

ROBOTSKI SISTEMI - MAG

UČNI NAČRT PREDMETA/COURSE SYLLABUS

Predmet:	Robotski sistemi - MAG
Course title:	ROBOTIC SYSTEMS - MAG
Članica nosilka/UL Member:	UL FS

Študijski programi in stopnja	Študijska smer	Letnik	Semestri	Izbirnost
Strojništvo - Razvojno raziskovalni program, druga stopnja, magistrski (od študijskega leta 2024/2025 dalje)	Mehatronika in laserska tehnika (smer)	1. letnik	1. semester	obvezni

Univerzitetna koda predmeta/University course code:	0566809
Koda učne enote na članici/UL Member course code:	6055-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:	Dominik Kozjek, Rok Vrabič
-----------------------------------	----------------------------

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.

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.

Vsebina:**Content (Syllabus outline):**

1. Predavanje: Uvod
 - Predstavitev predmeta
 - Uvod v robotiko
 - Predstavitev tipov in delitve robotov
 - Pregled področij uporabe robotov
2. Predavanje: Koordinatni sistemi v robotiki
 - Rotacijske matrike v 2D in 3D
 - Homogena transformacija v 2D
 - Opis rotacije v 3D
 - Kvaternioni
3. Predavanje: Direktna kinematika
 - Koordinatni sistem sklepov
 - Denavit-Hartenbergov zapis
 - Preračun direktne kinematike
4. Predavanje: Inverzna kinematika
 - Analitična rešitev
 - Geometrična rešitev
 - Numerična rešitev
5. Predavanje: Hitrostne razmere
 - Jakobijeva matrika za robotske roke
 - Transformacija hitrosti med koordinatnimi sistemi
 - Jakobijeva matrika pod- in pre-aktuiranih robotov
 - Statični model sil in navorov
 - Singularnosti

1. Lecture: Introduction
 - Course overview
 - Introduction to robotics
 - Types of robots
 - Areas of application
2. Lecture: Coordinate systems in robotics
 - Rotational matrices in 2D and 3D
 - Homogeneous transformation in 2D
 - Description of rotation in 3D
 - Quaternions
3. Lecture: Direct kinematics
 - Joint coordinate frame
 - Denavit-Hartenberg notation
 - Direct kinematics calculation
4. Lecture: Inverse kinematics
 - Analytical solution
 - Geometric solution
 - Numerical solution
5. Lecture: Velocity kinematics
 - The manipulator Jacobian
 - Transformation of velocities between coordinate systems
 - Jacobian of under- and over-actuated robots
 - Static force and torque model
 - Singularities

<p>6. Predavanje: Dinamika</p> <ul style="list-style-type: none"> - Enačbe gibanja robotskih rok, Newton-Eulerjev in Lagrangeov pristop <p>7. Predavanje: Planiranje poti</p> <ul style="list-style-type: none"> - Trajektorije - Interpolacija po točkah - Interpolacija rotacije, kvaternionov <p>8. Predavanje: Krmiljenje</p> <ul style="list-style-type: none"> - Krmiljenje robotskih aktuatorjev - Krmiljenje sklepov - Krmiljenje položaja - Krmiljenje navora <p>9. Predavanje: Aplikacije industrijskih robotov</p> <ul style="list-style-type: none"> - SCARA roboti, primi-položi - Robotske roke, manipulacija objektov - Integracija robotov z drugimi sistemi - Interakcija robot-človek <p>10. Predavanje: Kinematika kolesnih robotov</p> <ul style="list-style-type: none"> - Kinematika diferencialnega pogona - Kinematika holonomnih pogonov <p>11. Predavanje: Navigacija</p> <ul style="list-style-type: none"> - Reaktivna navigacija - Planiranje poti na karti - Algoritmi A*, D*, Voronoievi diagram, RRT <p>12. Predavanje: Kalmanov filter</p> <ul style="list-style-type: none"> - Kalmanov filter - 1D in 2D primer - Aplikacije v mobilni robotiki <p>13. Predavanje: Lokalizacija</p> <ul style="list-style-type: none"> - Lokalizacija s Kalmanovim filtrom - Monte-Carlo lokalizacija <p>14. Predavanje: Hkratno kartiranje in lokalizacija</p> <ul style="list-style-type: none"> - Princip - Razširitev opisa stanja z značilkami okolja - Negotovost položaja <p>15. Predavanje: Industrijske aplikacije mobilnih robotov</p> <ul style="list-style-type: none"> - Sistemi in tehnologije samodejno vodenih vozil (AGV) - Upravljanje flote - Storitveni roboti 	<p>6. Lecture: Dynamics</p> <ul style="list-style-type: none"> - Robot arm dynamics, Newton-Euler and Lagrange approaches - Direct dynamics <p>7. Lecture: Path planning</p> <ul style="list-style-type: none"> - Trajectories - Point-by-point interpolation - Interpolation of rotation, quaternions <p>8. Lecture: Control</p> <ul style="list-style-type: none"> - Control of robotic actuators - Joint control - Position control - Torque control <p>9. Lecture: Applications of industrial robots</p> <ul style="list-style-type: none"> - SCARA robots, pick-and-place - Robotic arms, object manipulation - Robot integration - Human-robot interaction <p>10. Lecture: Kinematics of wheeled robots</p> <ul style="list-style-type: none"> - Differential drive kinematics - Holonomic drive kinematics <p>11. Lecture: Navigation</p> <ul style="list-style-type: none"> - Reactive navigation - Path planning on a map - A*, D* algorithms, Voronoi diagrams, RRT <p>12. Lecture: Kalman filter</p> <ul style="list-style-type: none"> - Kalman filter - 1D and 2D examples - Applications in mobile robotics <p>13. Lecture: Localization</p> <ul style="list-style-type: none"> - Kalman filter localization - Monte-Carlo localization <p>14. Lecture: Simultaneous localization and mapping</p> <ul style="list-style-type: none"> - Approach - Extended state representation - Pose uncertainty <p>15. Lecture: Industrial application of mobile robots</p> <ul style="list-style-type: none"> - Systems and technologies of autonomous guided vehicles (AGVs) - Fleet management - Service robots
---	--

Temeljna literatura in viri/Readings:

1. Peter Corke: Robotics, Vision and Control, Springer-Verlag Berlin Heidelberg,

2011 [COBISS.SI-ID [15787291](#)]

2. Tadej Bajd, Matjaž Mihelj, Marko Munih: Introduction to Robotics, Springer Dordrecht Heidelberg New York London, 2013 [COBISS.SI-ID [9761364](#)]
3. Gupta, A. K., Arora, S. K. Industrial automation and robotics [COBISS.SI-ID [30368005](#)]
4. Gregor Klančar, Andrej Zdešar, Sašo Blažič, Igor Škrjanc: Wheeled Mobile Robotics, Butterworth-Heinemann, 2017 [COBISS.SI-ID [11671636](#)]
5. Morgan Quigley, Brian Gerkey, William D. Smart: Programming Robots with ROS, O'Reilly Media, 2015 [COBISS.SI-ID [11614292](#)]
6. Joseph Lentin: Mastering ROS for Robotics Programming, Packt Publishing, 2018 [COBISS.SI-ID [12392020](#)]

Cilji in kompetence:

Cilji:

1. Spoznati delovanje vseh vrst robotov, uporabljenih v industriji.
2. Spoznati upravljanje, programiranje in razvoj lastnih aplikacij v robotiki.
3. Spoznati načine integracije industrijskih robotov z drugimi sistemi.
4. Spoznati programske in strojne vmesnike v robotiki.

Kompetence:

1. S1-MAG + P2-MAG: Sposobnost razumevanja delovanja vseh vrst industrijskih robotov.
2. S6-MAG: Sposobnost razvoja namenskega programa in lastnih aplikacij v robotiki.
3. S7-MAG: Sposobnost integracije industrijskih robotov z drugimi sistemi.
4. P6-MAG: Sposobnost nadgrajevanja robotov in gradnje novih robotskih komponent.

Objectives and competences:

Objectives:

1. Understanding all kinds of industrial robotics.
2. Understanding control, programming, and development of custom robotic applications.
3. Understanding integration of robots with other industrial systems.
4. Understanding software and hardware interfaces in robotics.

Competences:

1. S1-MAG + P2-MAG: Understanding the operation of all kinds of industrial robots.
2. S6-MAG: Development of custom robotic software and applications.
3. S7-MAG: The ability to integrate industrial robots with other systems.
4. P6-MAG: The ability to upgrade existing robots and develop new robotic components.

Predvideni študijski rezultati:

Znanja:

Z2: Predmet je namenjen spoznavanju robotskih sistemov in njihove uporabe v industrijskih aplikacijah. Obravnavani so robotski manipulatorji (robotske roke) in industrijski samodejno vodeni vozički (mobilni roboti). S pridobljenimi kompetencami so študenti sposobni razvoja robotskih aplikacij, integracije

Intended learning outcomes:

Learning outcomes:

Z2: The course focuses on robotic systems and their industrial applications. Both articulate robots (robot arms) as well as mobile robots (autonomous guided vehicles) are considered. The acquired student competences include the abilities to develop custom robotic applications, to

<p>robotov z drugimi sistemi ter razvoja robotskih komponent in programja.</p> <p>Spretnosti:</p> <p>S2.1: Uporaba in programiranje industrijskih robotov s pomočjo učnih enot, namenskih programskih jezikov in odprtokodnih vmesnikov.</p> <p>S2.2: Načrtovanje in izvedba integracije industrijskih robotov z drugimi sistemi na osnovi povezovanja robotskih krmilnikov.</p> <p>S2.3: Načrtovanje in implementacija lastnih robotskih gradnikov in sistemov.</p>	<p>integrate robots with other industrial systems, and to develop robotic software and hardware components.</p> <p>Skills:</p> <p>S2.1: Using and programming of industrial robots by using teach pendants, programming languages, and open-source interfaces.</p> <p>S2.2: Design and implementation of integration of industrial robots with other systems based on the understanding robotic controllers.</p> <p>S2.3: Design and implementation of custom robotic building blocks and systems.</p>
--	--

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 namenski didaktičnimi pripomočki: industrijskimi roboti, mobilnimi roboti, prenosnimi računalniki, namensko programsko opremo.

P8 Izdelava in predstavitev aplikativnih seminarskih nalog.

P11 Uporaba izvršljivih knjig.

P14 Virtualni eksperimenti.

Learning and teaching methods:

P1 Formal lectures with domain-specific theoretical and practical examples.

P2 Contents treated in orderly and pre-explained systematic manner.

P4 Laboratory work with dedicated teaching aids (industrial robots, mobile robots, laptops, domain-specific software).

P8 Design and presentation of applicative seminar papers.

P11 Use of executable notebooks.

P14 Virtual Experiments.

Načini ocenjevanja:

Delež/ Weight

Assessment:

Teoretične vsebine (predavanja), preverjane pisno.	50,00 %	Theory (lectures) graded with written exams.
Praktične vsebine (vaje), preverjane pisno.	50,00 %	Practical work (tutorials) graded with written exams.

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:

Rok Vrabič:

1. 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](https://doi.org/10.1109/TASE.2023.3323099). [COBISS.SI-ID [169026819](https://cobiss.si/169026819)]
2. MALUS, Andreja, KOZJEK, Dominik, **VRABIČ, Rok**. Real-time order dispatching for a fleet of autonomous mobile robots using multi-agent reinforcement learning. CIRP annals, 69/1, accepted, in press, 2020. [COBISS.SI-ID [24176643](https://cobiss.si/24176643)]
3. PLETESKI, 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>, <https://repozitorij.uni-lj.si/IzpisGradiva.php?id=151584>, DOI: [10.1109/TIM.2023.3318710](https://doi.org/10.1109/TIM.2023.3318710). [COBISS.SI-ID [166014211](https://cobiss.si/166014211)]
4. **VRABIČ, Rok**, KOZJEK, Dominik, MALUS, Andreja, ZALETELJ, Viktor, BUTALA, Peter. Distributed control with rationally bounded agents in cyber-physical production systems. CIRP annals, 67/1:507-510, 2018. [COBISS.SI-ID [16026651](https://cobiss.si/16026651)]
5. 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, 68/1:495-498, 2019. [COBISS.SI-ID [16704539](https://cobiss.si/16704539)]

Dominik Kozjek:

1. DUAN, Songlin, **KOZJEK, Dominik**, MEHR, Edward, ANDERS, Mark, CAO, Jian. *Forming force prediction in double-sided incremental forming via GNN-based transfer learning*. Journal of manufacturing processes. [Online ed.]. Jun. 2024, vol. 120, str. 867-877, ilustr. ISSN 2212-4616. <https://www.sciencedirect.com/science/article/pii/S1526612524004535>, DOI: [10.1016/j.jmapro.2024.04.093](https://doi.org/10.1016/j.jmapro.2024.04.093). [COBISS.SI-ID [198433283](https://cobiss.si/198433283)].
2. 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>, Repozitorij Univerze v Ljubljani - RUL, DOI: [10.1016/j.cirp.2020.04.001](https://doi.org/10.1016/j.cirp.2020.04.001). [COBISS.SI-ID [24176643](https://cobiss.si/24176643)].
3. 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.
[COBISS.SI-ID [95688963](#)].

4. 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, Dhinaharan (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>. [COBISS.SI-ID [154249987](#)].
5. PODRŽAJ, Primož, REZNICHENKO, Igor, POŽRL, Tomaž, JENKO, Marjan, BRAČUN, Drago, **KOZJEK, Dominik**. *Matlab based synthesis of a PID controlled magnetic levitation system*. V: ICMAME 2023 : International Conference on Mechanical, Automotive and Mechatronics Engineering : 29-30 April 2023, Dubai, UAE : proceedings. [Dubai: ICMAME, 2023]. Str. 316-321, ilustr. [COBISS.SI-ID [152866563](#)].