Course guide
270428 - RA - Advanced Robotics

Last modified: 02/02/2024

Unit in charge: Barcelona School of Informatics
Teaching unit: 707 - ESAII - Department of Automatic Control.

Degree: BACHELOR'S DEGREE IN ARTIFICIAL INTELLIGENCE (Syllabus 2021). (Compulsory subject).

Academic year: 2023 **ECTS Credits:** 6.0 **Languages:** Catalan, Spanish

LECTURER

Coordinating lecturer: ANAÍS GARRELL ZULUETA

Others: Segon quadrimestre:
ANAÍS GARRELL ZULUETA - 11, 12
ISIAH ZAPLANA AGUT - 11, 12

PRIOR SKILLS

Mathematics

* To know and be able to apply the concept of derivative and partial derivative.
* To know the basic methods of graphical representation of functions (asymptotes, maxima, minima, ...).
* To know the elementary properties of trigonometric functions.
* To know the basic concepts of manipulation and operation with matrices.

Programming and Data Structure

* To know how to specify, design and implement simple algorithms with an imperative programming language.
* To know how to build correct, efficient and structured programs.
* To know the concepts of interpreted languages and compiled languages.
* To know search algorithms on data structures (tables, lists, trees, ...).

Computer Architecture and Technology

* To know at a functional level the different types of logic gates.
* To know how to analyze and implement simple combinational and sequential logic systems.
* To know the basic structure of a computer.
* To know the input / output and interruption subsystem of computers.

Robotics Area

Knowledge of ROS
Knowledge of Matlab, Peter Corke library

DEGREE COMPETENCES TO WHICH THE SUBJECT CONTRIBUTES

Specific:
CE15. To acquire, formalize and represent human knowledge in a computable form for solving problems through a computer system in any field of application, particularly those related to aspects of computing, perception and performance in intelligent environments or environments.
CE17. To develop and evaluate interactive systems and presentation of complex information and its application to solving human-computer and human-robot interaction design problems.
CE24. To ideate, design and build intelligent robotic systems to be applied in production and service environments, and that have to be capable of interacting with people. Also, to create collaborative and social intelligent robotic systems.
CE25. To ideate, design and integrate mobile robots with autonomous navigation capability, fleet formation and interaction with humans.
CE26. To design and apply techniques for processing and analyzing images and computer vision techniques in the area of artificial intelligence and robotics
CE28. To plan, ideate, deploy and direct projects, services and systems in the field of artificial intelligence, leading its implementation and continuous improvement and assessing its economic and social impact.

Generical:
CG3. To define, evaluate and select hardware and software platforms for the development and execution of computer systems, services and applications in the field of artificial intelligence.
CG4. Reasoning, analyzing reality and designing algorithms and formulations that model it. To identify problems and construct valid algorithmic or mathematical solutions, eventually new, integrating the necessary multidisciplinary knowledge, evaluating different alternatives with a critical spirit, justifying the decisions taken, interpreting and synthesizing the results in the context of the application domain and establishing methodological generalizations based on specific applications.
CG5. Work in multidisciplinary teams and projects related to artificial intelligence and robotics, interacting fluently with engineers and professionals from other disciplines.
CG6. To identify opportunities for innovative applications of artificial intelligence and robotics in constantly evolving technological environments.
CG7. To interpret and apply current legislation, as well as specifications, regulations and standards in the field of artificial intelligence.
CG8. Perform an ethical exercise of the profession in all its facets, applying ethical criteria in the design of systems, algorithms, experiments, use of data, in accordance with the ethical systems recommended by national and international organizations, with special emphasis on security, robustness , privacy, transparency, traceability, prevention of bias (race, gender, religion, territory, etc.) and respect for human rights.
CG9. To face new challenges with a broad vision of the possibilities of a professional career in the field of Artificial Intelligence. Develop the activity applying quality criteria and continuous improvement, and act rigorously in professional development. Adapt to organizational or technological changes. Work in situations of lack of information and / or with time and / or resource restrictions.

Transversal:
CT1. Entrepreneurship and innovation. Know and understand the organization of a company and the sciences that govern its activity; Have the ability to understand labor standards and the relationships between planning, industrial and commercial strategies, quality and profit.
CT2. Sustainability and Social Commitment. To know and understand the complexity of economic and social phenomena typical of the welfare society; Be able to relate well-being to globalization and sustainability; Achieve skills to use in a balanced and compatible way the technique, the technology, the economy and the sustainability.
CT3. Efficient oral and written communication. Communicate in an oral and written way with other people about the results of learning, thinking and decision making; Participate in debates on topics of the specialty itself.
CT5. Solvent use of information resources. Manage the acquisition, structuring, analysis and visualization of data and information in the field of specialty and critically evaluate the results of such management.
CT8. (ENG) Perspectiva de gènere. Conèixer i comprendre, des del propi àmbit de la titulació, les desigualtats per raó de sexe i gènere a la societat; Integrar les diferents necessitats i preferències per raó de sexe i de gènere en el disseny de solucions i resolució de problemes.

Basic:
CB3. That students have the ability to gather and interpret relevant data (usually within their area of ??study) to make judgments that include a reflection on relevant social, scientific or ethical issues.
CB5. That the students have developed those learning skills necessary to undertake later studies with a high degree of autonomy

TEACHING METHODOLOGY

The teaching methodology will be generally deductive in nature. The aim is to avoid the expository/lecture method. The approach will always be the same:

·- Propose a problem
·- Try to solve it
·- Add the necessary pieces of theory to be able to solve the problem adequately.

There will be no distinction between theory classes and problem-solving, as in classroom sessions the presentation of concepts and the resolution of application problems are intercalated. The laboratory classes are the complement where students put the concepts into practice using simulators and/or real robotic systems.

In addition to the classroom and laboratory activities, students must solve and submit a set of exercises to the teachers for evaluation. These exercises allow them to consolidate the acquired knowledge, serve as a mechanism for self-evaluation and teamwork.

LEARNING OBJECTIVES OF THE SUBJECT

1.Learn to program robots and design robotic applications.
2.Be able to make judgments that include a reflection on relevant social, scientific or ethical issues related to current robotics and its potential applications.
3.Learn to coordinate actions between robots.
4.Be able to merge different sources of information to obtain, formalize and represent the physical environment in a computable way for problem solving.
5.Application of Computer Vision techniques to Robotic Systems
6.Application of Artificial Intelligence techniques to Robotic Systems
7.Creation of interaction systems between robots and humans

STUDY LOAD

Type	Hours	Percentage
Hours small group	30,0	20.00
Hours large group	30,0	20.00
Self study	90,0	60.00

Total learning time: 150 h

CONTENTS

Introduction

Description:
The contents that were achieved in the previous subject Introduction to robotics will be reviewed.

Planning Methods Based on Graphs

Description:
Introduction to the route planning problem through meshes where the robot can only occupy discrete positions. These situations can be modeled as graphs where nodes correspond to grid positions and edges to routes between adjacent grid cells. We present several algorithms that can be used to plan paths between a start node and an end node, including breadth-first search or the grassfire algorithm, Dijkstra's algorithm, and the A* procedure

Configuration space

Description:
Introducing the concept of configuration space, which is a mathematical tool we use to think about the set of positions our robot can reach. Then the notion of obstacles in the configuration space will be studied. This formulation allows one to think of path planning problems in terms of constructing trajectories for a point through configuration space. We will also describe some approaches that can be used to discretize the continuous configuration space into graphs so that we can apply graph-based tools to solve our motion planning problems.

Planning Methods Based on Sampling

Description:
The concept of sampling-based path planning techniques will be presented. This involves randomly sampling points in the configuration space and then creating collision-free edges between neighboring sample points to form a graph that captures the structure of the robot's configuration space. Probabilistic Road Maps and Randomly Exploring Rapid Trees (RRTs) methods and their application to motion planning problems will be presented.

Methods of Artificial Potential Fields

Description:
A new approach to motion planning involves the construction of artificial potential fields that are designed to attract the robot to the desired goal configuration and move it away from obstacles in the configuration space. The motion of the robot can be guided by considering the gradient of this potential function. They will illustrate these techniques in the context of a simple two-dimensional configuration space.

Motion Planning

Description:
Constraints in configuration space, graphs and trees, and A* graph search.
Motion planning on a discretized configuration space grid, planners based on random sampling, virtual potential fields, and nonlinear optimization.

Robot Control

Description:
First- and second-order linear error dynamics, stability of a feedback control system, and robot motion control when controller output commands joint velocities.
Motion control of robots when the controller output commands the joint torsions, force control and hybrid motion-force control.

Mobile robots with wheels

Description:
Kinematic models of mobile robots with omnidirectional and non-holonomic wheels.
Controllability, motion planning and feedback control of non-holonomic wheeled mobile robots; odometry for wheeled mobile robots; and mobile manipulation.

Dynamics of open chains

Description:
Lagrangian formulation of dynamics, centripetal and Coriolis forces, robot mass matrix, rigid body dynamics, and inverse Newton-Euler dynamics for an open chain robot.
Direct dynamics of an open chain, task space dynamics, constrained dynamics, and practical effects due to gears and friction.

Generation of trajectories

Description:
Point-to-point trajectories in a straight line and polynomial trajectories passing through traveling points.
Optimal movements in time along a specified trajectory under robot dynamics and actuator limits.

Control of manipulators

Description:
Local motion control strategies vs. centralized
Independent control of "joints".
Anticipated torque action computed.
Lyapunov stability analysis of MIMO controls.
Feedback linearization.
Control of the operating space.
Indirect vs. Force Control Strategies direct
Impedance control.
Direct force control.
Cascading controllers.

ACTIVITIES

Review of the contents of the subject Introduction to Robotics.

Description:
The contents that were achieved in the previous subject Introduction to robotics will be reviewed.

Specific objectives:
2

Related competencies :
CG7. To interpret and apply current legislation, as well as specifications, regulations and standards in the field of artificial intelligence.
CG8. Perform an ethical exercise of the profession in all its facets, applying ethical criteria in the design of systems, algorithms, experiments, use of data, in accordance with the ethical systems recommended by national and international organizations, with special emphasis on security, robustness , privacy, transparency, traceability, prevention of bias (race, gender, religion, territory, etc.) and respect for human rights.
CG5. Work in multidisciplinary teams and projects related to artificial intelligence and robotics, interacting fluently with engineers and professionals from other disciplines.
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CE28. To plan, ideate, deploy and direct projects, services and systems in the field of artificial intelligence, leading its implementation and continuous improvement and assessing its economic and social impact.
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Full-or-part-time: 10h
Theory classes: 2h
Self study: 8h

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Specific objectives:
2, 4

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CB5. That the students have developed those learning skills necessary to undertake later studies with a high degree of autonomy
CB3. That students have the ability to gather and interpret relevant data (usually within their area of ??study) to make judgments that include a reflection on relevant social, scientific or ethical issues.

Full-or-part-time: 12h
Theory classes: 2h
Laboratory classes: 4h
Self study: 6h

Configuration space

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Introducing the concept of configuration space, which is a mathematical tool we use to think about the set of positions our robot can reach. Then the notion of obstacles in the configuration space will be studied. This formulation allows one to think of path planning problems in terms of constructing trajectories for a point through configuration space. We will also describe some approaches that can be used to discretize the continuous configuration space into graphs so that we can apply graph-based tools to solve our motion planning problems.

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Full-or-part-time: 8h
Theory classes: 2h
Laboratory classes: 2h
Self study: 4h

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Specific objectives:
2, 4

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Full-or-part-time: 12h
Theory classes: 2h
Laboratory classes: 2h
Self study: 8h

Methods of Artificial Potential Fields

Description:
A new approach to motion planning involves the construction of artificial potential fields that are designed to attract the robot to the desired goal configuration and move it away from obstacles in the configuration space. The motion of the robot can be guided by considering the gradient of this potential function. They will illustrate these techniques in the context of a simple two-dimensional configuration space.

Specific objectives:
1, 2, 3, 4, 6

Related competencies :
CG4. Reasoning, analyzing reality and designing algorithms and formulations that model it. To identify problems and construct valid algorithmic or mathematical solutions, eventually new, integrating the necessary multidisciplinary knowledge, evaluating different alternatives with a critical spirit, justifying the decisions taken, interpreting and synthesizing the results in the context of the application domain and establishing methodological generalizations based on specific applications.
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Full-or-part-time: 14h
Theory classes: 4h
Laboratory classes: 2h
Self study: 8h

Motion Planning

Description:
Obstacles a l'espai de configuració, grafs i arbres, i cerca de grafs A*.
Planificació de moviments en una graella de l'espai de configuració discretitzat, planificadors basats en mostreig aleatori, camps potencials virtuals i optimització no lineal.

Full-or-part-time: 12h
Theory classes: 2h
Laboratory classes: 2h
Self study: 8h

Robot Control

Description:
First- and second-order linear error dynamics, stability of a feedback control system, and robot motion control when controller output commands joint velocities.
Motion control of robots when the controller output commands the joint torsions, force control and hybrid motion-force control.

Specific objectives:
2, 6

Related competencies :
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Full-or-part-time: 18h
Theory classes: 4h
Laboratory classes: 4h
Self study: 10h

Mobile robots with wheels

Description:
Kinematic models of mobile robots with omnidirectional and non-holonomic wheels.
Controllability, motion planning and feedback control of non-holonomic wheeled mobile robots; odometry for wheeled mobile robots; and mobile manipulation.

Full-or-part-time: 12h
Theory classes: 2h
Laboratory classes: 4h
Self study: 6h

Dynamics of open chains

Description:
Lagrangian formulation of dynamics, centripetal and Coriolis forces, robot mass matrix, rigid body dynamics, and inverse Newton-Euler dynamics for an open chain robot.
Direct dynamics of an open chain, task space dynamics, constrained dynamics, and practical effects due to gears and friction.

Full-or-part-time: 12h
Theory classes: 2h
Laboratory classes: 4h
Self study: 6h

Generation of trajectories

Description:
Point-to-point trajectories in a straight line and polynomial trajectories passing through traveling points.
Optimal movements in time along a specified trajectory under robot dynamics and actuator limits.

Full-or-part-time: 12h
Theory classes: 2h
Laboratory classes: 2h
Self study: 8h

Control of manipulators

Description:
Local motion control strategies vs. centralized
Independent control of "joints".
Anticipated torque action computed.
Lyapunov stability analysis of MIMO controls.
Feedback linearization.
Control of the operating space.
Indirect vs. Force Control Strategies direct
Impedance control.
Direct force control.
Cascading controllers.

Full-or-part-time: 20h
Theory classes: 4h
Laboratory classes: 4h
Self study: 12h

Interaction systems between Robots and Humans

Description:
Application of the knowledge obtained in the creation of a system capable of interacting with humans. Learning new assessment methods.

Specific objectives:
1, 2, 4, 6, 7

Related competencies :
CG4. Reasoning, analyzing reality and designing algorithms and formulations that model it. To identify problems and construct valid algorithmic or mathematical solutions, eventually new, integrating the necessary multidisciplinary knowledge, evaluating different alternatives with a critical spirit, justifying the decisions taken, interpreting and synthesizing the results in the context of the application domain and establishing methodological generalizations based on specific applications.
CG7. To interpret and apply current legislation, as well as specifications, regulations and standards in the field of artificial intelligence.
CG8. Perform an ethical exercise of the profession in all its facets, applying ethical criteria in the design of systems, algorithms, experiments, use of data, in accordance with the ethical systems recommended by national and international organizations, with special emphasis on security, robustness , privacy, transparency, traceability, prevention of bias (race, gender, religion, territory, etc.) and respect for human rights.
CG9. To face new challenges with a broad vision of the possibilities of a professional career in the field of Artificial Intelligence. Develop the activity applying quality criteria and continuous improvement, and act rigorously in professional development. Adapt to organizational or technological changes. Work in situations of lack of information and / or with time and / or resource restrictions.
CG3. To define, evaluate and select hardware and software platforms for the development and execution of computer systems, services and applications in the field of artificial intelligence.
CG5. Work in multidisciplinary teams and projects related to artificial intelligence and robotics, interacting fluently with engineers and professionals from other disciplines.
CG6. To identify opportunities for innovative applications of artificial intelligence and robotics in constantly evolving technological environments.
CE15. To acquire, formalize and represent human knowledge in a computable form for solving problems through a computer system in any field of application, particularly those related to aspects of computing, perception and performance in intelligent environments or environments.
CE28. To plan, ideate, deploy and direct projects, services and systems in the field of artificial intelligence, leading its implementation and continuous improvement and assessing its economic and social impact.
CE17. To develop and evaluate interactive systems and presentation of complex information and its application to solving human-computer and human-robot interaction design problems.
CE24. To ideate, design and build intelligent robotic systems to be applied in production and service environments, and that have to be capable of interacting with people. Also, to create collaborative and social intelligent robotic systems.
CE25. To ideate, design and integrate mobile robots with autonomous navigation capability, fleet formation and interaction with humans.
CE26. To design and apply techniques for processing and analyzing images and computer vision techniques in the area of artificial intelligence and robotics
CT5. Solvent use of information resources. Manage the acquisition, structuring, analysis and visualization of data and information in the field of specialty and critically evaluate the results of such management.
CT8. (ENG) Perspectiva de gènere. Conèixer i comprendre, des del propi àmbit de la titulació, les desigualtats per raó de sexe i gènere a la societat; Integrar les diferents necessitats i preferències per raó de sexe i de gènere en el disseny de solucions i resolució de problemes.
CT1. Entrepreneurship and innovation. Know and understand the organization of a company and the sciences that govern its activity; Have the ability to understand labor standards and the relationships between planning, industrial and commercial strategies, quality and profit.
CT2. Sustainability and Social Commitment. To know and understand the complexity of economic and social phenomena typical of the welfare society; Be able to relate well-being to globalization and sustainability; Achieve skills to use in a balanced and compatible way the technique, the technology, the economy and the sustainability.
CT3. Efficient oral and written communication. Communicate in an oral and written way with other people about the results of learning, thinking and decision making; Participate in debates on topics of the specialty itself.
CB5. That the students have developed those learning skills necessary to undertake later studies with a high degree of autonomy
CB3. That students have the ability to gather and interpret relevant data (usually within their area of ??study) to make judgments that include a reflection on relevant social, scientific or ethical issues.

Full-or-part-time: 8h
Theory classes: 2h
Self study: 6h

Final Project

Specific objectives:
1, 2, 3, 4, 5, 6

Related competencies :
CG4. Reasoning, analyzing reality and designing algorithms and formulations that model it. To identify problems and construct valid algorithmic or mathematical solutions, eventually new, integrating the necessary multidisciplinary knowledge, evaluating different alternatives with a critical spirit, justifying the decisions taken, interpreting and synthesizing the results in the context of the application domain and establishing methodological generalizations based on specific applications.
CG7. To interpret and apply current legislation, as well as specifications, regulations and standards in the field of artificial intelligence.
CG8. Perform an ethical exercise of the profession in all its facets, applying ethical criteria in the design of systems, algorithms, experiments, use of data, in accordance with the ethical systems recommended by national and international organizations, with special emphasis on security, robustness , privacy, transparency, traceability, prevention of bias (race, gender, religion, territory, etc.) and respect for human rights.
CG9. To face new challenges with a broad vision of the possibilities of a professional career in the field of Artificial Intelligence. Develop the activity applying quality criteria and continuous improvement, and act rigorously in professional development. Adapt to organizational or technological changes. Work in situations of lack of information and / or with time and / or resource restrictions.
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CT8. (ENG) Perspectiva de gènere. Conèixer i comprendre, des del propi àmbit de la titulació, les desigualtats per raó de sexe i gènere a la societat; Integrar les diferents necessitats i preferències per raó de sexe i de gènere en el disseny de solucions i resolució de problemes.
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CB5. That the students have developed those learning skills necessary to undertake later studies with a high degree of autonomy
CB3. That students have the ability to gather and interpret relevant data (usually within their area of ??study) to make judgments that include a reflection on relevant social, scientific or ethical issues.

GRADING SYSTEM

The course will be evaluated continuously. There will be no final exam.
Throughout the course, a series of exercises will be requested that will help the teacher evaluate the student at the end of the course. These exercises can be both face-to-face and non-face-to-face and can consist of the presentation of the results of practices developed in the laboratory (NL), as well as the theoretical / practical solution of problems proposed by the teacher in class (NT). In addition, a final project (NPF) will have to be presented at the end of the course, consisting of a report, a presentation, and a demonstration with a robot or a simulation.

The final grade of the course will be calculated as follows:NF=0'1NL+0'1NT+0,5NPF+0.15EP+0.15EP

BIBLIOGRAPHY

Basic:
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- Siegwart, Roland; Nourbakhsh, Illah Reza; Scaramuzza, Davide. Introduction to autonomous mobile robots. 2nd ed. MIT Press, 2011. ISBN 9780262015356.
- Siciliano, Bruno; Khatib, Oussama. Springer handbook of robotics. 2nd ed. Springer International Publishing, 2016. ISBN 9783319325521.
- Murphy, R.R. Introduction to AI robotics. The MIT Press, 2019. ISBN 9780262348157.