COMILLAS UNIVERSIDAD PONTIFICIA
ICAI ICADE CIHS

Syllabus
2025 - 2026

TECHNICAL SHEET OF THE SUBJECT

Data of the subject	
Subject name	Autonomous Mobile Robots
Subject code	DEAC-MIINT-521
Involved programs	Máster Universitario en Ingeniería Industrial y Máster en Industria Inteligente [Second year] Máster en Industria Inteligente [First year]
Level	Postgrado Oficial Master
Quarter	Semestral
Credits	3,0 ECTS
Type	Obligatoria
Department	Department of Electronics, Control and Communications
Coordinator	Jaime Boal Martín-Larrauri
Schedule	Afternoon
Office hours	Arrange an appointment through email.

Teacher Information	
Teacher	
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Teacher	
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SPECIFIC DATA OF THE SUBJECT

Contextualization of the subject

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 criteria to choose the most appropriate sensors and kinematic configuration for each situation, will understand the most common localization, planning and path tracking algorithms, and will have hands-on experience with ROS 2, the framework that is the *de facto* standard for researchers and developers designing and building mobile robots around the world.

Prerequisites

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

Competencies - 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.
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.

Máster en Industria Inteligente	
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.
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.
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.
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.
CG7.	Being able to take responsibility for their own professional development and their specialization in one or more fields of study.
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.

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.

THEMATIC BLOCKS AND CONTENTS

Contents - Thematic Blocks

Theory

1. Introduction to robotics

- The history of robotics
- Types of robots (industrial manipulators, collaborative robots, wheeled, legged, flying...)
- The see-think-act-cycle

2. Robot Operating System (ROS 2)

- What is ROS?
- File system
- Computational graph (nodes, parameters, messages, topics, services, actions...)
- ROS 2 in Python
- Launch files
- Visualization and debugging tools

3. Perception

- Classification and operating principle of sensors commonly used in robotics

4. Wheeled kinematics

- Types of wheels
- Holonomic vs. non-holonomic systems
- Forward and inverse kinematics of a differential drive robot
- Other kinematic configurations (tricycle, Ackermann, robots with omni and Mechanum wheels...)

5. Localization

- Histogram filter (Markov localization)
- Kalman filters
- Particle filter (Monte Carlo localization)
- Introduction to SLAM (Simultaneous Localization and Mapping)

6. Path planning

- Grid methods: A*
- Roadmap methods: Visibility graphs and generalized Voronoi diagrams (GVD)
- Sampling methods: Probabilistic roadmaps (PRM) and rapidly exploring random trees (RRT, RRT*)
- Virtual potential fields

7. Path tracking

- Follow-the-carrot
- Pure pursuit
- Other path-tracking techniques (Stanley, LQR, MPC...)

Laboratory

1. Exploration: Wall following

Students will become familiar with ROS 2 and CoppeliaSim, the robot simulator that will be used throughout the course, and will develop a Python application (ROS 2 node) to enable a differential-drive robot to explore a maze-like environment without crashing by following the walls.

2. Localization: Particle filter

Building on the previous lab assignment, the students will implement a basic particle filter from scratch that will allow the robot to localize itself as it safely explores the environment following the walls.

3. Path planning: Roadmaps

Students will implement a deterministic and a probabilistic roadmap (PRM) 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.

4. Path tracking: Pure pursuit

Students will program a tracking node to follow the smoothed path from the previous session.

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 of the subject

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 Methodology: Activities

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.

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.

Tutorial sessions will be organized upon request, both in groups and individually, to address any questions that arise after working through the different topics and to guide students in their learning process.

Non-Presential Methodology: Activities

Personal study. Students are expected to carry out individual work after the lectures in order to understand and internalize the knowledge covered in every unit.

Laboratory sessions. The lab sessions will require prior preparation and will conclude with the submission of a report.

SUMMARY STUDENT WORKING HOURS

IN-CLASS HOURS	
Lectures	Lab sessions
16	14
OUT-OF-CLASS HOURS	
Self-study	Lab sessions
20	40
ECTS CREDITS: 3.0 (90 hours)	

EVALUATION AND CRITERIA

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%
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%

Ratings

Regular assessment

The weight of each of the evaluation activities will be the following:

- Theory (40%)
  - Quizzes: 10%

    - Final exam: 30%
- Laboratory (60%)
    - Assignments: 40%
    - 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 from 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. Anyway, unjustified absences to laboratory sessions will be penalized in the evaluation.

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

Activities	Date of realization	Delivery date
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 Bibliography

- Slides and notes prepared by the instructors (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 Bibliography

- 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/