COMILLAS
UNIVERSIDAD PONTIFICIA
ICAI ICADE CIHS

COURSE SYLLABUS 2025-2026

GENERAL INFORMATION

Course information	
Name	Autonomous Mobile Robots
Code	DEAC-MIINT-521
Main program	Máster Universitario en Ingeniería Industrial
Offered in	Máster Universitario en Ingeniería Industrial + Máster en Industria Inteligente [2nd year] Máster en Industria Inteligente [1st year]
Level	Official Master's Degree
Semester	2nd (Spring)
Credits	3.0 ECTS
Type	Elective (MII), Compulsory (MIINT)
Department	Electronics, Control and Communications
Coordinator	Jaime Boal Martín-Larrauri

Instructor	
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Lab instructor	
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COURSE SPECIFIC INFORMATION

Contextualization of the course

Contribution to the professional profile of the degree

Industry 4.0 is fostering collaboration between humans and robots, which must be able to safely share the same workspace. Autonomous mobile robots can operate in an intelligent and orchestrated manner with minimal human intervention to optimize processes, improve flexibility, and enable mass customization. For example, replacing conveyor belts to transport materials around the factory floor while avoiding obstacles, coordinating with their fleet mates, and identifying in real-time where they need to pick up and drop off.

This course is designed as an introductory walk through all the modules that allow a mobile robot to behave autonomously. By the end of the course, students will have well-formed criteria to choose the most appropriate sensors and kinematic configuration for a given application, understand the most common localization and planning algorithms, and have hands-on experience with ROS 2, the de facto standard open-source framework used by researchers and developers around the world to build robotics applications.

Prerequisites

Students willing to take this course should be familiar with Python programming, linear algebra, probability and statistics, control theory, and machine learning.

Competences[1] – Objectives

Competences – Máster Universitario en Ingeniería Industrial

General

BA2.	Be able to apply and integrate their knowledge, understanding, scientific foundation and problem-solving skills in new and imprecisely defined environments, including multidisciplinary contexts both in research and in highly specialized professional fields. *Saber aplicar e integrar sus conocimientos, la comprensión de estos, su fundamentación científica y sus capacidades de resolución de problemas en entornos nuevos y definidos de forma imprecisa, incluyendo contextos de carácter multidisciplinar tanto investigadores como profesionales altamente especializados.*
CG1.	Have adequate knowledge of the scientific and technological aspects of mathematical, analytical, and numerical methods in engineering, electrical engineering, energy engineering, chemical engineering, mechanical engineering, mechanics of continuous media, industrial electronics, automation, manufacturing, materials, quantitative management methods, industrial computing, urban planning, infrastructures, etc. *Tener conocimientos adecuados de los aspectos científicos y tecnológicos de: métodos matemáticos, analíticos y numéricos en la ingeniería, ingeniería eléctrica, ingeniería energética, ingeniería química, ingeniería mecánica, mecánica de medios continuos, electrónica industrial, automática, fabricación, materiales, métodos cuantitativos de gestión, informática industrial, urbanismo, infraestructuras, etc.*

Competences – Máster en Industria Conectada

General

CG1.	Have acquired advanced knowledge and demonstrated, in a research and technological or highly specialized context, a detailed and well-founded understanding of the theoretical and practical aspects, as well as of the work methodology in one or more fields of study. *Haber adquirido conocimientos avanzados y demostrado, en un contexto de investigación científica y tecnológica o altamente especializado, una comprensión detallada y fundamentada de los aspectos teóricos y prácticos y de la metodología de trabajo en uno o más campos de estudio.*
CG2.	Know how to apply and integrate their knowledge, understanding, scientific rationale, and problem-solving skills to new and imprecisely defined environments, including highly specialized multidisciplinary research and professional contexts. *Saber aplicar e integrar sus conocimientos, la comprensión de estos, su fundamentación científica y sus capacidades de resolución de problemas en entornos nuevos y definidos de forma imprecisa, incluyendo contextos de carácter multidisciplinar tanto investigadores como profesionales altamente especializados.*
CG5.	Be able to transmit in a clear and unambiguous manner, to specialist and non-specialist audiences, results from scientific and technological research or state-of-the-art innovation, as well as the most relevant foundations that support them. *Saber transmitir de un modo claro y sin ambigüedades, a un público especializado o no, resultados procedentes de la investigación científica y tecnológica o del ámbito de la innovación más avanzada, así como los fundamentos más relevantes sobre los que se sustentan.*
CG6.	Have developed sufficient autonomy to participate in research projects and scientific or technological collaborations within their thematic area, in interdisciplinary contexts and, where appropriate, with a high knowledge transfer component. *Haber desarrollado la autonomía suficiente para participar en proyectos de investigación y colaboraciones científicas o tecnológicas dentro de su ámbito temático, en contextos interdisciplinares y, en su caso, con una alta componente de transferencia del conocimiento.*

[1] Competences in English are a free translation of the official Spanish version.

CG7.	Being able to take responsibility for their own professional development and their specialization in one or more fields of study. *Ser capaces de asumir la responsabilidad de su propio desarrollo profesional y de su especialización en uno o más campos de estudio.*
Specific	
CE6.	Understand the role of mobile robots in the improvement of industrial processes and be able to design and implement software that allows them to behave autonomously. *Comprender el papel de los robots móviles en la mejora de los procesos industriales y ser capaz de diseñar e implementar software que permita que se comporten de forma autónoma.*
Learning outcomes	
RA1.	Be familiar with the cycle that enables a robot to operate autonomously and the most commonly used sensors and actuators.
RA2.	Derive the kinematic equations of a wheeled mobile robot.
RA3.	Apply PID control algorithms to enable a robot to navigate autonomously through the environment.
RA4.	Understand and be able to implement the most common localization algorithms, both discrete and continuous.
RA5.	Understand why when a mobile robot is in an unknown or changing environment it is necessary to estimate its position and build a map simultaneously.
RA6.	Apply path planning and tracking algorithms, including those that allow obstacle avoidance.
RA7.	Understand the structure of the Robot Operating System (ROS) and use it to build robotic software.
RA8.	Assemble all the basic modules that allow a mobile robot to behave autonomously.

CONTENTS

Contents
Theory
Unit 1. Introduction to robotics
1.1 The history of robotics 1.2 Types of robots (industrial manipulators, collaborative robots, wheeled, legged, flying…) 1.3 The see-think-act cycle
Unit 2. Perception
2.1 Robot sensors (encoders, range sensors, radar, LiDAR, cameras…) 2.2 Fundamentals of computer vision
Unit 3. Wheeled kinematics
3.1 Types of wheels 3.2 Holonomic vs. non-holonomic systems 3.3 Forward and inverse kinematics of a differential drive robot 3.4 Other kinematic configurations (tricycle, Ackermann, robots with omni and Mecanum wheels…)

Unit 4. Robot Operating System (ROS 2)
4.1 What is ROS? 4.2 File system 4.3 Computational graph (nodes, parameters, messages, topics, services, actions…) 4.4 ROS 2 in Python 4.5 Launch files 4.6 Visualization and debugging tools
Unit 5. Localization
5.1 Histogram filters (Markov localization) 5.2 Kalman filters 5.3 Particle filters (Monte Carlo localization) 5.4 Introduction to SLAM (Simultaneous Localization and Mapping)
Unit 6. Path planning
6.1 Grid methods: A* 6.2 Roadmap methods: Visibility graphs and generalized Voronoi diagrams (GVD) 6.3 Sampling methods: Probabilistic roadmaps (PRM) and rapidly exploring random trees (RRT, RRT*) 6.4 Virtual potential fields
Unit 7. Path tracking
7.1 Follow-the-carrot 7.2 Pure pursuit 7.3 Other path-tracking techniques (Stanley, LQR, MPC…)
Laboratory
Lab 1. Wall following
In the first lab session, students will become familiar with ROS 2 and CoppeliaSim, the robot simulator used throughout the course. They will build a Python application (ROS 2 node) to command a simulated differential drive robot to follow a wall. The goal is to understand the publisher/subscriber mechanism and allow the robot to explore an unknown environment without crashing.
Lab 2. Particle filter localization
The aim of this session is that students improve their understanding of the particle filter algorithm. Building on the previous lab assignment, they will implement a basic particle filter from scratch on a new node that will make the robot localize itself as it safely moves following the walls.
Lab 3. Path planning with A*
In the third lab session, students will implement an A* node to plan the path from a known initial pose to a given destination. The path will be smoothed to make it easier to follow regardless of the robot's kinematics.
Lab 4. Pure pursuit tracking
Finally, students will program a tracking node to follow the smoothed path from the previous session.
Final project
The final project is an integration activity in which every team will bring together and refine all the modules developed during the lab assignments. The simulated robot will start at a random position in a new larger environment, will have to first localize itself within a known map, and then race to reach a given destination. There will be a competition in which extra credit will be awarded.

TEACHING METHODOLOGY

General methodological aspects	
Inspired by the "learn by doing" paradigm, this course is designed to provide students with the tools they require to develop a robotics application by the end of the term. In every unit, after the initial explanation of each concept, the instructor will propose individual and group quizzes and activities (some of which will be graded) to test students' understanding. Once they are more confident with the material, they will be asked to implement what they have learned in a lab session where they will start building blocks that will help them advance in their final project.	
In-class activities	**Competences**
▪ **Lectures:** The lecturer will introduce the fundamental concepts of each unit, along with some practical recommendations, and will go through worked examples to support the explanation. Active participation will be encouraged by raising open questions to foster discussion and by proposing online quizzes and short application exercises to be solved in class either on paper or using a software package.	CG1, CG7, CE6
▪ **Lab sessions:** Under the instructor's supervision, students, divided into small groups, will apply the concepts and techniques covered in the lectures to simulated versions of commercial mobile robots.	CG1, CG2, CG5, CG6, CG7, CE6
▪ **Tutoring** for groups or individual students will be organized upon request.	–
Out-of-class activities	**Competences**
▪ Personal study of the course material and resolution of the proposed exercises.	CG1, CG7, CE6
▪ Lab session preparation to make the most of in-class time.	CG1
▪ Lab results analysis and report writing.	CG2, CG5, CE6
▪ Development of a final project in small groups.	CG1, CG2, CG5, CG6, CG7, CE6

STUDENT WORK-TIME SUMMARY

IN-CLASS HOURS			
Lectures		**Lab sessions**	
16		14	
OUT-OF-CLASS HOURS			
Self-study	**Lab preparation**	**Lab report writing**	**Final project**
20	4	12	24
		ECTS credits:	**3.0 (90 hours)**

EVALUATION AND GRADING CRITERIA

The use of AI to produce entire assignments or significant parts of them, without citing the source or tool used, or without explicit permission in the assignment description, will be considered plagiarism and will be subject to the University's General Regulations.

Evaluation activities	Grading criteria	Weight
Quizzes	▪ Understanding of the theoretical concepts.	10%
Final exam	▪ Understanding of the theoretical concepts. ▪ Application of these concepts to problem-solving. ▪ Critical analysis of the numerical results. ▪ Written communication skills.	30%
Lab assignments	▪ Understanding of the theoretical concepts. ▪ Application of these concepts to problem-solving. ▪ Ability to use and develop software for mobile robots. ▪ Critical analysis of the experimental results. ▪ Oral and written communication skills.	40%
Final project	▪ Ability to use and develop software for mobile robots. ▪ Critical analysis of the experimental results. ▪ Working robustness. ▪ Autonomy and problem-solving skills. ▪ Teamwork. ▪ Oral and written communication skills.	20%

Grading

Regular assessment

- **Theory** (40%)
  - Quizzes: 10%
  - Final exam: 30%
- **Laboratory** (60%)
  - Lab assignments: 40%
  - Final project: 20%

The final grade will be computed according to these **restrictions**:

- The mark of the final exam must be greater or equal to 4 out of 10 points.
- The laboratory weighted average must be at least 5 out of 10.

If all the restrictions are met, the final grade of the course will be determined according to the weights indicated above. Otherwise, it will be the minimum of the two restrictions.

Retake

There will be a retake exam that will replace the final exam of the regular assessment period. As long as the laboratory has a passing grade, all the remaining marks will be preserved; otherwise, a new individual project will have to be developed, and all failed lab assignments repeated. The final grade will be computed as in the regular assessment period and under the same restrictions.

Course rules

- Class attendance is mandatory according to Article 93 of the General Regulations (Reglamento General) of Comillas Pontifical University and Article 6 of the Academic Rules (Normas Académicas) of the ICAI School of Engineering. Not complying with this requirement may have the following consequences:
  - Students who fail to attend more than 15% of the lectures may be denied the right to take the final exam during the regular assessment period.
  - Regarding laboratory, absence to more than 15% of the sessions can result in losing the right to take the final exam of the regular assessment period and the retake. Missed sessions must be made up for credit.
- According to Article 168, section 2.e) of the General Regulations of Universidad Pontificia Comillas, a serious offense is defined as *"any action aimed at falsifying or defrauding the systems used to assess academic performance."* If any irregularity is detected in an academic activity, the work will be graded with a zero (0.0), and disciplinary proceedings may be initiated. In laboratory assignments and the final project, the following will be considered irregularities: the total or partial copying of source code or answers from other students, whether from the current academic year or previous years. The literal or paraphrased reproduction of content from external sources without proper citation will also be considered an attempt of plagiarism. This includes content generated using generative artificial intelligence models, which must comply with the guidelines outlined in the following section.

Guidelines for the use of generative artificial intelligence (AI)

- **Exams.** The use of generative artificial intelligence models or programming assistants is strictly prohibited in the exams. These activities must reflect exclusively the student's own knowledge and individual work.
- **Laboratory.** The use of AI-based programming assistants and generative language models is permitted under the following conditions:
  - These tools may be used as support for understanding technical concepts, obtaining suggestions on how to approach the proposed exercises, and generating code snippets or initial drafts of reports.
  - Their use must always be complementary and must not replace the student's individual work. Submitting automatically generated content as one's own, without proper understanding, review, and adaptation, is not allowed.
  - Any relevant content generated wholly or partially using these tools must be explicitly cited, clearly indicating which parts were generated with AI and which tools were used. The sequence of prompts must be included as an annex at the end of the report.
  - Instructors reserve the right to ask oral questions regarding content generated with AI assistance to assess the student's understanding. Failure to explain or justify such content may negatively impact the grade for the activity.
- The responsible use of these tools is encouraged as a means of supporting individual study (e.g., to clarify concepts, generate additional exercises, or receive feedback). However, students should be aware that responses generated by AI models may contain errors, and it is their responsibility to critically assess and verify the information provided.

WORK PLAN AND SCHEDULE[2]

Activities	Date/Periodicity	Deadline
Quizzes	In every lecture	–
Final exam	After the lecture period	–
Lab sessions	From week 3	–
Self-study of the concepts covered in the lectures	After each lesson	–
Lab preparation	Before every lab session	–
Lab report writing	–	One week after the end of each session

BIBLIOGRAPHY AND RESOURCES

Basic references

- Slides prepared by the lecturer (available in Moodle).
- R. Siegwart, I. R. Nourbakhsh, and D. Scaramuzza, *Introduction to Autonomous Mobile Robots*, 2nd Ed., MIT Press, 2011. ISBN-13: 978-0-262-01535-6
- S. Thrun, W. Burgard, and D. Fox, *Probabilistic Robotics*, 1st Ed., MIT Press, 2006. ISBN-13: 978-0-262-20162-9
- Robot Operating System (ROS 2), [Online]. Available: https://www.ros.org

Complementary references

- B. Siciliano and O. Khatib (eds.), *Springer Handbook of Robotics*, 2nd Ed., Springer-Verlag Berlin Heidelberg, 2016. ISBN-13: 978-3-319-32550-7
- P. Corke, *Robotics, Vision and Control: Fundamental Algorithms in Python*, 3rd Ed., Springer International Publishing, 2023. ISBN-13: 978-3-031-06468-5
- R. Szeliski, *Computer Vision: Algorithms and Applications*, 1st Ed., Springer, 2011. ISBN-13: 978-1-848-82934-3
- K. M. Lynch and F. C. Park, *Modern Robotics: Mechanics, Planning and Control*, 1st Ed., Cambridge University Press, 2017. ISBN-13: 978-1-107-15630-2
- S. M. LaValle, *Planning Algorithms*, 1st Ed., Cambridge University Press, 2006. ISBN-13: 978-0-521-86205-9
- CoppeliaSim, [Online]. Available: https://www.coppeliarobotics.com/

[2] A detailed work plan of the subject can be found in the course summary sheet (see following page). Nevertheless, this schedule is tentative and may vary to accommodate the rhythm of the class.

	In-class activities				Out-of-class activities				Learning outcomes
Week	Time [h]	Lecture	Laboratory	Assessment	Time [h]	Self-study	Lab preparation and report writing	Other activities	Code
1	2	Course overview (0.5h) Unit 1. Introduction to robotics (1.5h)			1	Review and self-study (1h)			RA1
	2	Unit 2. Perception (2h)		Quiz	1	Review and self-study (1h)			RA1
2	2	Unit 2. Perception (1h) Unit 3. Wheeled kinematics (1h)		Quiz	2	Review and self-study (2h)			RA1, RA2
	2	Unit 4. ROS 2 (2h)		Quiz	2	Review and self-study (2h)			RA7
3	2		Lab 1. Wall following (2h)		4		Lab preparation (1h) Report writing (3h)		RA1, RA2, RA3, RA7
	2	Unit 5. Localization (2h)		Quiz	4	Review and self-study (2h)		Final project development (2h)	RA4, RA5
4	2	Unit 5. Localization (2h)		Quiz	2	Review and self-study (2h)			RA4, RA5
	2		Lab 2. Particle filter localization (2h)		4		Lab preparation (1h) Report writing (3h)		RA4, RA7, RA8
5	2	Unit 6. Path planning (2h)		Quiz	4	Review and self-study (2h)		Final project development (2h)	RA6
	2		Lab 3. Path planning with A* (2h)		4		Lab preparation (1h) Report writing (3h)		RA6, RA7, RA8
6	2	Unit 7. Path tracking (2h)			4	Review and self-study (2h)		Final project development (2h)	RA6
	2		Lab 4. Pure pursuit tracking (2h)		4		Lab preparation (1h) Report writing (3h)		RA6, RA7, RA8
7	2		Final project (2h)		6			Final project development (6h)	RA1 – RA8
	2		Final project (2h)		6			Final project development (6h)	RA1 – RA8
8	2		Final project (2h)		6			Final project development (6h)	RA1 – RA8
				Final exam Final project[3]	6	Final exam preparation (6h)			RA1 – RA8

[3] The final exam and the final project presentation will be held the week after the lecture period.