

# AVTONOMNI ROBOTSKI SISTEMI

## UČNI NAČRT PREDMETA/COURSE SYLLABUS

<b>Predmet:</b>	AVTONOMNI ROBOTSKI SISTEMI
<b>Course title:</b>	AUTONOMOUS ROBOT SYSTEMS
<b>Članica nosilka/UL Member:</b>	UL FS

<b>Študijski programi in stopnja</b>	<b>Študijska smer</b>	<b>Letnik</b>	<b>Semestri</b>	<b>Izbirnost</b>
Strojništvo, tretja stopnja, doktorski	Proizvodno inženirske znanosti, kibernetika in mehatronika (smer)	1. letnik, 2. letnik	1. semester, 2. semester	izbirni

**Univerzitetna koda predmeta/University course code:**

0033468

**Koda učne enote na članici/UL Member course code:**

7313

<b>Predavanja /Lectures</b>	<b>Seminar /Seminar</b>	<b>Vaje /Tutorial s</b>	<b>Klinične vaje /Clinical tutorials</b>	<b>Druge oblike študija /Other forms of study</b>	<b>Samostojno delo /Individual student work</b>	<b>ECTS</b>
90					160	10

**Nosilec predmeta/Lecturer:**

Rok Vrabič

**Izvajalci predavanj:**

Rok Vrabič

**Izvajalci seminarjev:**

**Izvajalci vaj:**

**Izvajalci kliničnih vaj:**

**Izvajalci drugih oblik:**

**Izvajalci praktičnega usposabljanja:**

**Vrsta predmeta/Course type:**

Izbirni predmet /Elective course

**Jeziki/Languages:**

Predavanja/Lectures:

Angleščina, Slovenščina

Vaje/Tutorial:

Angleščina, Slovenščina

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

Veljajo splošni pogoji za doktorski študij.

General prerequisites for the third level studies.

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

1. Uvod v avtonomne sisteme  
Pregled konceptov in tehnologij avtonomnih sistemov. Uvod v agente in večagentne sisteme. Primeri avtonomnih robotskih sistemov v industrijskih aplikacijah. Trendi in izzivi na področju avtonomne robotike.

2. Osnove robotskih manipulatorjev  
Kinematika in dinamika robotskih manipulatorjev. Krmiljenje in programiranje manipulatorjev. Senzorji in aktuatorji. Varnostni vidiki. Primeri uporabe manipulatorjev v industrijskih aplikacijah.

3. Mobilni roboti in navigacija  
Kinematika in dinamika mobilnih robotov. Krmiljenje in navigacija. Lokalizacija in kartiranje. Avtomatsko vodeni vozički (AGV) in avtonomni mobilni roboti (AMR). Primeri uporabe v industriji in logistiki.

4. Arhitektura avtonomnih robotskih sistemov  
Elementi arhitekture in komunikacijska infrastruktura. Porazdeljeni sistemi in porazdeljeno odločanje. Programski okvir ROS/ROS2. Integracija senzorjev, aktuatorjev in algoritmov. Primeri arhitektur za industrijske aplikacije.

5. Osnove umetne inteligence v robotiki  
Uvod v strojno učenje in globoko učenje. Nevronske mreže, konvolucijske nevrnske mreže, rekurenčne nevrnske mreže. Učenje nevronskih mrež.

1. Introduction to Autonomous Systems  
Overview of concepts and technologies in autonomous systems. Introduction to agents and multi-agent systems. Examples of autonomous robotic systems in industrial applications. Trends and challenges in the field of autonomous robotics.

2. Fundamentals of Robotic Manipulators  
Kinematics and dynamics of robotic manipulators. Control and programming of manipulators. Sensors and actuators. Safety aspects. Examples of manipulator applications in industrial settings.

3. Mobile Robots and Navigation  
Kinematics and dynamics of mobile robots. Control and navigation. Localization and mapping. Automated Guided Vehicles (AGVs) and Autonomous Mobile Robots (AMRs). Examples of applications in industry and logistics.

4. Architecture of Autonomous Robotic Systems  
Elements of architecture and communication infrastructure. Distributed systems and distributed decision-making. ROS/ROS2 software framework. Integration of sensors, actuators, and algorithms. Examples of architectures for industrial applications.

5. Fundamentals of Artificial Intelligence in Robotics  
Introduction to machine learning and

<p>Aplikacije umetne inteligence v robotiki.</p> <p>6. Računalniški vid in percepcija Osnove računalniškega vida. Obdelava slik in videa. Zaznavanje objektov in segmentacija. 3D rekonstrukcija in ocena položaja. Primeri uporabe računalniškega vida v robotiki.</p> <p>7. Senzorski sistemi in obdelava podatkov Pregled tipičnih senzorskih sistemov v avtonomni robotiki (kamere, LiDAR, IMU, kodirniki). Kalibracija senzorjev. Obdelava in fuzija senzorskih podatkov. Uporaba vgradnih sistemov. Primeri senzorskih sistemov v industrijskih aplikacijah.</p> <p>8. Načrtovanje gibanja in krmiljenje Osnove načrtovanja gibanja. Konfiguracija prostora in preiskovanje. Načrtovanje poti in izogibanje oviram. Krmiljenje gibanja in sledenje trajektorijam. Primeri načrtovanja gibanja v industrijskih aplikacijah.</p> <p>9. Robotska manipulacija in prijemanje Zaznava in ocena položaja objektov. Načrtovanje prijemov. Krmiljenje sil in navorov. Primeri avtonomne robotske manipulacije v industrijskih aplikacijah, kot je pobiranje in odlaganje objektov.</p> <p>10. Simulacija in modeliranje robotskih sistemov Osnove modeliranja in simulacije robotov. Fizikalno osnovani simulatorji (Gazebo, PyBullet, MuJoCo). Integracija simulacij z ROS/ROS2. Uporaba simulacij za razvoj in testiranje algoritmov. Prenos iz simulacije v realno okolje.</p> <p>11. Spodbujevalno učenje v robotiki Osnove spodbujevalnega učenja. Markovski odločitveni procesi. Q-učenje in globoko Q-učenje. Metode akter-kritik in PPO. Uporaba spodbujevalnega učenja za krmiljenje robotov in optimizacijo strategij.</p> <p>12. Večagentni sistemi in sodelovanje Koncepti večagentnih sistemov. Komunikacija in koordinacija med</p>	<p>deep learning. Neural networks, convolutional neural networks, recurrent neural networks. Training neural networks. Applications of artificial intelligence in robotics.</p> <p>6. Computer Vision and Perception Fundamentals of computer vision. Image and video processing. Object detection and segmentation. 3D reconstruction and pose estimation. Examples of computer vision applications in robotics.</p> <p>7. Sensor Systems and Data Processing Overview of typical sensor systems in autonomous robotics (cameras, LiDAR, IMU, encoders). Sensor calibration. Processing and fusion of sensor data. Use of embedded systems. Examples of sensor systems in industrial applications.</p> <p>8. Motion Planning and Control Fundamentals of motion planning. Configuration space and search. Path planning and obstacle avoidance. Motion control and trajectory tracking. Examples of motion planning in industrial applications.</p> <p>9. Robotic Manipulation and Grasping Object detection and pose estimation. Grasp planning. Force and torque control. Examples of autonomous robotic manipulation in industrial applications, such as pick-and-place tasks.</p> <p>10. Simulation and Modeling of Robotic Systems Fundamentals of robot modeling and simulation. Physics-based simulators (Gazebo, PyBullet, MuJoCo). Integration of simulations with ROS/ROS2. Using simulations for algorithm development and testing. Transfer from simulation to real-world environments.</p> <p>11. Reinforcement Learning in Robotics Fundamentals of reinforcement learning. Markov Decision Processes. Q-learning and deep Q-learning. Actor-critic methods and PPO. Application of reinforcement learning for robot control and strategy optimization.</p>
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<p>agenti. Porazdeljeno odločanje in načrtovanje. Sodelovalno učenje in učenje po učnem načrtu. Primeri večagentnih sistemov v industrijski robotiki.</p> <p>13. Varnost in robustnost avtonomnih sistemov Varnostni izzivi v avtonomni robotiki. Zaznavanje in izogibanje trkom. Načrtovanje varnih trajektorij. Robustnost in odpornost na napake. Etični vidiki avtonomnih sistemov. Standardi in predpisi.</p> <p>14. Praktični primeri in študije primerov Pregled realnih aplikacij avtonomne robotike v industriji (montaža, pakiranje, logistika). Analiza študij primerov in dobrih praks. Izzivi pri implementaciji avtonomnih rešitev.</p> <p>15. Prihodnost avtonomnih robotskih sistemov Aplikacije generativne umetne inteligence v robotiki.</p>	<p>12. Multi-Agent Systems and Collaboration Concepts of multi-agent systems. Communication and coordination between agents. Distributed decision-making and planning. Collaborative learning and curriculum learning. Examples of multi-agent systems in industrial robotics.</p> <p>13. Safety and Robustness of Autonomous Systems Safety challenges in autonomous robotics. Collision detection and avoidance. Safe trajectory planning. Robustness and fault tolerance. Ethical aspects of autonomous systems. Standards and regulations.</p> <p>14. Practical Examples and Case Studies Overview of real-world applications of autonomous robotics in industry (assembly, packaging, logistics). Analysis of case studies and best practices. Challenges in implementing autonomous solutions.</p> <p>15. Future of Autonomous Robotic Systems Applications of generative artificial intelligence in robotics.</p>
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### Temeljna literatura in viri/Readings:

1. Peter Corke: Robotics, Vision and Control, Springer-Verlag Berlin Heidelberg, 2011 [15787291]
2. Tadej Bajd, Matjaž Mihelj, Marko Munih: Introduction to Robotics, Springer Dordrecht Heidelberg New York London, 2013 [9761364]
3. Gregor Klančar, Andrej Zdešar, Sašo Blažič, Igor Škrjanc: Wheeled Mobile Robotics, Butterworth-Heinemann, 2017 [11671636]
4. Morgan Quigley, Brian Gerkey, William D. Smart: Programming Robots with ROS, O'Reilly Media, 2015 [11614292]
5. Michael Wooldridge: An introduction to multiagent systems, Chichester : Wiley, 2011 [15492118]
6. Mike Barley et al.: Safety and Security in Multiagent Systems, Springer Berlin Heidelberg, 2009 [e-knjiga]

### Cilji in kompetence:

### Objectives and competences:

<b>Cilji:</b>	<b>Goals:</b>
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Razumevanje osnovnih konceptov in tehnologij avtonomnih robotskih sistemov. Poznavanje kinematike, dinamike in krmiljenja robotskih manipulatorjev ter mobilnih robotov. Sposobnost načrtovanja arhitekture avtonomnih robotskih sistemov in integracije komponent. Razumevanje osnov umetne inteligence, strojnega učenja in računalniškega vida v kontekstu robotike. Poznavanje senzorskih sistemov in obdelave podatkov v avtonomni robotiki. Sposobnost načrtovanja gibanja in krmiljenja robotov. Razumevanje principov robotske manipulacije in prijemanja. Poznavanje simulacijskih orodij in modeliranja robotskih sistemov. Razumevanje osnov spodbujevalnega učenja in njegove aplikacije v robotiki. Poznavanje konceptov večagentnih sistemov in sodelovanja med roboti. Razumevanje varnostnih in etičnih vidikov avtonomnih robotskih sistemov. Sposobnost analize praktičnih primerov in študij primerov iz industrije. Poznavanje trendov in prihodnosti avtonomnih robotskih sistemov.

### **Kompetence:**

Sposobnost načrtovanja, implementacije in integracije avtonomnih robotskih sistemov. Znanje programiranja in krmiljenja robotskih manipulatorjev in mobilnih robotov. Sposobnost razvoja algoritmov za lokalizacijo, kartiranje in navigacijo mobilnih robotov. Znanje uporabe umetne inteligence, strojnega učenja in računalniškega vida v robotiki. Sposobnost obdelave in fuzije senzorskih podatkov. Znanje načrtovanja gibanja in krmiljenja robotov za izogibanje oviram in sledenje trajektorijam. Sposobnost implementacije algoritmov za robotsko manipulacijo in prijemanje. Znanje uporabe simulacijskih orodij za razvoj in testiranje robotskih sistemov. Sposobnost aplikacije spodbujevalnega učenja za krmiljenje robotov in optimizacijo strategij. Znanje načrtovanja in implementacije večagentnih sistemov in sodelovanja

Understanding the basic concepts and technologies of autonomous robotic systems. Knowledge of kinematics, dynamics, and control of robotic manipulators and mobile robots. Ability to design the architecture of autonomous robotic systems and integrate components. Understanding the fundamentals of artificial intelligence, machine learning, and computer vision in the context of robotics. Knowledge of sensor systems and data processing in autonomous robotics. Ability to plan robot motion and control. Understanding the principles of robotic manipulation and grasping. Knowledge of simulation tools and modeling of robotic systems. Understanding the basics of reinforcement learning and its application in robotics. Knowledge of multi-agent system concepts and collaboration between robots. Understanding the safety and ethical aspects of autonomous robotic systems. Ability to analyze practical examples and case studies from industry. Knowledge of trends and the future of autonomous robotic systems.

### **Competences:**

Ability to design, implement, and integrate autonomous robotic systems. Knowledge of programming and control of robotic manipulators and mobile robots. Ability to develop algorithms for localization, mapping, and navigation of mobile robots. Knowledge of applying artificial intelligence, machine learning, and computer vision in robotics. Ability to process and fuse sensor data. Knowledge of planning robot motion and control for obstacle avoidance and trajectory tracking. Ability to implement algorithms for robotic manipulation and grasping. Knowledge of using simulation tools for developing and testing robotic systems. Ability to apply reinforcement learning for robot control and strategy optimization. Knowledge of designing and implementing multi-agent systems

med roboti. Sposobnost upoštevanja varnostnih in etičnih vidikov pri razvoju avtonomnih robotskih sistemov. Znanje analize in reševanja praktičnih problemov v industrijski robotiki. Sposobnost sledenja trendom in prilagajanja novim tehnologijam na področju avtonomne robotike.	and collaboration between robots. Ability to consider safety and ethical aspects in the development of autonomous robotic systems. Knowledge of analyzing and solving practical problems in industrial robotics. Ability to follow trends and adapt to new technologies in the field of autonomous robotics.
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### **Predvideni študijski rezultati:**

Študent bo sposoben razumeti in uporabiti osnovne koncepte in tehnologije avtonomnih robotskih sistemov, pridobil bo znanje o kinematiki, dinamiki in krmiljenju robotskih manipulatorjev ter mobilnih robotov, sposoben bo načrtovati arhitekturo avtonomnih robotskih sistemov in integrirati komponente, razumel bo osnove umetne inteligence, strojnega učenja in računalniškega vida v kontekstu robotike, pridobil bo znanje o senzorskih sistemih in obdelavi podatkov v avtonomni robotiki, sposoben bo načrtovati gibanje in krmiljenje robotov, razumel bo principe robotske manipulacije in prijemanja, pridobil bo znanje o simulacijskih orodjih in modeliranju robotskih sistemov, razumel bo osnove spodbujevalnega učenja in njegove aplikacije v robotiki, pridobil bo znanje o konceptih večagentnih sistemov in sodelovanja med roboti, razumel bo varnostne in etične vidike avtonomnih robotskih sistemov, sposoben bo analizirati praktične primere in študije primerov iz industrije ter pridobil znanje o trendih in prihodnosti avtonomnih robotskih sistemov.

### **Intended learning outcomes:**

Upon completion of the study, the student will be able to understand and apply the basic concepts and technologies of autonomous robotic systems, acquire knowledge about kinematics, dynamics, and control of robotic manipulators and mobile robots, be capable of designing the architecture of autonomous robotic systems and integrating components, understand the fundamentals of artificial intelligence, machine learning, and computer vision in the context of robotics, gain knowledge about sensor systems and data processing in autonomous robotics, be able to plan robot motion and control, understand the principles of robotic manipulation and grasping, acquire knowledge about simulation tools and modeling of robotic systems, comprehend the basics of reinforcement learning and its applications in robotics, obtain knowledge about the concepts of multi-agent systems and collaboration between robots, understand the safety and ethical aspects of autonomous robotic systems, be capable of analyzing practical examples and case studies from industry, and acquire knowledge about the trends and future of autonomous robotic systems.

### **Metode poučevanja in učenja:**

Predavanja, laboratorijske vaje, seminarsko delo, e-izobraževanje, konzultacije. Seminarsko delo v čim večji meri navezuje se na področje doktorskega raziskovanja. Študij z

### **Learning and teaching methods:**

Lectures, laboratory exercises, seminar work, e-learning, consultations. Seminar work will be related to the field of doctoral research as much as possible. Study using the recommended

uporabo priporočene literature.	literature.
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<b>Načini ocenjevanja:</b>	<b>Delež/Weight</b>	<b>Assessment:</b>
Ustni izpit, poročilo o seminarskem delu. Pogoji za opravljanje ustnega izpita je uspešno izdelano in pozitivno ocenjeno seminarsko delo. Način: projektni seminar (60%), predstavitev rezultatov seminarja v okviru laboratorija (20%), ustno izpraševanje (20%).	100,00 %	Oral exam, report on seminar work. The condition for admission to oral exam is successful completion of seminar work, rewarded with a passing grade. Method: project seminar (60%), presentation of seminar results in the laboratory (20%), oral examination (20%).

<b>Ocenjevalna lestvica:</b>	<b>Grading system:</b>
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:**

##### **doc. dr. Rok VRABIČ**

1. 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 [COBISS.SI-ID 166014211]
2. VRABIČ, Rok, ERKOYUNCU, John, FARSI, Maryam, ARIANSYAH, Dedy. An intelligent agent-based architecture for resilient digital twins in manufacturing. CIRP annals. 2021, vol. 70, iss. 1, str. 349-352,[COBISS.SI-ID 76795907]
3. ŠKULJ, Gašper, SLUGA, Alojz, 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 [COBISS.SI-ID 16704539]
4. ZALETELJ, Viktor, VRABIČ, Rok, HOZDIĆ, Elvis, BUTALA, Peter. A foundational ontology for the modelling of manufacturing systems. Advanced engineering informatics : the science of supporting knowledge-intensive activities. Oct. 2018, vol. 38, str. 129-141 [COBISS.SI-ID 16126491]
5. 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 [COBISS.SI-ID 16026651]