer (eg Raspberry Pi)
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13. Predavanje: Linux za vgradne sisteme - Značilnosti, distribucije - Postavitev izbrane distribucije na mikroračunalniku (npr. Raspberry Pi) - Osnovna administratorska opravila, uporaba ukaznega poziva - Upravljanje z aplikacijami 14. Predavanje: Programirljiva vezja FPGA - Zgradba in delovanje vezij FPGA - Razvojno okolje za programiranje vezij FPGA (primer Xilinx; orodja, postopki...) - Implementacije mikrokontrolerov z vezji FPGA (primer Xilinx Microblaze) 15. Predavanje: Programiranje vezij FPGA za krmilne aplikacije - Osnove programiranja v strojno opisnem jeziku (Verilog) - Simulacije delovanja kode – pisanje testne kode, vizualizacija signalov (Verilog) - Razvoj vgradnega krmilnika na osnovi FPGA (mikrokontrolnik, periferne enote, krmilni program v jeziku C) - primer	- Basic admin tasks, using CLI interface - Application management 14. Lecture Programmable logic: FPGA - Structure and operation of FPGAs - FPGA Programming Development Environment (Xilinx example; tools, procedures ...) - Implementing a MCU in a FPGA (Xilinx Microblaze example) 15. Lecture: Programming FPGAs for control applications - Fundamentals of programming in HDL (Hardware Description Language) (Verilog) - Code simulations – writing test benches, signal visualization (Verilog) - Developing a FPGA based embedded controller (microcontroller, peripherals, control program in language C) - example
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Temeljna literatura in viri/Readings:

1. Valvano J. Embedded Systems: Real-Time Operating Systems for Arm Cortex M Microcontrollers – 2nd edition. CreateSpace Independent Publishing Platform, 2012. [COBISS.SI-ID 10282068] 2. Monk S. Programming FPGAs: Getting Started with Verilog – 1st edition. McGraw-Hill Education TAB, 2016. [COBISS.SI-ID 11741780] 3. Puhon, J., & Tuma, T. (2007). Uvod v mikrokontrolniške sisteme: zgradba in programiranje. Fakulteta za elektrotehniko. [COBISS.SI-ID 231485440]

Cilji in kompetence:

Cilji: 1. Spoznati zgradbo in delovanje sodobnih digitalnih platform (mikrokontrolniki in vezji FPGA) ter možnosti njihove uporabe v mehatroniki in krmiljenju sistemov, razumeti njihove zmogljivosti in specifikacije. 2. Spoznati metode in postopke razvoja strojne opreme za krmilne aplikacije na osnovi zmogljivih mikrokontrolerov in vezij FPGA s posebnim poudarkom na interdisciplinarnem pristopu. 3. Spoznati metode in postopke razvoja krmilnega programja za mikrokontrolnike s posebnim poudarkom na verifikaciji. Kompetence: 1. P6-MAG in S7-MAG: Sposobnost samostojnega izvajanja zahtevnih razvojno-raziskovalnih nalog na področju mehatronike in krmiljenja z uporabo mikrokontrolerov in	Objectives and competences: Objectives: 1. To learn the structure and operation of modern digital platforms (microcontrollers and FPGA circuits) and the possibilities of their use in mechatronics and control systems, to understand their capabilities and specifications. 2. To learn the methods and procedures of hardware development for control applications based on powerful microcontrollers and FPGA circuits with particular emphasis on an interdisciplinary approach. 3. To learn the methods and procedures for the development of controller software for microcontrollers, with particular emphasis on verification. Competences: 1. P6-MAG and S7-MAG: Ability to independently perform complex R&D tasks in the field of mechatronics and control
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vezij FPGA ter sposobnost kreativnega reševanja kompleksnih nalog na tem področju strojništva. 2. S10-MAG: Sposobnost uporabe sodobnih raziskovalnih metod in postopkov. Zmožnost raziskovanja in prenašanja spoznanj v prakso. 3. S8-MAG in P5-MAG: Sposobnost iskanja virov, kritične presoje informacij, samostojnega nadgrajevanja pridobljenih znanj in poglobljanja znanja na področju mehatronike in krmiljenja. 4. S9-MAG: Usposobljenost za delo v skupini in interdisciplinarno povezovanje pri reševanju RR nalog na področju mehatronike in krmiljenja.	engineering using microcontrollers and FPGA circuits, as well as the ability to creatively solve complex tasks in the field of mechanical engineering. 2. S10-MAG: Ability to apply modern research methods and procedures. Ability to explore and put lessons learned into practice. 3. S8-MAG and P5-MAG: Ability to search for resources, critically evaluate information, independently upgrade the acquired knowledge and deepen the knowledge in mechatronics and control eng. 4. S9-MAG: Ability to work in teams and interdisciplinary collaborate in solving R&D tasks in the field of mechatronics and control eng.
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Predvideni študijski rezultati:

Znanja: Z2: Poglobljeno teoretično, metodološko in analitično znanje na področju uporabe mikrokrmilnikov in vezij FPGA v mehatroniki, ki je osnova za zelo zahtevno strokovno delo in omogoča izvedbo nosilnih nalog v interdisciplinarnih razvojnih skupinah na področju mehatronike in laserske tehnike. Spretnosti: S2.1 Obvladovanje zelo zahtevnih, kompleksnih delovnih procesov in metodoloških orodij na področju mehatronike. S2.2 Načrtovanje in vodenje delovnega procesa na podlagi ustvarjalnega reševanja problemov, povezanih s področjem mehatronike. S2.3 Sposobnost izvirnih dognanj/stvaritev in kritične refleksije.	Knowledge: Z2: In-depth theoretical, methodological and analytical knowledge on applications of microcontrollers and FPGA circuits in mechatronics, which is the basis for very demanding professional work and enables the carrying out of leading tasks in interdisciplinary development teams in the field of mechatronics and laser technology. Skills: S2.1 Mastering highly comprehensive, complex workflows and methodological tools in the field of mechatronics. S2.2 Design and manage workflows based on creative problem solving related to mechatronics. S2.3 Ability for original findings / creations and critical reflection.
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Metode poučevanja in učenja:

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 (razvojni sistemi z mikrokrmilniki	P1 Lectures by solving selected - typical for the eng. discipline - 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 teaching aids (development systems with Arduino and Raspberry PI microcontrollers, mechatronic
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Arduino in Raspberry PI, modeli mehatronskih sistemov, razvojni sistem za vezja Xilinx FPGA).	systems models, development system for Xilinx FPGA circuits).
P5 Uporaba študijskega gradiva v obliki e-verzij: predstavitve predavanj, zbirke nalog z vaj, navodil za izvedbo laboratorijskih vaj	P5 Use of electronics study materials: presentation of lectures, workbooks, instructions for laboratory work
P14 Virtualni eksperimenti	P14 Virtual Experiments
P15 Uporaba video vsebin kot priprava na vaje	P15 Using video content to prepare for tutorials

Načini ocenjevanja:	Delež/Weight	Assessment:
Pisno ocenjevanje teorije (predavanja).	50,00 %	Theoretical exam (lectures).
Praktično delo na vajah.	50,00 %	Practical work at tutorials.

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:

Dominik Kozjek:

- KOZJEK, Dominik**, CARTER, Fred M., PORTER, Conor, MOGONYE, Jon-Erik, EHMANN, Kornel F., CAO, Jian. Data-driven prediction of geometry- and toolpath sequence-dependent intra-layer process conditions variations in laser powder bed fusion. *Journal of manufacturing processes*. [Print ed.]. Aug. 2023, vol. 100, str. 34-46, ilustr. ISSN 1526-6125.
<https://www.sciencedirect.com/science/article/pii/S1526612523004772>, DOI: [10.1016/j.jmapro.2023.05.021](https://doi.org/10.1016/j.jmapro.2023.05.021). [COBISS.SI-ID [159011331](#)]
- CARTER, Fred M., **KOZJEK, Dominik**, PORTER, Conor, CLARK, Samuel J., FEZZAA, Kamel, FUJISHIMA, Makoto, IRINO, Naruhiro, CAO, Jian. Melt pool instability detection using coaxial photodiode system validated by in-situ X-ray imaging. *CIRP annals*. 2023, vol. 72, iss. 1, str. 205-208, ilustr. ISSN 0007-8506. <https://www.sciencedirect.com/science/article/pii/S000785062300029X>, DOI: [10.1016/j.cirp.2023.03.031](https://doi.org/10.1016/j.cirp.2023.03.031). [COBISS.SI-ID [159004163](#)]
- VRABIČ, Rok, **KOZJEK, Dominik**, MALUS, Andreja, ZALETELJ, Viktor, BUTALA, Peter. Distributed control with rationally bounded agents in cyber-physical production systems. *CIRP annals*. 2018, vol. 67, iss. 1, str. 507-510, ilustr. ISSN 0007-8506.
<https://www.sciencedirect.com/science/article/pii/S0007850618300611>, <https://repozitorij.uni-lj.si/IzpisGradiva.php?id=101584>, DOI: [10.1016/j.cirp.2018.04.037](https://doi.org/10.1016/j.cirp.2018.04.037). [COBISS.SI-ID [16026651](#)]
- VRABIČ, Rok, **KOZJEK, Dominik**, BUTALA, Peter. Knowledge elicitation for fault diagnostics in plastic injection moulding : a case for machine-to-machine communication. *CIRP annals*. 2017, vol. 66, iss. 1, str. 433-436, ilustr. ISSN 0007-8506. http://ac.els-cdn.com/S000785061730001X/1-s2.0-S000785061730001X-main.pdf?_tid=cd2847e6-348c-11e7-aaa9-00000aacb360&acdnat=1494316680_7dd186475f057f97faa6af363539e6bb, <https://repozitorij.uni-lj.si/IzpisGradiva.php?id=101580>, DOI: [10.1016/j.cirp.2017.0001](https://doi.org/10.1016/j.cirp.2017.0001). [COBISS.SI-ID [15490587](#)]
- PORTER, Conor, CARTER, Fred M., **KOZJEK, Dominik**, CLARK, Samuel J., FEZZAA, Kamel, MOGONYE, Jon-Erik, CAO, Jian. Qualitative analysis of potential pore healing phenomenon in L-PBF using operando high speed X-ray imaging. V: GAO, Robert X. (ur.), XU, Xun (ur.), RAGAI, Ihab (ur.). 51st SME North American Manufacturing Research Conference : NAMRC 51 : New Brunswick, New Jersey. Amsterdam: Elsevier, 2023. Vol. 35, suppl., str. 636-642, ilustr. Manufacturing letters, Vol. 35, suppl. ISSN 2213-8463. <https://www.sciencedirect.com/science/article/pii/S2213846323001098>, DOI: [10.1016/j.mfglet.2023.08.052](https://doi.org/10.1016/j.mfglet.2023.08.052). [COBISS.SI-ID [170535171](#)]

Gašper Škulj:

1. **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](https://doi.org/10.1016/j.cirp.2019.03.012). [COBISS.SI-ID [16704539](#)]
2. 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](https://doi.org/10.1109/TIM.2023.3318710). [COBISS.SI-ID [166014211](#)]
3. BRAČUN, Drago, **ŠKULJ, Gašper**, KADIŠ, Miran. Spectral selective and difference imaging laser triangulation measurement system for on line measurement of large hot workpieces in precision open die forging. *International journal of advanced manufacturing technology*. apr. 2017, vol. 90, iss. 1-4, 917-926 str, ilustr. ISSN 0268-3768. <http://link.springer.com/article/10.1007%2Fs00170-016-9460-0>, DOI: [10.1007/s00170-016-9460-0](https://doi.org/10.1007/s00170-016-9460-0). [COBISS.SI-ID [14855195](#)]
4. VRABIČ, Rok, **ŠKULJ, Gašper**, MALUS, Andreja, KOZJEK, Dominik, SELAK, Luka, BRAČUN, Drago, PODRŽAJ, Primož. An architecture for sim-to-real and real-to-sim experimentation in robotic systems. V: MOURTZIS, Dimitris (ur.). *Towards digitalized manufacturing 4.0 : 54th CIRP CMS 2021 : 22nd-24th September 2021, University of Patras – Greece*. [S. l.]: Elsevier, 2021. Vol. 104, str. 336-341, ilustr. Procedia CIRP, vol. 104. ISSN 2212-8271. <https://www.sciencedirect.com/science/article/pii/S2212827121009550>, [Repozitorij Univerze v Ljubljani – RUL](#), DOI: [10.1016/j.procir.2021.11.057](https://doi.org/10.1016/j.procir.2021.11.057). [COBISS.SI-ID [95688963](#)]
5. PODRŽAJ, Primož, POŽRL, Tomaž, JENKO, Marjan, SELAK, Luka, **ŠKULJ, Gašper**, RIHAR, Lidija, VRABIČ, Rok, BRAČUN, Drago, BERLEC, Tomaž, KOZJEK, Dominik. The applicability of Arduino microcontroller with a LoRa shield as an element in IoT. V: WYLD, David C. (ur.), NAGAMALAI, Dhinakaran (ur.). *11th International Conference on Signal Image Processing and Multimedia : SIPM 2023 : May 27 ~ 28, 2023, Vancouver, Canada*. [Chennai]: AIRCC, 2023. Vol. 13, nr. 9, str. [21]-31, ilustr. Computer science and information technology, vol. 13, nr. 9. ISBN 978-1-925953-95-4. ISSN 2231-5403. <https://aircconline.com/csit/papers/vol13/csit130903.pdf>, [Repozitorij Univerze v Ljubljani – RUL](#). [COBISS.SI-ID [154249987](#)]