

KRMILJENJE MEHATRONSKIH SISTEMOV

UČNI NAČRT PREDMETA/COURSE SYLLABUS

Predmet:	Krmiljenje mehatronskih sistemov
Course title:	MECHATRONIC SYSTEM CONTROL
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 2023/2024 dalje)	Mehatronika (smer)	3. letnik	1. semester	obvezni

Univerzitetna koda predmeta/University course code: 0563958

Koda učne enote na članici/UL Member course code: 3075-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: Dominik Kozjek, Primož Podržaj

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
□ Zgodovinski pregled razvoja krmilne tehnike
□ Osnovni pojmi povezani s krmiljenjem (povratna zveza, referenca, motnja, upravljanje, krmiljenje)
□ Krmiljenje položaja in hitrosti

2. Predstavitev mehatronskih sistemov s pomočjo blokovnih diagramov
□ Krmiljenje gladine
□ Krmiljenje temperature
□ Vlak na magnetno levitacijo

3. Dif. enačba in prenosna karakteristika
□ Dif. enačba in linearizacija
□ Definicija prenosne karakteristike

4. Delitev sistemov glede na prenosne karakteristike
□ Proporcionalni, diferencirni in integrirni sistem ničtega, prvega in drugega reda
□ Primeri in opis analogij (mehatronski)

5. Poenostavitev krmilnih sistemov predstavljenih s pomočjo blokovnih diagramov

1. Introduction
□ Historical overview of the control engineering development
□ The basic terms related to control (feedback, reference, disturbance, open loop, closed loop control)
□ Control of position and velocity

2. Block diagram representation of mechatronic systems
□ Water level control
□ Temperature control
□ Magnetic levitation train control

3. Dif. equation and transfer characteristics
□ Dif. equation and linearization
□ Definition of transfer characteristics

4. System division based on the transfer characteristics
□ Proportional, differential in integral system of zeroth, first and second order
□ Applications and analogies (mechatronic)

5. Raduction of control systems represented by block diagrams

<ul style="list-style-type: none"> □ Osnove blokovne algebre □ Primer kompleksnejšega krmilnega sistema (mehatronske primer; dve zanki) 	<ul style="list-style-type: none"> □ The basics of block diagram algebra □ Example of a complex control system (mechatronic; two loops)
<p>6. Stabilnost sistemov</p> <ul style="list-style-type: none"> □ Definicija stabilnosti □ Povezava med stabilnostjo in modeli sistemov □ Kako jo v praksi zagotovimo 	<p>6. System stability</p> <ul style="list-style-type: none"> □ Definition of stability □ The relation between system model and stability □ How to provide it in practice
<p>7. PID krmilnik</p> <ul style="list-style-type: none"> □ Prenosna funkcija PID krmilnika □ Lastnosti posameznih komponent □ P, PI, PD in PID krmilnik 	<p>7. PID controller</p> <ul style="list-style-type: none"> □ Transfer function of PID controller □ Properties of the components □ P, PI, PD and PID controller
<p>8. Odstopki v stacionarnem stanju</p> <ul style="list-style-type: none"> □ Odstopki glede na referenco □ Odstopki glede na motnjo □ Vpliv P in I komponente PID krmilnika □ Demonstracija na preprostem primeru krmiljenja gladine 	<p>8. Steady state errors</p> <ul style="list-style-type: none"> □ Errors in relation to the reference □ Errors in relation to the disturbance □ Influence of P and I component of PID controller □ Demonstration on a simple water level control system
<p>9. Maksimalen prenehaj sistema in čas trajanja prehodnega pojava</p> <ul style="list-style-type: none"> □ Vpliv P in I komponente PID krmilnika □ Vpliv D komponente PID krmilnika 	<p>9. Maximal overshoot and transient time</p> <ul style="list-style-type: none"> □ Influence of P and I component of PID controller □ Influence of D component of PID controller
<p>10. Nastavljanje parametrov PID krmilnika</p> <ul style="list-style-type: none"> □ Nastavljanje parametrov po Ziegler-Nicholsu □ Nastavljanje parametrov po Samalu 	<p>10. PID tuning</p> <ul style="list-style-type: none"> □ Ziegler-Nichols tuning method □ Samalu tuning method
<p>11. Realizacija PID krmilnika</p> <ul style="list-style-type: none"> □ Realni PID krmilnik na Arduino □ Obravnava problemov v praksi (integralsko nasičenje I komponente, šum in D komponenta) 	<p>11. PID controller realization</p> <ul style="list-style-type: none"> □ Real PID controller with Arduino □ Real environment challenges (integral wind-up, noise and D component)
<p>12. Uporaba Matlab/Simulinka</p> <ul style="list-style-type: none"> □ Control System Toolbox □ Blokovski diagrami v Simulinku □ Sinteza sistema s pomočjo Matlaba 	<p>12. Matlab/Simulink application</p> <ul style="list-style-type: none"> □ Control System Toolbox □ Block diagrams in Simulink □ Matlab based system synthesis
<p>13. Preprost mehanski sistem kot krmiljeni sistem (obrnava v Matlab/Simulinku)</p> <ul style="list-style-type: none"> □ Prenosna karakteristika 	<p>13. Simple mechanical system as a control system (Matlab/Simulink based analysis)</p> <ul style="list-style-type: none"> □ Transfer characteristics □ Response using P, PI, PD and PID

<ul style="list-style-type: none"> □ Določitev odzivov pri uporabi P, PI, PD in PID krmilnik <p>14. Servomotor kot primer krmilnega sistema</p> <ul style="list-style-type: none"> □ Servomotor, koordinatne osi oziroma linearna vodila □ Krmiljenje položaja in hitrosti <p>15. Sinteza odprtozankno nestab. sistema</p> <ul style="list-style-type: none"> □ Mag. Levitacija (vlak Maglev) 	<p>controller</p> <p>14. Servomotor as an example of a control system</p> <ul style="list-style-type: none"> □ Servomotor, axes of motion – linear guides □ Position and velocity control <p>15. Open loop unstable system synthesis</p> <ul style="list-style-type: none"> □ Mag. Levitation (Maglev train)
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Temeljna literatura in viri/Readings:

1. Norman S. Nise: Control Systems Engineering (7th Ed.), Wiley, 2015
2. Christopher T. Kilian: Modern Control Technology: Components and Systems (2nd Ed.), Delmar Thomson Learning, 2001
3. Primož Podržaj: Linearna teorija krmiljenja sistemov, Univerza v Ljubljani, 2017

Cilji in kompetence:

Cilji:

1. Spoznati temeljne principe analize in sinteze krmilnih sistemov.
2. Spoznati najosnovnejše naprave, s katerimi je moč krmiliti mehatronske sisteme.
3. Spoznati programsko opremo namenjeno krmiljenju mehatronskih sistemov.

Kompetence:

1. S2-PAP: Sposobnost samostojnega dela v okviru znanj pridobljenih pri predmetu
2. S12-PAP, P7-PAP: Sposobnost uporabe namenske programske opreme za krmiljenje specifičnih mehatronskih sistemov
3. P3-PAP: Obvlada temeljna strokovna znanja s področja krmiljenja
4. P4-PAP: Pozna osnovne naprave, s katerimi je moč krmiliti mehatronske sisteme
5. P9-PAP: Diplomant je sposoben samostojno opravljati razvojno aplikativna, inženirska in strokovna dela ter reševati posamezne dobro definirane naloge na področju

Objectives and competences:

Objectives:

1. Knowledge of basic control system analysis and synthesis.
2. Knowledge of the most basic devices used to control mechatronic systems.
3. Knowledge of the software used for mechatronic system control purposes.

Competences:

1. S2-PAP: The ability to work autonomously in the framework of the obtained knowledge.
2. S12-PAP, P7-PAP: The ability to use software used to control specific mechatronic systems.
3. P3-PAP: Mastering the fundamental specialised knowledge in the field of control engineering.
4. P4-PAP: Knowing the basic devices used to control mechatronic systems.
5. P9-PAP: The graduates are able to independently perform applied developmental, engineering and professional work, and solve well-defined individual tasks in the field of mechatronic system control.

Predvideni študijski rezultati:

Znanja:

Z1: Poznavanje analize in sinteze krmiljenja mehatronskih sistemov, ter uporaba krmilnih naprav in s tem povezane programske opreme.

Spretnosti:

S1.2: Obvladovanje krmiljenja zahtevnih, kompleksnih mehatronskih sistemov ob samostojni uporabi znanja.

S1.3: Diagnosticiranje in reševanje problemov, ki se pojavljajo v zvezi s krmiljenjem mehatronskih sistemov.

Intended learning outcomes:

Knowledge:

Z1: Knowledge of analysis and synthesis of mechatronic system control, and application of control devices together with the related software.

Skills:

S1.2: Mastering demanding and complex mechatronic system related tasks by independent usage of knowledge in new working situations

S1.3: Mechatronic system control related diagnostics and problem solving.

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.

P4 Laboratorijske vaje z namenskimi didaktičnimi pripomočki kot so mikrokrmilniki (Arduino) ali računalnik Raspberry Pi.

P8 Izdelava in predstavitev aplikativnih seminarskih nalog

Learning and teaching methods:

P1 Auditorial lectures with solving selected field-specific theoretical and applied use cases.

P2 Presenting the content according to the explained system.

P4 Laboratory exercises with special-purpose didactic devices (microcontrollers (Arduino) or Raspberry Pi computer.

P8 Making and presenting applied seminar exercises.

Načini ocenjevanja:

**Delež/
Weight**

Assessment:

Pisni izpit	50,00 %	Written examination
Ustno izpraševanje	30,00 %	Oral examination
Projekt	20,00 %	Project

Reference nosilca/Lecturer's references:

Primož Podržaj:

1. **PODRŽAJ, Primož**, REGOJEVIĆ, Braco, KARIŽ, Zoran. An enhanced mechanical system for studying the basics of control system dynamics. IEEE transactions on education, 2005, letn. 48, št. 1, str. 23-28. [COBISS.SI-ID [7942427](#)]

2. **PODRŽAJ, Primož**, KARIŽ, Zoran. Programljivi logični krmilniki na temelju rešitve algebraične Riccatijeve enačbe = Programmable logic controllers based on the algebraic Riccati equation solution. Strojniški vestnik, 2006, letn. 52, št. 12, str. 852-86. [COBISS.SI-ID [9821979](#)]
3. SIMONČIČ, Samo, **PODRŽAJ, Primož**. The applicability of welding force for spot weld quality assurance. International journal of microstructure and materials properties, 2014, vol. 9, iss. 3/5, str. 422-432. [COBISS.SI-ID [14332443](#)]
4. SIMONČIČ, Samo, **PODRŽAJ, Primož**. Vision-based control of a line-tracing mobile robot. Computer applications in engineering education, Sep. 2014, vol. 22, iss. 3, str. 474-480. [COBISS.SI-ID [12092187](#)]
5. FINŽGAR, Miha, **PODRŽAJ, Primož**. Machine-vision-based human-oriented mobile robots : a review. Strojniški vestnik, ISSN 0039-2480, May 2017, vol. 63, no. 5, str. 331-348, [COBISS.SI-ID [15492635](#)]

Dominik Kozjek:

1. MALUS, Andreja, **KOZJEK, Dominik**, VRABIČ, Rok. Real-time order dispatching for a fleet of autonomous mobile robots using multi-agent reinforcement learning. CIRP annals. 2020, vol. 69, iss. 1, str. 397-400, ilustr. ISSN 0007-8506. <https://www.sciencedirect.com/science/article/pii/S0007850620300226?via%3Dihub>, DOI: 10.1016/j.cirp.2020.04.001. [COBISS.SI-ID [24176643](#)]
 2. 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. In: MOURTZIS, Dimitris (ed.). 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>, DOI: 10.1016/j.procir.2021.11.057. [COBISS.SI-ID [95688963](#)]
 3. **KOZJEK, Dominik**. Zbirka nalog in rešitev za laboratorijske vaje : Osnove mehatronskih sistemov (3. letnik, PAP). Ljubljana: Fakulteta za strojništvo, 2021. 1 USB ključ, ilustr. [COBISS.SI-ID [74534147](#)]
 4. HOZDIČ, Elvis, **KOZJEK, Dominik**, BUTALA, Peter. A cyber-physical approach to the management and control of manufacturing systems. Strojniški vestnik. Jan. 2020, vol. 66, no. 1, str. 61-70, si 8, ilustr. ISSN 0039-2480. <https://www.sv-jme.eu/article/a-cyber-physical-approach-to-the-management-and-control-of-manufacturing-systems/>, DOI: 10.5545/sv-jme.2019.6156. [COBISS.SI-ID [17016347](#)]
- PURIĆ, Diko, ANIČIĆ, Nebojša, **KOZJEK, Dominik**, VRABIČ, Rok. Metoda globokega učenja za napovedovanje napak pri proizvodnem procesu. In: BERLEC, Tomaž (ed.), BROJAN, Miha (ed.), DROBNIČ, Boštjan (ed.). [Zbornik del]. Ljubljana: Fakulteta za strojništvo, 2017. F. 132-139, ilustr. ISBN 978-961-6980-38-8. [COBISS.SI-ID [15657499](#)]