COMILLAS UNIVERSIDAD PONTIFICIA ICAI ICADE CIHS

Syllabus 2023 - 2024

GENERAL INFORMATION

Data of the subject	
Subject name	Autonomous Mobile Robots
Subject code	DEAC-IMAT-324
Mainprogram	Grado en Ingeniería Matemática e Inteligencia Artificial
Involved programs	Grado en Ingeniería Matemática e Inteligencia Artificial [Third year]
Credits	7,5 ECTS
Type	Obligatoria (Grado)
Department	Department of Electronics, Control and Communications
Coordinator	Jaime Boal Martín-Larrauri
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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, and planning 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 Mechanum 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, pointers, smart pointers, and references
- Basic syntax (expressions and flow control statements)
- Functions and classes
- Containers: Standard Template Library (STL)
- 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: EKF and particle filter

Building on the previous lab assignment, the students will implement an Extended Kalman Filter (EKF) and a basic particle filter from scratch that will allow the robot to localize itself as it safely explores following the walls.

4. Path planning and tracking: RRT* and pure pursuit

The students will first implement an RRT* 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. Subsequently, they will program a pure pursuit tracking node to navigate the smoothed path with a Turtlebot3.

5. Simultaneous localization and mapping (SLAM)

The students will learn to use the SLAM module integrated within Nav2, possibly the best open and professionally supported navigation framework available for ROS 2.

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 robot will start at a random position in a new environment, will have to first 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

Evaluation activities	Evaluation criteria	Weight
• Quizzes • Midterm • Final exam	• Understanding of the theoretical concepts. • Application of these concepts to problem-solving. • Critical analysis of the numerical results. • Written communication skills.	45 %
• 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.	30 %
• 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.	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.

Students who commit an irregularity in any graded activity will receive a mark of zero in the activity and disciplinary procedures will follow (cf. Article 168 of the General Regulations (Reglamento General) of Comillas Pontifical University).

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
Final project	From week 11	Last week
Midterm preparation	One week before the test	
Final exam preparation	April	

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
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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
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- 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/

AUTONOMOUS MOBILE ROBOTS: TENTATIVE WEEKLY SCHEDULE