



## GENERAL INFORMATION

Data of the subject	
Subject name	Autonomous Mobile Robots
Subject code	DEAC-IMAT-324
Main program	<a href="#">Bachelor's Degree in Mathematical Engineering and Artificial Intelligence</a>
Involved programs	Grado en Ingeniería Matemática e Inteligencia Artificial [Third year]
Level	Reglada Grado Europeo
Quarter	Semestral
Credits	7,5 ECTS
Type	Obligatoria (Grado)
Department	Department of Electronics, Control and Communications
Coordinator	Jaime Boal Martín-Larrauri
Office hours	Arrange an appointment through email.

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## DESCRIPTION OF THE SUBJECT



## Contextualization of the subject

### Prerequisites

#### Contribution to the professional profile of the degree

Artificial intelligence has applications beyond data and the virtual world. It can also empower physical systems with which we interact on a daily basis, extending their capabilities and allowing them to autonomously perform tedious, repetitive, or potentially dangerous tasks in place of a human being. This subject integrates knowledge acquired during the bachelor's degree both in the mathematics block (algebra, probability and statistics, machine learning, computational geometry...) and in the technology part (programming, operating systems, electronic systems, dynamic systems...) to make a wheeled mobile robot capable of navigating autonomously through an environment without human intervention (e.g., to carry a package from one place to another).

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, mapping, 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 taking this course should have a solid foundation in Python programming, linear algebra, probability and statistics, control theory, and machine learning.

## Course contents

### Contents

#### 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 Mecanum wheels...)

## 5. Localization

- Histogram filter (Markov localization)
- Kalman filters
- Particle filter (Monte Carlo localization)

## 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...)

## 8. Simultaneous localization and mapping (SLAM)

- EKF SLAM
- GraphSLAM
- SEIF SLAM
- FastSLAM

## 9. Fundamentals of C++ for robotics

- Data types
- Basic syntax (expressions and flow control statements)
- Containers: Standard Template Library (STL)
- Functions
- Pointers, smart pointers, and references
- Classes
- ROS 2 in C++

## Laboratory

### 1. Robot Operating System (ROS 2)

ROS is the de facto standard for robotics development in the research community and it has steadily been adopted for industrial applications in the past few years. The objective of this lab session is to make initial contact with ROS 2, become familiar with all of its components, and learn how to build simple robotic software.

### 2. Exploration: Wall following

Students will learn to communicate ROS 2 and CoppeliaSim, the robot simulator used throughout the course, and build a Python node to command a differential drive robot to follow a wall in environments with intersections. The solution will be tested on both a simulated and a physical Turtlebot3 robot. The goal is to be able to explore an unknown environment without crashing.



### 3. 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.

### 4. Path planning and tracking

The students will first implement a planning algorithm from the set covered during the lectures to obtain 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. Subsequently, they will program a pure pursuit tracking node to navigate the smoothed path.

### Project

The final project is an integration activity in which every team will bring together and refine all the modules developed during the lab assignment, both in simulation and using a physical TurtleBot3. The robot will start at a random position in a maze-like environment. It will first have to localize itself, and then race to reach a given destination in the shortest time possible. There will be a competition in which extra credit will be awarded.

## EVALUATION AND CRITERIA

The use of AI to produce full assignments or substantial parts thereof, without proper citation of the source or tool used, or without explicit permission in the assignment instructions, will be considered plagiarism and therefore subject to the University's General Regulations.

Evaluation activities	Evaluation criteria	Weight
<ul style="list-style-type: none"><li>Quizzes</li><li>Midterm</li><li>Final exam</li></ul>	<ul style="list-style-type: none"><li>Understanding of the theoretical concepts.</li><li>Application of these concepts to problem-solving.</li><li>Critical analysis of the numerical results.</li><li>Written communication skills.</li></ul>	45
<ul style="list-style-type: none"><li>Lab assignments</li></ul>	<ul style="list-style-type: none"><li>Understanding of the theoretical concepts.</li><li>Application of these concepts to problem-solving.</li><li>Ability to use and develop software for mobile robots.</li><li>Critical analysis of the experimental results.</li><li>Oral and written communication skills.</li></ul>	30
<ul style="list-style-type: none"><li>Project</li></ul>	<ul style="list-style-type: none"><li>Ability to use and develop software for mobile robots.</li><li>Critical analysis of the experimental results.</li><li>Working robustness.</li><li>Autonomy and problem-solving skills.</li><li>Teamwork.</li><li>Oral and written communication skills.</li></ul>	25



## Grading

### Regular assessment

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

- Theory (45%)
  - Quizzes: 5%
  - Midterm: 10%
  - Final exam: 30%
- Laboratory (55%)
  - Assignments: 30%
  - Project: 25%

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 theory weighted average must reach 5 out of 10.
- 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 three 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 midterm and final 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—for example, 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	Every lecture	
Midterm	Week 8	
Final exam	Regular examination period	
Lab sessions	Weekly	
Self-study of the concepts covered in the lectures	After each lesson	
Problem solving	Weekly	
Lab preparation	Before every lab session	
Lab report writing		One week after the end of each session
Project	From week 11	Last week
Midterm preparation	One week before the test	
Final exam preparation	April	



# COMILLAS

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**Syllabus**  
**2025 - 2026**

## BIBLIOGRAPHY AND RESOURCES

### Basic References

- 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
- 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
- P. Corke, *Robotics, Vision and Control: Fundamental Algorithms in Python*, 3rd Ed., Springer International Publishing, 2023. ISBN-13: 978-3-031-06468-5
- J. Lospinoso, *C++ Crash Course: A Fast-Paced Introduction*, 1st Ed., No Starch Press, 2019. ISBN-13: 978-1-593-27888-5
- CoppeliaSim, [Online]. Available: <https://www.coppeliarobotics.com/>

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