COMILLAS
UNIVERSIDAD PONTIFICIA
ICAI ICADE CIHS

COURSE SYLLABUS
2019-2020

GENERAL INFORMATION

Course information	
Name	Cyber-Physical Systems and Robotics
Code	DEA-MIC-525
Degree	Máster Universitario en Ingeniería Industrial + Máster en Industria Conectada [2nd year]
Semester	2nd (Spring)
ECTS credits	3.0
Type	Compulsory
Department	Electronics, Control and Communications
Coordinator	Jaime Boal Martín-Larrauri

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DETAILED INFORMATION

Contextualization of the course

Contribution to the professional profile of the degree

Cyber-physical systems (CPS) are engineered networked systems that are built from, and depend upon, the seamless integration and coordination of computational algorithms and physical components. With applications in many domains such as energy (smart grids), healthcare (medical monitoring), manufacturing (collaborative robots), or transportation (self-driving cars), CPS are bound to revolutionize the way technology interacts with real-world entities by exceeding today's systems in terms of autonomy, functionality, efficiency, usability, safety, and reliability. Since there is a lot of ongoing research in this field, the scope of this course is limited to introducing the principles, foundations, and challenges of CPS.

As a remarkable representative of CPS, robotic systems are ideal to gain some practical insight into what cyber-physical systems will achieve. Therefore, the core of this course is conceived as an introductory walk through some of the most extensively used techniques in the field of mobile robotics, in which the student will be progressively exposed to a number of algorithms that allow a robot to behave autonomously.

By the end of the course, students will understand what a cyber-physical system is, will have well-formed criteria to choose the most appropriate type of robot for a given application, and hands-on experience with some of the most commonly used localization and planning algorithms. As a result they will be able to start developing truly autonomous robotic systems or join cutting-edge research groups in which a solid background is often requested.

Prerequisites

Students willing to take this course should be familiar with linear algebra, basic probability and statistics, machine learning, and undergraduate-level programming. Previous experience with Python and an object-oriented programming language (especially C++) is also desired although not strictly required.

CONTENTS

Contents
Theory
Unit 1. Cyber-physical systems
1.1 What is a cyber-physical system? 1.2 Applications 1.3 Challenges
Unit 2. Introduction to robotics
2.1 Introduction 2.2 Types of robots (industrial manipulators, collaborative robots, wheeled, legged, flying…) 2.3 The see-think-act cycle
Unit 3. Perception and locomotion
3.1 Sensor classification 3.2 Fundamentals of computer vision 3.3 Wheeled kinematics
Unit 4. Localization
4.1 Markov localization 4.2 Kalman filter 4.3 Particle filter 4.4 Simultaneous localization and mapping (SLAM)
Unit 5. Motion planning
5.1 Path planning 5.2 Obstacle avoidance
Unit 6. Robot Operating System (ROS)
6.1 What is ROS? 6.2 General concepts (master, nodes, topics, services…)
Laboratory
Lab 1. Perception and locomotion
In the first lab session, students will become familiar with V-REP, the robot simulator that they will use throughout the course, by interfacing it with Python to control a differential drive robot.
Lab 2. Particle filter localization
The aim of this session is that students improve their understanding of the particle filter algorithm using a simple yet realistic environment.
Lab 3. Motion planning
In the third lab session, students will be asked to implement an algorithm to guide a robot to a particular location of a previously known environment where there may be unexpected obstacles.
Lab 4. Robot Operating System (ROS)
ROS is de facto standard for robotics development in the research community and it is slowly but firmly being adopted for industrial applications. The objective of this lab session is that students make initial contact with ROS and get an insight into its possibilities.
Final project
The final project is nothing more, and nothing less, than an integration activity. Students will put all the modules developed in the previous lab sessions together in order to solve a challenge proposed by the instructor. The topic of the project will be announced at the beginning of the course to allow students to start working on it as soon as possible.

Competences and learning outcomes

Competences[1]

General competences

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.

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 competences

CE6. Have an overview of the characteristics of cyber-physical systems, as well as the role of collaborative and mobile robotics in the improvement of industrial processes.

Tener una visión general de las características de los sistemas ciberfísicos, así como del papel de las robóticas colaborativa y móvil en la mejora de los procesos industriales.

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

Learning outcomes

By the end of the course students should:

RA1. Define what cyber-physical systems are and highlight the main challenges they currently face.

RA2. Enumerate several fields where cyber-physical systems are widely used nowadays or are bound to become relevant in the near future.

RA3. Identify the different types of robots and indicate which are best suited for a given application.

RA4. Be familiar with the main sensors used in a robot.

RA5. Understand the computer vision pipeline.

RA6. Cite the properties, advantages and disadvantages of the most common types of features.

RA7. Derive the kinematic equations of a wheeled mobile robot.

RA8. Understand and be able to implement the most common localization algorithms.

RA9. Explain why when a robot is placed in an unknown position of a previously unexplored environment, it has to estimate its current location and build the map simultaneously.

RA10. Describe the main path planning algorithms.

RA11. Deal with unexpected obstacles during navigation.

RA12. Understand the structure of the Robot Operating System (ROS).

RA13. Develop, implement, and test algorithms in an autonomous manner.

RA14. Provide evidence to assess the validity and performance of the proposed solution.

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 in 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

ASSESSMENT AND GRADING CRITERIA

Assessment 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 numerical exercises' results.	30%
Lab assignments	▪ Application of theoretical concepts to real problem-solving. ▪ Ability to use and develop robotics software. ▪ Written communication skills.	35%
Final project	▪ Problem analysis. ▪ Quality of the proposed solution. ▪ Teamwork. ▪ Oral presentation skills. ▪ There will be an intra-group evaluation method to differentiate among team members.	25%

GRADING AND COURSE RULES

Grading

Regular assessment

- **Theory** will account for 40%, of which:
  - Quizzes: 10%
  - Final exam: 30%
- **Lab** will account for the remaining 60%, of which:
  - Lab assignments: 35%
  - Final project: 25%

In order to pass the course, the weighted average mark must be greater or equal to 5 out of 10 points, the mark of the final exam must be greater or equal to 4 out of 10 points, and the laboratory mark (the weighted average of the assignments and the final project) must be at least 5 out of 10 points. Otherwise, the final grade will be the lower of the three marks.

Retake

Lab marks will be preserved as long as the weighted average of the assignments and the final project results in a passing grade. Otherwise a new project will have to be developed and handed in. In addition, all students will take a final exam. The resulting grade will be computed as follows:

- **Theory** will account for 40%, of which:
  - Quizzes: 10%
  - Final exam: 30%
- **Lab** will account for the remaining 60%, of which:
  - If the student passed the lab during regular assessment
    - Lab assignments: 35%
    - Final project: 25%
  - Otherwise
    - Final project: 60%

As in the regular assessment period, in order to pass the course, the weighted average mark must be greater or equal to 5 out of 10 points, the mark of the final exam must be greater or equal to 4 out of 10 points, and the mark of the laboratory must be at least 5 out of 10 points. Otherwise, the final grade will be the lower of the three marks.

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

WORK PLAN AND SCHEDULE[2]

In and out-of-class activities	Date/Periodicity	Deadline
Final exam	After the lecture period	–
Lab sessions	Weeks 3 to 6	–
Review and 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
Final project	From week 3	Last week

STUDENT WORK-TIME SUMMARY			
IN-CLASS HOURS			
Lectures	Lab sessions		Assessment
15	13		2
OUT-OF-CLASS HOURS			
Self-study	Lab preparation	Lab report writing	Final project
22	4	12	22
		ECTS credits:	3 (90 hours)

BIBLIOGRAPHY

Basic bibliography

- Slides prepared by the lecturer (available in Moodlerooms).
- 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
- P. Corke, *Robotics, Vision and Control: Fundamental Algorithms in MATLAB*, 2nd Ed., Springer International Publishing, 2017. ISBN-13: 978-3-319-54412-0
- Virtual Robot Experimentation Platform (V-REP), [Online]. Available: http://www.coppeliarobotics.com

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
- S. Thrun, W. Burgard, and D. Fox, *Probabilistic Robotics*, 1st Ed., MIT Press, 2006. ISBN-13: 978-0-262-20162-9
- R. Szeliski, *Computer Vision: Algorithms and Applications*, 1st Ed., Springer, 2011. ISBN-13: 978-1-848-82934-3
- Robot Operating System (ROS), [Online]. Available: http://www.ros.org
- MATLAB Robotics System Toolbox, [Online]. Available: https://mathworks.com/products/robotics.html
- MATLAB Computer Vision System Toolbox, [Online]. Available: https://mathworks.com/products/computer-vision.html

[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) Cyber-physical systems (1.5h)			1	Review and self-study (1h)			RA1, RA2
	2	Introduction to robotics (2h)			1	Review and self-study (1h)			RA3
2	2	Perception (1.8h)		Quiz (0.2 h)	2	Review and self-study (2h)			RA4, RA5, RA6
	2	Locomotion (1.8h)		Quiz (0.2 h)	2	Review and self-study (2h)			RA7
3	2		Lab 1 (2h)		4		Lab preparation (1h) Report writing (3h)		RA4, RA5, RA6, RA7
	2	Localization (1.8h)		Quiz (0.2 h)	4	Review and self-study (2h)		Final project development (2h)	RA8
4	2	Localization (1.8h)		Quiz (0.2 h)	2	Review and self-study (2h)			RA8, RA9
	2		Lab 2 (2h)		4		Lab preparation (1h) Report writing (3h)		RA8, RA9, RA13, RA14
5	2	Motion planning (1.8h)		Quiz (0.2 h)	4	Review and self-study (2h)		Final project development (2h)	RA10, RA11
	2		Lab 3 (2h)		4		Lab preparation (1h) Report writing (3h)		RA10, RA11, RA13, RA14
6	2	ROS (2h)			4	Review and self-study (2h)		Final project development (2h)	RA12
	2		Lab 4 (2h)		4		Lab preparation (1h) Report writing (3h)		RA12
7	2		Final project (2h)		6			Final project development (6h)	RA3 – RA11, RA13, RA14
	2		Final project (2h)		6			Final project development (6h)	RA3 – RA11, RA13, RA14
8	2		Final project (1h)	Final project demonstration (1h)	4			Final project presentation preparation (4h)	RA3 – RA11, RA13, RA14
				Final exam[3]	8	Final exam preparation (8h)			RA1 – RA12

[3] The final exam will be held on the first week of March.