Co-funded by the
Erasmus+ Programme
of the European Union

MIR
MARINE &
MARITIME
INTELLIGENT
ROBOTICS

MIR STUDENT HANDBOOK

2021 -2023

www.master-mir.eu

UNIVERSITÉ DE TOULON
NTNU
UNIVERSITAT JAUME I
TÉCNICO LISBOA

A FEW WORDS FROM THE MIR COORDINATION TEAM...

Erasmus Mundus MIR Director - Assoc Prof Ricard Marxer

MIR Master programme aims at building the capacity of future engineers to enable advancements in the development and operation of new robotics systems with far-reaching impact on techniques necessary for ocean exploration and exploitation.

Such systems will necessarily use a new breed of autonomous surface and underwater robots: teleoperated/semi-autonomous robots, specialized robots for deep sea operations, and robots for infrastructure inspection and maintenance, often working in cooperation and networked via aerial, acoustic, and optical links.

The challenges that lie ahead can only be met by bringing together fast-paced developments in robotics and AI methods with a view to sustained autonomy and on-line decision making in the unforgiving marine environment. As a MIR student you will receive training in state-of-the-art applied robotics targeted at enhancing the efficiency, health, safety and environmental performance of the offshore industry, maritime operations, and marine science studies. We are confident that following this programme will open many opportunities for your future career and development.

MIR Education Manager - Prof Vincent Hugel

The Academic programme of the MIR has been designed in collaboration with leading industries and research centers in the fields of Artificial Intelligence and Marine and Maritime Robotics, ensuring that MIR graduates have the necessary skills and knowledge to continue on to do research as well as to lead promising carriers in the offshore, naval, marine and maritime industries. The innovative combination of Artificial Intelligence, Robotics for marine and maritime applications renders this programme highly competitive in the rapidly growing blue growth sectors.

MIR Internationalisation - Céline Barbier

Erasmus Mundus MIR Master Programme aims at structuring and strengthening the international partnerships with academic and industry partners worldwide to support the new generation of leading engineers in marine and maritime intelligent robotics. In addition, MIR students shall develop professional training and managerial leadership skills enabling them to pioneer this new field internationally. MIR's international dimension shall benefit from a large network of collaborations and new research/innovation projects in the fields of automation and marine science to enhance the excellence of the Programme.

MIR Student Administrator
Ms Célia Cau

MIR Financial Manager
Ms Laïs Moutte

CONTENTS

HOW TO USE THE STUDENT HANDBOOK

The purpose of this handbook is to provide you as a MIR student an overview of the modules you will be required to follow, a description of the study tracks and some generic guidance on the thesis project in Semester 4. Herein, you will find information regarding all study tracks and mobilities.

For up to date information please always consult the MIR website **master-mir.eu** and internal information services provided to you by your hosting institute. This handbook is for generic information purposes only and non binding.

For more information please do not hesitate to contact us:
mundus-mir@univ-tln.fr

Assoc Prof Ricard Marxer
MIR Director and Head of DYNI, LIS laboratory

Prof Vincent Hugel
Education Manager and COSMER laboratory Director

Céline Barbier
MIR Internationalisation

THE MIR PROGRAMME

Students follow the MIR programme over 2 years (4 semesters / 120 ECTS).
The first year in France – Semester 1 and semester 2 – at the University of Toulon (UTLN) commences by building up a solid background in marine science, robotics and AI.
In the second year during semester 3, students choose to specialize in one of the three study tracks, namely "Applied robotics for underwater intervention missions" at UJI, Spain, "Safe autonomous subsea operations" at NTNU, Norway, or "Cooperative marine robotics for scientific and commercial applications" at IST-UL, Portugal.
Semester 4 is devoted to a Master's thesis in the context of a research or industry internship. It is carried out at any of MIR's main or associate partners, always under the co-supervision of a main partner.

	SEMESTER 1 30 ECTS	SEMESTER 2 30 ECTS	SEMESTER 3 30 ECTS	SEMESTER 4 30 ECTS
	Teaching units			
Study track 1 **APPLIED ROBOTICS FOR UNDERWATER INTERVENTION MISSIONS**	‣ Marine science & environment ‣ Artificial Intelligence ‣ Robotics UTLN	‣ Transversal skills (reliability & risk assessment, AI fairness & transparency, etc.) ‣ AI & robotics, and its applications taught by UTLN and guest lecturers ‣ Joint introduction to study track specialisations (UJI, NTSU, IST) ‣ Industry led seminars (options) ‣ Entrepreneurship industry & research project UTLN	**# UNDERWATER INTERVENTIONS** UJI	Thesis with principal supervision at UJI (may be conducted at an associate partner)
Study track 1 **SAFE AUTONOMOUS SUBSEA OPERATIONS**			**# DEEP SEA OPERATIONS** NTNU	Thesis with principal supervision at NTNU or UTLN (may be conducted at an associate partner)
Study track 1 **COOPERATIVE MARINE ROBOTICS FOR SCIENTIFIC & COMMERCIAL APPLICATIONS**			**# COOPERATIVE ROBOTICS** IST	Thesis with principal supervision at IST (may be conducted at an associate partner)

Induction weeks (2 weeks induction with joint industry introduction days)

MIR Joint Annual Symposium & Championship (1 week to be held at a different partner each year)

MIR Joint Annual Symposium & Championship (1 week to be held at a different partner each year)

MIR LEARNING OBJECTIVES AND SKILLS

A MIR Graduate upon completion of the programme will:

- have a deepened understanding of marine processes and challenges in order to develop robots that will interact in-and-with it, as well as develop technological solutions to mitigate and adapt to future environmental challenges (such as pollution, climate change impacts, etc.)
- master the spectrum of sensors/actuators specific to underwater and sea-surface robotics. Understand their functions, limitations and be capable of implementing them on robots and using them.
- be capable of modelling external forces onto robotic systems and use simulation tools to predict the behaviour in a marine environment.
- develop and use a general framework for mission planning, programming, and execution of single and multiple, networked marine robots working in cooperation. Master the theoretical foundations and practical aspects of networked control systems and distributed estimation and control.
- be experts in data-driven computational approaches to sensing, control, decision-making and autonomous behaviour. Provide maritime robots with Artificial Intelligence (AI) capabilities ranging from perceptual abilities to autonomous motion and navigation planning.
- be proficient in the main Machine Learning techniques and paradigms applicable to robotics. Know the state-of-the-art in ML-based solutions to robotic-specific problems, including Deep Learning applications to computer vision, acoustic sensing and reinforcement learning.
- tackle surface and underwater technological applications in coastal, offshore, deep sea environments relevant to maritime navigation, surveillance, environmental monitoring, geotechnical surveying, offshore oil and gas, ocean farming, and renewables industries.

The MIR programme is industry focused and taught using learning by doing principles, so upon completion MIR graduate will be qualified to:

- apply the necessary communication and research skills for integrated team work
- manage innovation projects and systematically assess risks and reliability issues
- recognize technical, financial, ethical and regulatory boundaries to AI and marine technological innovations development and operation
- have an in-depth understanding of blue growth industry sectors and innovation technology development opportunities.

MIR - A PROGRAMME WITH NUMEROUS OPPORTUNITIES FOR PROFESSIONAL AND ACADEMIC DEVELOPMENT

The MIR programme apart from teaching modules by international leading experts in the field, has a number of additional activities aimed at supporting the professional development of its students whether they choose to continue on to do a PhD or to follow a career in blue growth industries. These activities do not receive ECTS yet they are a mandatory component of the programme.

Induction Weeks:

As a MIR student you will be expected to participate in the induction week activities , which aim at welcoming you to the university, helping you settle in as well as giving you a headstart with the local language and familiarisation with the surrounding area. A complete programme will be communicated with you closer to your arrival.

International Annual Marine and Maritime Intelligent Robotics Symposium:

Every year in June you will have the opportunity to participate in a one week International Symposium on Marine and Maritime Intelligent Robotics with leading researchers, and industry representatives. In year 2 you will have the opportunity to present an abstract of your research thesis during the symposium and exchange with leading experts in the field. The symposium is held in parallel with the MIR championships and changes country annually.

Marine and Maritime Intelligent Robotics Championship:

You will have the opportunity to compete in the Marine and Maritime Intelligent Robotics championships, an international event with international participants. Challenges will be defined by an expert researcher and industry representative international committee.

Careers fairs:

As part of the MIR programme you will have the opportunity to participate in careers fairs and exchange with representatives and headhunters from leading companies from the fields of marine and maritime intelligent robotics, marine exploration, offshore and defense sectors.

Local Language courses:

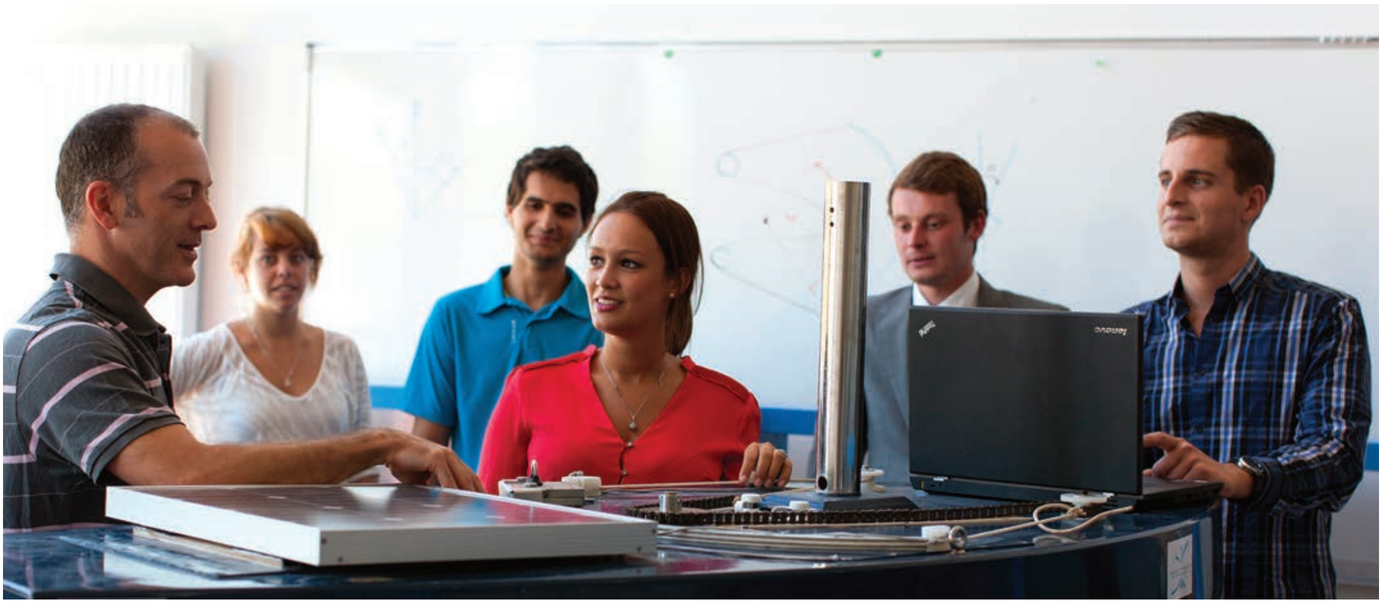
No matter which study track you choose, during each mobility you will be offered local language courses, enabling you to integrate more easily in the everyday life activities of the country you will be staying in. These classes are obligatory for students which do not have a B2 level in the local language.

Participation in recognised international conferences:

The MIR programme wishes to provide motivation for excellence, and therefore it offers to fund conference fees to students with accepted papers in established international conferences validated by the MIR management committee.

Personal Tutor:

At the University of Toulon you will be assigned a personal tutor which will help guide you through the programme and answer any questions regarding the curriculum and study track.



MIR - AN INTERNATIONAL CONSORTIUM OF EXCELLENCE

The MIR consortium consists of 50+ industry and research partners in 21 countries with which MIR students have the possibility to conduct their thesis and can continue on to do a PhD.

Brazil

- Fundaçao Universidade de Brasilia

Cambodia

- Institute of Technology of Cambodia

Chile

- Universidad de Chile

Colombia

- Universidad Pontificia Bolivariana

France

- French national research institute for the digital sciences (INRIA)
- Toulon Var Technologies (TVT)
- Sofresud
- University of Montpellier
- ECA Group
- Cybernetix
- ixBlue
- CNIM
- THALES
- Nexeya
- Alierys
- Searov
- Subsea tech
- French Ocean Institute, IFREMER
- Chamber of commerce and industry, Var region
- Kietta
- National Superior Maritime School (ENSM)
- National Engineering School (ENSTA Bretagne)
- NAVAL Group
- Alseamar
- Sea proven

Germany

- German Research Centre for Artificial Intelligence (DFKI)
- University of Bremen, MARUM

Greece

- Strategis – Maritime Information, Communication and Technologies Cluster
- University of the Aegean

Italy

- Genova University

Lebanon

- Antonine University

Malaysia

- Universiti Kuala Lumpur

Morocco

- University of Sidi Mohamed Ben Abdellah

Norway

- Water Linked AS
- BlueEye

Portugal

- Geosurveys
- IN2SEA
- Spin.Works
- Abyssal

Peru

- Universidad Nacional de San Agustin de Arequipa

South Africa

- Nelson Mandela University

Spain

- IQUA robotics
- Robotnik
- Ingenieria y Soluciones De Movilidad S.L. (INGESOM)
- Universitat de les Illes Balears
- Aquaculture Institute of Torre de la Sal
- Fundación CEIMAR

Tunisia

- National Engineering school of Sousse

Ukraine

- Taras Shevchenko National University of Kyiv

United Arab Emirates

- Khalifa University of Science & Technology, Abu Dhabi

United Kingdom

- Stat Marine

Vietnam

- Hanoi University of Science and Technology (HUST),
- National Vietnam Hanoï University of Science VNU-HUS
- Vietnam Academy of Science and Technology

CURRICULUM YEAR 1
Université de Toulon

UNIVERSITÉ DE TOULON

SEMESTER 1 : OVERVIEW

Semester 1 will be held at UTLN. It will start with a 2 week Induction period focusing on language and soft skills acquisition including socialising events for the students.
Semester 1 is divided into three thematic blocks.
Block 0 (4 ECTS) is dedicated to transversal skills
Block 1 on Marine environment (7 ECTS)
Block 2 on Robotics and control (10 ECTS)
Block 3 on Artificial Intelligence (9 ECTS)

Summary of Semester 1

<table>
<tr><th>Module Title</th><th>Number of Teaching hours</th><th>Total ECTS</th></tr>
<tr><td colspan="3">BLOCK 0 Transversal skills (4 ECTS)</td></tr>
<tr><td>Scientific writing skills and methods</td><td>10</td><td>1</td></tr>
<tr><td>Innovation, Design thinking and Project Management</td><td>30</td><td>3</td></tr>
<tr><td>Student tutoring</td><td>1</td><td>0</td></tr>
<tr><td>French as a foreign language (mandatory unless B2 level - No ECTS attributed, to take exam and obtain language level certification possible)</td><td>30</td><td>0</td></tr>
<tr><td>English as a foreign language (optional based on level)</td><td>25</td><td>0</td></tr>
<tr><td>Programming language level-up (optional based on level)</td><td>20</td><td>0</td></tr>
<tr><td colspan="3">BLOCK 1 Marine Environment (7 ECTS)
• Knowledge of physical water properties and marine processes :
• Marine processes : waves, swell, 30 m depth current profiling, influence of winds.
• Types of water flow, physical phenomena specific to water, interaction with solids.
• Hydrodynamics : Navier Stokes equations, etc.
• Water properties : perception (attenuation of EM waves), sound propagation, etc.
• Influence of salinity/temperature on water properties.
• Sensors for USV, AUV/ROV to get exteroceptive information about the marine environment : DVL, acoustic sonars, radars</td></tr>
<tr><td>Fundamentals of marine and coastal processes</td><td>47</td><td>5</td></tr>
<tr><td>Underwater acoustics</td><td>24</td><td>2</td></tr>
<tr><td colspan="3">BLOCK 2 - Robotics and control (10 ECTS)</td></tr>
<tr><td>Geometric, kinematic and dynamical modeling of robotic systems</td><td>29</td><td>2,5</td></tr>
</table>

Modeling of marine systems	23	2,5
Control theory of multivariable linear systems	70	5
BLOCK 3 - Artificial Intelligence (9 ECTS) The AI block covers the fundamentals of machine learning with a focus on deep learning and reinforcement learning, the two subfields most relevant to robotics. The concepts, methods and approaches taught in this block will be illustrated and assessed on marine and maritime problems.		
Machine learning	30	3
Deep learning	30	3
Reinforcement learning	30	3

SEMESTER 1 : ANALYTICAL DESCRIPTION OF MODULES

BLOCK 0- Transversal skills (4 ECTS)

Scientific writing skills and methods			
Credits: 1 Semester 1 Compulsory: Yes			
Format	Lecture: 10	Tutorial work: 0	Practical work: 0
Lecturers: Dr K. Pediaditi			

Objectives:
This is an introductory course which aims to provide students with the research skills and study methodologies necessary to be able to respond to the self study and group work requirements of this programme. Using practical exercises, students will be familiarised with the various writing and referencing standards expected of them. An induction to the various physical and online learning and research facilities provided to them will also be carried out. The aim of this course is to provide students the tools and methods to learn how to learn for themselves building a solid basis for student focused learning.

Contents:
Introduction to scientific writing and research skills.

- Data sources, accessibility and their critical evaluation
- Literature review and critical documentation analysis
- Referencing and plagiarism
- Writing mechanics, manuscript planning and organizational strategies,
- Presentation skills
- Learning how to integrate documentation development into best engineering practices

Practical Work:
A series of practical's using individual and group exercises will provide students with a solid background in referencing standards, how to critically review scientific articles, as well as skills on how to conduct professional presentations.

Key skills acquired :

- Familiarisation with master program physical and online learning facilities and tools
- Documentation and database critical evaluation
- Basic principles of scientific writing style and composition
- presentation skills
- Referencing

Assessment:
100% continuous assessment

Recommended texts:
The notes of the course will be given by lecturer.

Further readings:

- Hofmann A.H, 2016, 3rd edition, Scientific Writing and communication: Papers, Proposals and Presentations, Oxford publishing
- Joan Van Emden & Becker L, 2018, 4th edition, Writing for engineers, Palgrave

Innovation, Design thinking and Project Management			
Credits: 3 Semester 1 Compulsory: Yes			
Format	Lecture: 0	Tutorial work: 30	Practical work: 0
Lecturers: Dr K. Pediaditi, Prof N. Thirion			

Objectives:
This is an introductory course on innovation, design thinking and project management. Using real innovation challenges provided by industry stakeholders, students applying learning by doing principles, experience innovation management and apply design thinking methods to come up with innovative engineering solutions for real life challenges.

Contents:
- Introduction to Innovation management processes
- Design Thinking
- Project management processes
- Case study industry innovation challenge

Practical Work:
Design thinking experts in combination with industry representatives support students in a one week intensive learning by doing design thinking workshop, identify a real life need and develop a pragmatic design solution. Students practice working in groups, working under pressure, applying different innovation design thinking methods, prototype development as well as practicing their presentation skills by pitching/presenting to industry representatives their design solution/ product.

Key skills acquired :
- Project management skills, such as planning, scheduling, budgeting
- Understanding of design thinking and innovation management principles
- Group work and professional presentation skills

Assessment:
100% continuous assessment

Recommended texts:
The notes of the course will be given by lecturer.

Further readings:

- Walter Brenner, Falk Uebernickel, 2016, Design Thinking for Innovation, Research and Practice, https://doi.org/10.1007/978-3-319-26100-3
- Owen, Charles L. “Design thinking: Driving innovation.” *The Business Process Management Institute* (2006): 1-5.

BLOCK 1- Marine Environment (7 ECTS)

Fundamentals of marine and coastal processes			
Credits: 5 Semester 1 Compulsory: Yes			
Format	Lecture: 41	Tutorial work: 6	Practical work: 0
Lecturers: Assoc Prof Y. Ourmieres, Prof A. Molcard, Prof B. Zakardjian			

Objectives:
The main objectives of this course are (i) provide a general background in the field of marine sciences , (ii) introduce the basics of fluid mechanics applied to the ocean, (iii) provide the main dynamical solutions in a coastal environment (iv) provide a specific focus on wave dynamics (v) provide insights on modern oceanography products (numerical products, ocean databases)

Contents:
- General background on the marine physical environment
- Fluid mechanics: Euler equation, general equations based on the ocean and atmospheric forces analysis. Notions of fluid turbulence.
- Analytical solutions in coastal environment: Ekman solution / wind induced currents, inertial oscillations, tides, specific coastal processes : upwelling, downwelling, buoyancy currents, river plumes
- Waves dynamics : waves induced current and pressure, stokes solutions, notion on the wave spectral approach for wave forecasting
- Modern oceanography : ocean observing systems, existing numerical products, forecasting structures, ocean observations databases, data formats.- Marine pollution : TBC

Practical Work:
- Practical work on ocean numerical modelling, ocean data processing, numerical format, ocean visualization tools, ocean databases. (using ad-hoc computer software).
- Practical work at sea on board of the French oceanographic fleet ships for data collection and observation, and data treatment acquired at sea.

Key skills acquired :
After completing this course the students will be able to:
- Apprehend and investigate the processes at play in a coastal environment
- Calculate / simulate (forecast) / analyse coastal currents
- Calculate / simulate (forecast) / analyse wave induced currents
- Get and exploit the available information in marine sciences databases for a specific zone or a specific coastal process
- Provide a complete picture of the dynamical coastal processes to be taken into account for marine object deployments

Assessment:
25% final examination and 75% continuous assessment

Recommended texts:
The notes of the course will be given by lecturer.

Underwater Acoustics			
Credits: 2 Semester 1 Compulsory: Yes			
Format	Lecture: 12	Tutorial work: 12	Practical work: 0
Lecturers: Prof M. Saillard			

Objectives:
The aim of this course is to give the students understanding of both Physics of acoustic waves and signal processing techniques, in order to be able to suggest which system is appropriate for given specifications, to predict its performances through simple models, to implement data processing algorithms and to interpret the results. The complementarity of deep learning techniques with physics based approach is highlighted.

Contents:
Propagation of acoustic waves, interaction of acoustic waves with boundaries (sea floor, surface waves) and scattering from inhomogeneities (bubbles, natural or artificial objects), Doppler effect.
Signal processing : positioning, detection and ranging, estimation of velocity, ambiguity.
Imaging techniques : time reversal, synthetic aperture.

Practical Work:
University of Toulon operates various instruments to record datasets (hydrophones, Doppler current profilers), including long time series for deep learning approaches. Industrial partners have also some facilities. The students will thus apply the processing techniques to real data acquired in the “real life”. They will also develop software to simulate underwater wave propagation for various environmental conditions (night, day, wind, shallow water...).The practical work is organized as homework with regularly spaced “plenary sessions” under the supervision of a lecturer. Students will have permanent access to the laboratory facilities. The results will be written down in a short dissertation and a brief oral presentation will be organized.

In addition to this course, a complementary course in semester 2 is dedicated to the technology of acoustic sensors and systems (industrial partner iXBlue).

Key skills acquired :
After completing this course the students will be able to:

- Take into account the physical processes that play a role in the performance of the acoustic sensor/system
- Find the appropriate information in the bibliography
- Propose the acoustic sensor/system suited for the specifications
- Perform the data processing and analyze the results with critical mind
- Explain in a synthetic way the issues and the proposed solution

Assessment:
100% continuous assessment.

Recommended texts:
The notes of the course will be given by lecturer.

BLOCK 2 - Robotics and control (10 ECTS)

Geometric, kinematic and dynamical modeling of robotic systems			
Credits: 2.5 Semester 1 Compulsory: Yes			
Format	Lecture: 14	Tutorial work: 9	Practical work: 6
Lecturers: Assoc Prof C. Anthierens, Prof V. Hugel			

Objectives:
This course gives the mathematical and mechanical background for the analytical modeling of actuated kinematic chains in terms of positions, velocities, forces, and power. It includes direct and inverse geometric, kinematic and dynamical modeling.

Contents:
- Classification of rigid kinematic chains.
- Homogeneous coordinates.
- Geometric and kinematic modeling of serial and parallel robots.
- Ellipsoids of power/constraints.
- Quaternions.
- Dynamical modeling (Lagrange, Newton/Euler, Hamiltonian formalisms).
- Prerequisites:
- Solid mechanics. Linear algebra. Matrix calculus.

Practical/tutorial Work:
Participants will have to conduct practical work on real manipulators using matlab software under the supervision of the lecturer.
Participants will have to solve a large panel of practical exercises of mechanical-system dynamical modeling, taking constraints into account.

Key skills acquired :
After completing this course the students will be able to:
- Determine adapted coordinate systems
- Apply the techniques of direct and inverse geometric/kinematic modeling
- Simulate the control of a typical manipulator robot
- Apply the technique of Lagrange dynamics to have a dynamical model of the mechanical system under study
- Take into account Lagrange multipliers and generalized forces to take into account force constraints.

Assessment:
continuous assessment through coursework.

Recommended texts:
The notes of the course will be given by lecturer.

Further readings:
- Modeling, Identification and Control of Robots, W. Khalil, E. Dombre.
- The Variational Principles of Mechanics, Cornelius Lanczos.
- Variational principles in classical mechanics, Douglas Cline.

Modeling of marine systems			
Credits: 2.5 Semester 1 Compulsory: Yes			
Format	Lecture: 8	Tutorial work: 7	Practical work: 8
Lecturers: Assoc Prof M. Richier			

Objectives:
This course focuses on the modeling of underwater robots for design, sizing and control purposes. The student must be able to model the dynamical behavior of an underwater robot and to know how to take into account the interactions of an underwater vehicle with the aquatic environment. Traditional control principles of underwater robotic systems will also be presented in the framework of this module.

Contents:
- Refresher on fluid mechanics (hydrostatics, fluid flows).
- Hydrodynamical parameters: physical phenomena and identification.
- Dynamical model of submerged vehicle. Models of boats/drones.
- Underwater sensors.
- Control law principles for navigation.

Prerequisites:
- Solid mechanics (general theorems, Lagrange). Linear algebra. Matrix calculus. Fluid mechanics.

Practical Work:
- Participants will carry out practical work on matlab software to design control laws to control the motion of a submerged vehicle. Under the supervision of the lecturer.

Key skills acquired :
After completing this course the students will be able to:
- Model a submerged vehicle from a dynamical point of view
- Acquire the experience of the various influences of the hydrodynamical parameters
- Design control laws to control the motion of a vehicle in the aquatic environment
- Acquire the knowledge of the embedded sensors that are currently used in control loops.

Assessment:
continuous assessment through practical work report and coursework.

Recommended texts:
The notes of the course will be given by lecturer.

Further readings:
Handbook of Marine Craft Hydrodynamics and Motion Control, Thor I. Fossen.

Control theory of multivariable linear systems			
Credits: 5 Semester 1 Compulsory: Yes			
Format	Lecture: 40	Tutorial work: 30	Practical work: 0
Lecturers: Assoc Prof N. Boizot, A. Dhaisne, Prof T. Soriano			

Objectives:
The objective of this module is to present the theoretical basics and general concepts for the analysis and the control of multivariable dynamical systems that are linear or can be linearized around an operating point.

Contents:
Refreshments in monovariable systems,
- Identification of real systems, fine tuning of PID controllers, pole placement,
- Internal model, RST control methods,
- Case study: control of a wind turbine.
- Continuous-time and discrete-time state-space representation,
- State-space representation vs Laplace formalism,
- Solution to the state-space equation – Transition matrix,
- Controllability and observability, Kalman criterion,
- Lyapunov stability,
- State feedback control,
- Linear quadratic regulator (LQR),
- Synthesis of observers (Luenberger, Kalman).

Prerequisites:
- Fundamentals of control theory and basics of analysis and control of linear discrete and continuous systems.
- Identification and control of systems.
- Linear algebra.

Practical Work:
Case studies will be treated either using simulations made with the help of computing softwares/ languages such as Matlab or Python. Implementation on actual systems might also be considered.

Key skills acquired :
After completing this course the students will be able to:
- Model a control system as a multidimensional linear system;
- Analyse the stability, controllability and observability properties of a linear control system;
- Design a control algorithm for linear system based on an optimality criterion;
- Design an observer for linear systems.
- Master engineering methods and tools

Assessment:

50% continuous assessment, 50% from end of semester examination.

Recommended texts:
The notes of the course will be given by lecturer.

Further readings:

- Chen, Chi-Tsong. “Linear Systems Theory and Design” Saunders HBJ. 1970.
- Kailath, T. “Linear Systems” Prentice Hall. 1980.
- Jaulin, L. “Automation for Robotics”. ISTE. 2015.
- Analysis and Control of Linear Systems, P. de Larminat
- Applied Control Theory, James R. Leigh
- Digital Control Systems: Design, Identification and implementation, Ioan Doré Landau, Gianluca Zito

BLOCK 3 - Artificial Intelligence (9 ECTS)

The AI block covers the fundamentals of machine learning with a focus on deep learning and reinforcement learning, the two subfields most relevant to robotics. The concepts, methods and approaches taught in this block will be illustrated and assessed on marine and maritime problems.

Machine learning			
Credits: 3 Semester 1 Compulsory: Yes			
Format	Lecture: 15	Tutorial work: 15	Practical work: 0
Lecturers: Assoc Prof S. Paris, Assoc Prof A. Paiement, Assoc Prof R. Marxer, T. Montagu			

Objectives:
The course will present the main paradigms of automatically learning from data. The student will gain an understanding about the implications of working with high-dimensional and/or big amounts of data. In the course we will implement and apply basic algorithms to perform classification, regression and density estimation. Students will be capable of analyzing and explaining results of applying machine learning techniques. They will be able to identify over- and under- fitting and reason in terms of bias and variance of errors. The methods will be illustrated using publicly available software tools and data sets used to perform analysis on large volumes of data.

Contents:
- Big data and the curse of dimensionality
- Convexity and gradient. Mixed cost functions
- Nearest-neighbors and K-means.
- Kernel density estimation.
- Mixture models and Expectation-Maximization.
- Structural risk minimization and large-margin classifiers

Prerequisites:
Linear algebra. Functional analysis

Practical Work:
All approaches presented will be exemplified in labs, by implementing all or parts of the algorithm and analysing the results of applying them to synthetic and real world data. A focus will be put on marine-related data such as underwater imaging/acoustics and environmental measurements.
Links with industry:The data used and problems approached as examples in this module will be simplifications or approximations of real-world case studies brought in by industrial partners in current university research projects.

Key skills acquired :
- After completing this course the students will be able to:
- Analyze and explain the results of applying machine learning techniques
- Reason in terms of bias and variance of errors
- Implement and apply basic algorithms to perform classification, regression and dimensionality reduction
- Know the main catalogue of machine learning approaches for different scenarios and tasks
- Program numeric methods and visualization/representation of data

Assessment:
100% continuous assessment.

Recommended texts:
The notes and code (e.g. Jupyter notebooks) of the course will be provided by the lecturer.

Further readings:
Nasrabadi, Nasser M. “Pattern recognition and machine learning.” Journal of electronic imaging 16.4 (2007): 049901.

Deep learning			
Credits: 3 Semester 1 Compulsory: Yes			
Format	Lecture: 15	Tutorial work: 15	Practical work: 0
Lecturers: Assoc Prof R. Marxer, A. Heinzle			

Objectives:
After this course the students will be able to identify the deep learning (DL) approaches to be applied to multiple types of machine learning problems, depending on the task and the data inputs/outputs. Students will know how to build and train advanced DL models with the use of existing publicly available software tools. We will also introduce the main shortcomings and limitations of deep learning techniques such as the problem of interpretation and the exploitation of adversarial attacks.

Contents:
- Training procedure (SGD, Adam, RMSProp)
- Classification, regression, dimensionality reduction (AE).
- Sequence-based (RNN, encoder-decoder)
- Generative approaches (variational and GAN)
- Practical example: transfer learning
- Practical example: adversarial attack
- Practical example: feature visualisation

Practical Work:
The course is complemented with a group project on the planning and design of the full deep learning pipeline for a particular problem in a domain well mastered by the student (e.g. a hobby, a problem related to a family business). The project outcome will consist of a technical report detailing the data gathering methodology, the annotation task and the DL approach of choice. Furthermore the groups will be asked to provide time and budget estimates for the different tasks. Optionally some or all of the steps of the project (or an approximation) could be implemented and evaluated.

Key skills acquired :
After completing this course the students will be able to:
- Identify deep learning (DL) approaches to be applied to multiple type problems
- Analyse and prepare different kinds of data for exploitation in DL
- Build and train advanced DL models using existing publicly available software tools
- Take into account main shortcomings and limitations of deep learning techniques
- Work with computation graphs and deep learning environments

Assessment:
100% continuous assessment.

Recommended texts:
The notes and code (e.g. Jupyter notebooks) of the course will be given by lecturer.

Further readings:

- Schmidhuber, Jürgen. “Deep learning in neural networks: An overview.” Neural networks 61 (2015): 85-117.
- Nielsen, Michael A. Neural networks and deep learning. Vol. 25. USA: Determination press, 2015.
- Goodfellow, Ian, et al. Deep learning. Vol. 1. Cambridge: MIT press, 2016.

Reinforcement learning			
Credits: 3 Semester 1 Compulsory: Yes			
Format	Lecture: 15	Tutorial work: 15	Practical work: 0
Lecturers: Assoc Prof R. Marxer, Prof H. Glotin			

Objectives:
This course presents the main framework of reinforcement learning (RL). At the end of the course, the student will be able to identify and frame problems under this formalism. He will master the vocabulary associated with the RL field, and will be aware of the main obstacles to tackle when using and developing RL approaches (e.g. exploitation-exploration trade-off, sample efficiency). Moreover students will be capable of understanding and implementing "vanilla" algorithms of the core methods in RL (e.g. Q-learning and policy optimisation) and analyze/apply some specific advanced algorithms (e.g. A2C and PPO).

Contents:
- Value iteration, policy iteration
- Value learning (Q-learning)
- Policy learning (policy optimisation)
- Planning-based
- Mixed approaches

Practical Work:
The content of this course will be put into practice by implementing, visualizing and evaluating different algorithms on publicly available frameworks (e.g. gym). Simple RL environments, such as GridWorld or Cartpole will serve as the base for understanding the core concepts. While more complex scenarios such as the Atari games or robotic simulators will allow exploring more advanced approaches and reveal the limitations and remaining challenges of reinforcement learning.

Key skills acquired :
After completing this course the students will be able to:
- Identify and frame problems under the Markov Decision Process (MDP) formalism
- Master the vocabulary associated to the RL field
- Be aware of the main obstacles to tackle when using and developing RL approaches
- Understanding and implementing "vanilla" algorithms of the core methods in RL
- Analyze/apply some specific advanced algorithms

Assessment:
100% continuous assessment.

Recommended texts:
The notes and code (e.g. Jupyter notebooks) of the course will be provided by lecturer.

Further readings:
- Sutton, Richard S., and Andrew G. Barto. Introduction to reinforcement learning. Vol. 135. Cambridge: MIT press, 1998.
- Szepesvári, Csaba. "Algorithms for reinforcement learning." Synthesis lectures on artificial intelligence and machine learning 4.1 (2010): 1-103.

SEMESTER 2 CURRICULUM
Université de Toulon

UNIVERSITÉ DE TOULON

SEMESTER 2 : OVERVIEW

Semester 2 will be held at UTLN for all students and is divided into 3 thematic blocks.

- Block 0 (3 ECTS) is dedicated to the development of soft interdisciplinary skills relevant to AI and legislation in the marine and maritime sectors.
- Block 1 (15.5 ECTS) on advanced topics in marine intelligent robotics where the students learn how the fundamental knowledge in robotics, artificial intelligence and the marine environment that they acquired during the first semester is used to solve specific problems. Modules in this block will include case studies of AI and robotic applications to the marine and maritime blue growth sectors, such as ship detection, classification and tracking, or wildlife monitoring.
- Block 2 (4.5 ECTS) is dedicated to providing an introduction to the 3 specialisations of this master programme. Three short modules will not only concretise the expertise gathered from the previous blocks, but will provide students with a hands-on experience of the different specialisations that they will choose to follow in semester 3.
- Block 3 (7 ECTS) is on applied marine intelligent robotics consisting of professionally and industry related modules. Professionals from leading marine robotics and AI industries will be teaching the core of these modules providing state of the art and real case study materials to students.

Summary of Semester 2

Module Title	Number of Teaching hours	Total ECTS
BLOCK 0: transversal skills (3 ECTS)		
Risk and reliability engineering and AI potential	10	1
Legislation on international water and autonomous vehicles	10	1
Fairness, accountability and transparency in AI	10	1
Student tutoring	2	0
Annual Symposium and championship	35	0
French as a foreign language (mandatory unless B2 level, No ECTS attributed, to take exam and obtain language level certification possible)	30	0
English as a foreign language (optional based on level)	25	0
Internship of a maximum of 2 months (optional)	0	0
BLOCK 1: Advanced Marine Intelligent Robotics (15.5 ECTS) In this block of modules the student will learn how the fundamental knowledge in robotics, artificial intelligence and the marine environment that they acquired during the first semester is used to solve specific problems. Modules in this block will include case studies of AI and robotic applications to the marine and maritime blue growth sectors, such as ship detection, classification and tracking, or wildlife monitoring.		

Marine Mechatronics	24	2.5
Advanced control for autonomous vehicles	29	3
Optimization techniques	24	2
Data-driven machine perception	18	3
Adaptive autonomous robotic behaviour	25	2,5
Marine localisation and mapping	30	1.5
Explainable AI	10	1
Block 2 – Specialisations - Joint MIR study track courses (4.5 ECTS) This block is dedicated to short modules of specialized marine applications in intelligent robotics. These modules will not only concretise the expertise gathered from the previous blocks, but will provide students with a hands-on experience of the different specialisations that they will choose in the next semester.		
# Underwater interventions (UJI)	15	1.5
# Autonomy in subsea operation (NTNU)	15	1.5
# Cooperative robotics (IST-UL)	15	1.5
Block 3 - Applied MIR & Industry seminars (7 ECTS)		
Deep-sea vehicles and missions for ocean sciences	20	2
Underwater acoustic sensors	10	1
Entrepreneurship – Industry and research project	17	2
Intelligent robotics for seabed resources exploitation	10	1
Artificial intelligence and shipping	10	1

SEMESTER 2 : ANALYTICAL DESCRIPTION OF MODULES

BLOCK 0 Transversal skills (3 ECTS)

Risk and reliability engineering and AI potential			
Credits: 1 Semester 2 Compulsory: Yes			
Format	Lecture: 10	Tutorial work: 0	Practical work: 0
Lecturers: Dr. C.A. Thieme			

Objectives:
The objective of this module is to provide students with the necessary background and skills needed to apply artificial intelligence (AI) in the field of risk assessment.
The module will be based on practicals requiring each student to critically evaluate and apply current state-of-the-art techniques in risk assessment and artificial intelligence.

Contents:
- Introduction and fundamentals of risk management
- Regulations / Standards / Hazards Assessment HAZOP
- Introduction to Inspection, Maintenance and Repair, condition monitoring and structural health monitoring
- Potential of AI for risk assessment in offshore, marine and maritime sectors
- Marine and maritime case study analyses

Practical Work:
This module includes both group and individual practical exercises implementing learning-by-doing teaching principles. Lectures provided by offshore and maritime industry experts in risk management will provide real case studies to test acquired methods.

Key skills acquired :
After completing this course the students will be able to:
- Have an overview of the concepts and principles of risk and reliability engineering and their potential applications to marine robotics problems
- Identify pertinent approaches to data collection and interpretation for risk and reliability engineering methods
- Identify the potential applications of AI in marine and maritime engineering reliability optimization.

Assessment:
100% continuous assessment

Recommended texts:

The notes and presentations of the course will be provided based on the following material:

- Vinnem, J. E. (2014). Offshore Risk Assessment, Vol 2.: Principles, Modelling and Applications of QRA Studies. Springer.
- Darwiche, A. (2009). Modeling and reasoning with Bayesian networks. Cambridge university press.
- Ross, T. J. (2005). Fuzzy logic with engineering applications. John Wiley & Sons.
- Thomas M. Mitchell. 1997. Machine Learning (1 ed.). McGraw-Hill, Inc., New York, NY, USA
- Russell, S. J., & Norvig, P. (2016). Artificial intelligence: a modern approach. Malaysia; Pearson Education Limited.
- Hegde, J., & Rokseth, B. (2020). Applications of machine learning methods for engineering risk assessment–A review. Safety Science, 122, 104492.

Further readings:

- Chollet, F (2017) Deep Learning with Python. Manning Publications Co.
- Géron, A. (2017). Hands-on machine learning with Scikit-Learn and TensorFlow: concepts, tools, and techniques to build intelligent systems. " O'Reilly Media, Inc.".

Legislation on international water and autonomous vehicles			
Credits: 1 Semester 2 Compulsory: Yes			
Format	Lecture: 10	Tutorial work: 0	Practical work: 0
Lecturers: Prof M. Aznar (UJI)			

Objectives:
The objectives of this module is to provide students with the necessary background on key international maritime legislation which has the potential to affect the design and functionality of marine and maritime robotics technologies as well as AI implementation. Special emphasis shall be given to raising awareness of students to the rapidly developing field of AUV legislation reflecting on the implications this can have on their engineering projects.
The module will be based on practical's requiring each student to critically evaluate research proposals but also to develop their own.

Contents:
- Introduction to key International maritime regulatory frameworks
- Introduction to key maritime regulatory bodies, organisations and processes
- Marine pollution regulation and the potential held by intelligent robotics
- AUVs legislation

Practical Work:
This module includes analysis of legal case studies in the marine and offshore sectors.

Key skills acquired :
After completing this course the students will be able to:
- Have an overview of the maritime regulatory frameworks and governance bodies.
- Research and identify the most recent legislation in maritime operations, marine pollution and AUV
- Correlate the implications legislation has on marine intelligent robotics design.

Assessment:
100% continuous assessment

Recommended texts:
The notes of the course will be given by lecturer.

Fairness, accountability and transparency in AI			
Credits: 1 Semester 2 Compulsory: Yes			
Format	Lectures: 10	Practicals, case studies 0	Private study 10
Lecturers: Dr M. Miron (JRC)			

Objectives:
In this course we will discuss the aspects of fairness as a value-driven concept, with roots in law and ethics. Students will be familiarized with different biases occurring in a system, which may cause unfairness. Practical exercises will involve measuring and mitigating unfairness in machine learning models applied to classification problems. In addition, students will learn to use the most popular fairness frameworks.

Contents:

- Bias and fairness
  - Biases in machine learning systems
  - Fairness as a value driven concept
  - Ethics canvas
- Measuring unfairness
  - Group fairness
  - Individual fairness
  - Limitations
- Mitigating unfairness
  - Pre-processing methods
  - In-processing methods
  - Post-processing methods
  - Limitations

Prerequisites:

- Linear algebra
- Machine learning
- Programming (Python)

Practical Work:
Practical examples will accompany the theoretical description of the methods. The students will either work with popular datasets or they will be asked to formalize fairness for their chosen task.

Links with industry:
The practical examples concern scenarios which have a strong social impact. The students will learn to assess the social risk of the tools they develop or use and the impact they may have on the society or specific groups.

Key skills acquired :
After completing this course the students will be able to:

- Assess the fairness impact of a given system and determine where biases may occur
- Motivate the choice of particular unfairness metric and understand its limitations
- Measure unfairness in machine learning predictions
- Use unfairness mitigation frameworks and understand their limitations

Assessment:
100% continuous assessment

Recommended texts:
The notes and code (e.g. Jupyter notebooks) of the course will be provided by the lecturer.

Further readings:

- Tolan, Songül. “Fair and Unbiased Algorithmic Decision Making: Current State and Future Challenges.” arXiv preprint arXiv:1901.04730 (2019).
- Mehrabi, Ninareh, et al. “A survey on bias and fairness in machine learning.” arXiv preprint arXiv:1908.09635 (2019).
- Barocas, Solon, and Andrew D. Selbst. “Big data’s disparate impact.” Calif. L. Rev. 104 (2016): 671.
- Corbett-Davies, Sam, and Sharad Goel. “The measure and mismeasure of fairness: A critical review of fair machine learning.” arXiv preprint arXiv:1808.00023 (2018).

BLOCK 1 Advanced Marine Intelligent Robotics (15.5 ECTS)

Marine Mechatronics			
Credits: 2.5 Semester 2 Compulsory: Yes			
Format	Lecture: 3	Tutorial work: 6	Practical work: 15
Lecturers: Assoc Prof V. Creuze (Univ. Montpellier), Prof V. Hugel, Assoc Prof Claire Dune, Assoc Prof C. Anthierens			

Objectives:
At the end of this course, the student will be able to specify the actuation and proprioceptive perception organs of a robot or a robotic system, and to program it using closed loop control techniques.

Contents:
- Electrical motors for robotics (principles, models, sizing, control).
- Actuation and proprioceptive perception chain.
- Applied control laws
- Visual servoing

Prerequisites:
General mechanics, basics of electronics, control, python programming.

Practical Work:
- Participants will carry out tutorial and practical work on marine and underwater robots under the supervision of the lecturer. Matlab/Simulink and Ubuntu/ROS/python will be used to take over the robotic platforms :
- Marius sailing robot
- 8-thruster BlueROV underwater robot
- 3-thruster fully equipped CORAL underwater robot

Key skills acquired :
After completing this course the students will be able to:
- Specify the actuation and proprioceptive perception organs of a robot or a robotic system
- Determine the sizing parameters of a robotic system
- Program robots for control purposes

Assessment:
Continuous assessment

Recommended texts:
The notes of the course will be given by lecturer.

Advanced control for autonomous vehicles			
Credits: 3 Semester 2 Compulsory: Yes			
Format	Lecture: 23	Tutorial work: 6	Practical work: 0
Lecturers: Assoc Prof N. Boizot			

Objectives:
This course aims to provide students with the essential methods of nonlinear control. At the end of this course, the student must know how to analyze a system that is characterized by a nonlinear dynamical model, how to control it and how to estimate the state of the system.

Contents:
The course starts with the refreshing of several basics of differential geometry (Lie derivatives, vector field distribution). Then it deals with local and global stability: Lyapunov functions, LaSalle invariance principle.
Several control methods will be examined:
nonlinear control: linearization through feedback of mechanical systems, geometric control, stabilization with Lyapunov method, predictive control;
Pontryagin maximum principle, optimal synthesis, direct and indirect methods;
Sliding modes, variable-structure control;
Model-free control.
In this course, methods are mainly based on state-feedback control, but this lecture course will also focus on observers, in particular the extended Kalman filter possibly in its high-gain version.

Prerequisites:
Matrix calculus. Linear control theory (filtering and control). Optimization.

Practical Work:
Practical work will mostly consist in computer simulation performed under Matlab or Python, case studies related to marine / maritime environments will be preferred.

Key skills acquired :
After completing this course the students will be able to:
- stability analysis via Lyapunov functions
- computation of linearising feedback schemes for simple systems
- linearize nonlinear systems in the neighborhood of an equilibrium point
- design control law on the basis of a Lyapunov function
- design an observer for nonlinear systems

Assessment:
0.5 continuous assessment, 0.5 from end of semester examination.

Recommended texts:
The notes of the course will be given by lecturer.

Further readings:

- H. K. Khalil, Nonlinear Systems, Macmillan Publishing Company (1992).
- J. J. Slotine and W. Li, Applied nonlinear Control, Pearsons Publishing (1991).
- E. Sontag, Mathematical Control Theory, Springer (1990).
- L. Jaulin, Mobile Robotics, ISTE, Elsevier (2015).
- J. P. Gauthier and I. Kupka, Deterministic Observation Theory and Applications, Cambridge University Press (2001).
- D. Liberzon, Calculus of Variations and Optimal Control Theory, Princeton University Press (2012).
- U. Ledzewicz and H. Schättler, Geometric Optimal Control, Springer (2012).

Optimization Techniques			
Credits: 2 Semester 2 Compulsory: Yes			
Format	Lecture: 12	Tutorial work: 12	Practical work: 0
Lecturers: Assoc Prof C. Dune, Assoc Prof F. Chittaro			

Objectives:
Learn how to formulate a numerical optimization problem
Learn how to characterize the problem (linear or nonlinear, with or without constraints)
Learn how to select the optimization method that is adapted to the problem.

Contents:
- Refresher in mathematics Positivity, convexity, optimum Differentiability, Gradient and Hessian Existence conditions of optimum point
- Optimization without constraints Formulation of optimization problem Gradient method Conjugate direction method Methods of Newton and Levenberg-Marquardt
- Optimization with constraints Method of simplex (Nelder-Mead) Interior point method Lagrange multipliers Conditions of Karush-Kuhn-Tucker

Prerequisites:
Mathematics: numerical analysis, differentiability, continuity. Scientific programming: master scientific programming tools.

Practical Work:
Half of the module will be devoted to practical work using python and Jupiter on specific cases of optimization.

Key skills acquired :
After completing this course the students will be able to:
- identify optimization parameters, define cost function, describe constraints
- characterize the problem: linear/nonlinear, with or without constraints
- select the best suited optimization method
- make use of the appropriate optimization functions of a library.

Assessment:
100% continuous assessment

Recommended texts:
The notes of the course will be given by lecturer.

Data-driven machine perception			
Credits: 3 Semester 2 Compulsory: Yes			
Format	Lecture: 12	Tutorial work: 0	Practical work: 6
Lecturers: Assoc Prof R. Marxer, Assoc Prof A. Paiement, Prof H. Glotin			

Objectives:
This module aims at equipping students with the ability of creating machine learning (and deep learning) models for usual intelligent robotic perception tasks. Computer vision and machine listening on a marine environment are the two target fields of application of the contents of this course, however other modalities (e.g. hyperspectral imaging, natural language,...) will be discussed. After the module students will be capable at identifying perception tasks to which deep learning techniques can be applied. Students will be able to build specific models to solve these problems and assess their performance. They will also know the main specificities of image and audio for marine applications.

Contents:
- Introduction to deep computer vision
- Surface-level imaging
- Satellite imaging
- Introduction to deep machine listening
- Multichannel audio sensing
- Underwater localisation and tracking
- Case study 1: coastal surveillance
- Case study 2: satellite-based current estimation
- Case study 3: wildlife monitoring

Practical Work:
The laboratory coursework of this module will focus on a set of case-studies of ecologically-valid sensing problems for the marine environment. These scenarios belong to real research projects that have been worked on by researchers and in collaboration with industrial partners. This approach will equip students with real-world experience on solving robotic perception tasks through data-driven deep learning approaches and will confront them to the actual problems that professional practitioners encounter, both in the academic and industrial sector.
Each case study will be composed of well-defined tasks to put into practice the content acquired during the course. Additionally case-studies will present the limitations and challenges of the proposed approaches and will suggest future directions of work. Open-ended tasks search to motivate students into taking initiative and proposing creative solutions in a proactive manner, without knowledge about the outcome.

Key skills acquired :
After completing this course the students will be able to:
- Create deep learning models for usual intelligent robotic perception tasks
- Identifying perception tasks to which deep learning techniques can be applied
- Build specific models to solve these problems and assess their performance
- Know the main specificities of image and audio for marine applications

Assessment:
100% continuous assessment.

Recommended texts:
The notes of the course will be given by lecturer.

Adaptive autonomous robotic behaviour

Credits: 2.5 Semester 2 Compulsory: Yes			
Format	Lecture: 25	Tutorial work: 0	Practical work: 0
Lecturers: Dr J. Arjona-Medina (JKU), Assoc Prof R. Marxer			

Objectives:
Reinforcement Learning is getting more and more relevance in the field of Machine Learning, playing a fundamental role in a wide range of areas such as autonomous driving, robotics or health-care. Classical reinforcement learning techniques combined with Deep Learning allow for complex systems able to perform highly sophisticated tasks, unthinkable only one decade ago.
This course will provide a broad view of the most important state-of-the-art methods and the core challenges that Reinforcement Learning is facing nowadays. The goal of this course is to assimilate the key ideas and understand upcoming contributions to the field.

Contents:
The lectures are distributed in three main blocks: introduction, basic methods and advance methods. Additionally, a lecture about how to evaluate RL methods is introduced since it is a research topic itself. As a final lecture, an analysis of the latest major keystone in the field AlphaStar, is analyzed and discussed.

- Block I: Introduction
  - Deep Learning for Reinforcement Learning
  - Imitation Learning
- Block II: Basic methods
  - Deep Q-Network based methods
  - Policy Gradient based methods
  - Connections between inference and control
  - Planing with Monte Carlo Tree Search
- Block III: Advanced methods
  - Exploration in Reinforcement Learning
  - Hierarchical Reinforcement Learning
  - Direct Credit Assignment methods
  - Evaluation in Reinforcement Learning
  - AlphaStar: A case study

Practical Work:
As a practical work, a comparison among methods is proposed. Using the Behaviour Suite for Reinforcement Learning (Osband I. et al., 2019), students will have to implement and compare different methods in a collection of environments. Results will be discussed highlighting strengths and weaknesses of compared methods. Improvements might be considered as well as a bonus exercise.

Key skills acquired :
After completing this course the students will be able to:

- Have a broad view of the most important state-of-the-art methods
- Understand the current challenges in the field of Reinforcement Learning
- Recognize strengths and weaknesses of different methods
- Implement basic Deep Reinforcement Learning methods
- Integrate basic Deep Reinforcement Learning methods into a third party library
- Analyze and discuss Deep Reinforcement Learning systems.

Assessment:
100% continuous assessment

Recommended texts:
The notes and code (e.g. Jupyter notebooks) of the course will be provided by the lecturer.
Further readings:

- Sutton, Richard S., and Andrew G. Barto. Introduction to reinforcement learning. Vol. 135. Cambridge: MIT press, 1998.
- M. Hessel, J. Modayil, H. van Hasselt, T. Schaul, G. Ostrovski, W. Dabney, D. Horgan, B. Piot, M. G. Azar, and D. Silver. Rainbow: Combining improvements in deep reinforcement learning. ArXiv, 2017.
- D. Horgan, J. Quan, D. Budden, G. Barth-Maron, M. Hessel, H. van Hasselt, and D. Silver. Distributed prioritized experience replay. ArXiv, 2018. Sixth International Conference on Learning Representations (ICLR).
- V. Mnih, K. Kavukcuoglu, D. Silver, A. A. Rusu, J. Veness, M. G. Bellemare, A. Graves, M. Riedmiller, A. K. Fidjeland, G. Ostrovski, S. Petersen, C. Beattie, A. Sadik, I. Antonoglou, H. King, D. Kumaran, D. Wierstra, S. Legg, , and D. Hassabis. Human-level control through deep reinforcement learning. Nature, 518(7540):529–533, 2015.
- J. Schulman, S. Levine, P. Moritz, M. I. Jordan, and P. Abbeel. Trust region policy optimization. In 32st International Conference on Machine Learning (ICML), volume 37 of Proceedings of Machine Learning Research, pages 1889–1897. PMLR, 2015.
- RUDDER: Return Decomposition for Delayed Rewards, José Arjona-Medina*, Michael Gillhofer*, Michael Widrich*, Thomas Unterthiner, Johannes Brandstetter, Sepp Hochreiter. Neural Information Processing Systems (NeurIPS 2019),

Marine localisation and mapping			
Credits: 1.5 Semester 2 Compulsory: Yes			
Format	Lecture: 21	Practical work: 9	Private study: 30
Lecturers: Prof P. Ridao (UdG), Dr A. Comport			

Objectives:
After this course the students will be able to identify the Simultaneous Localization and Mapping (SLAM) approaches that can be used to solve the navigation problem of underwater robots to provide a pose estimate with a bounded uncertainty. Feature based and feature less (pose based) methods will be presented based on the Extended Kalman Filter (EKF) SLAM as well as the Particle Filter (PF) SLAM solutions. Besides the mathematical principles, real examples of SLAM methods applied to the navigation of Autonomous Underwater Vehicles (AUVs) will be used as examples.

Contents:
- Feature based EKF SLAM
- EKF SLAM Algorithm
- Motion Model
- Vehicle Motion
- Re-observing Features
- Adding New Features
- Examples of Feature Based SLAM Methods
- Feature Less Pose Based EKF SLAM
- Pose Based EKF SLAM Algorithm
- Vehicle Motion
- Pose Constraints Observations
- Adding New Poses
- Examples of Pose Based SLAM Methods

Prerequisites:
Robotic techniques for localization. Sensor.

Practical Work:
The course is complemented with a group project using a MATLAB simulation where the students will be requested to apply EKF SLAM techniques to localize a robot in 2D. The students will be given an incomplete MATLAB code and will be requested to complete parts of it to make it operative to solve their assigned problem. The output of the project will be a report describing the solution they have adopted.

Links with industry:
highlight if guest lectures or webinars or industry case studies site visits will be used. Encourage to use as much as possible.

Key skills acquired :
After completing this course the students will be able to:
- Understands the problems of the pure dead reckoning systems leading to unbounded uncertainty.
- Understand the principles of SLAM
- Apply 2D EKF SLAM methods for the localization of a robot

Assessment:
100% continuous assessment

Recommended texts:
Slides and course notes will be provided by the lecturer, together with references to already published texts by other authors.

Further readings:

- S. Thrun, W. Burgard, and D. Fox. Probabilistic Robotics (Intelligent Robotics and Autonomous Agents). 2001.
- José A. Castellanos, José Neira, and Juan D. Tardós. Map Building and SLAM Algorithms.
- D. Ribas, P. Ridao, and J. Neira. Underwater SLAM for Structured Environments Using an Imaging Sonar. Number 65 in Springer Tracts in Advanced Robotics. Springer Verlag, Heidelberg, Alemania, August 2010.

Explainable AI			
Credits: 1 Semester 2 Compulsory: Yes			
Format	Lecture: 10	Practicals, case studies: 0	Private study: 10
Lecturers: Dr M. Miron (JRC)			

Objectives:
Having interpretable machine learning systems is a way to establish trust and to better understand automatic decisions. This course introduces the concepts and methods for designing interpretable machine learning models or interpreting black box models. Students will be able to use publicly available interpretability tools for their desired task and within machine learning pipelines. They will be able to explain and justify their choice of method, considering its advantages and disadvantages, as well as the case when it should be applied.

Contents:
- Intrinsec interpretability
- Linear regression
- Logistic regression
- Decision Tree
- Post-hoc interpretability
- Local interpretable model-agnostic explanations (LIME)
- Partial dependence plots (PDP)
- Permutation feature importance (PFI)
- Shapely additive explanations (SHAP)
- Deep learning interpretability
- Occlusion Sensitivity
- GradCAM
- SmoothGrad

Prerequisites:
- Linear algebra
- Machine learning
- Programming (Python)

Practical Work:
Practical examples will accompany the theoretical description of the methods. The students will either work with popular datasets or with their preferred data.

Links with industry:
The implementations used are already part of machine learning pipelines in the industry. However, for educational purposes, the data will not have the dimensionality or the complexity of real-world data.

Key skills acquired :
After completing this course the students will be able to:
- Have an overview of the most important interpretability methods
- Understand when to apply the different types of machine learning interpretability methods
- Integrate popular interpretability tools into machine learning pipelines
- Analyze and visualize interpretations for tabular data, text and images

Assessment:
100% continuous assessment

Recommended texts:
The notes and code (e.g. Jupyter notebooks) of the course will be provided by the lecturer.

Further readings:

- Molnar, Christoph. 2019. Interpretable Machine Learning: A Guide for Making Black Box Models Explainable. https://christophm.github.io/interpretable-ml-book/
- Miron, Marius. 2018. Machine Learning Interpretability, Literature review, http://mariusmiron.com/interpretability/

BLOCK 2 - Specialisations - Joint MIR study track courses (4.5 ECTS)

# Underwater interventions - UJI			
Credits: 1.5 Semester 2 Compulsory: Yes			
Format	Lecture: 15	Tutorial work: 0	Practical work: 0
Lecturers: Prof P. J. Sanz, Assoc Prof R. Marín and Assoc Prof J.V. Martí (UJI)			

Objectives:
It is the aim of this subject to introduce the technology associated with the underwater intervention systems from a very general viewpoint. So, starting out with the historic evolution of these systems it will be reviewed the complete state-of-the-art, starting with ROVs (Remotely Operated Vehicles) till arrive nowadays to the I-AUVs (Autonomous Underwater Vehicles for Intervention) under development. The underlying question, along the course, will be: what kind of capabilities are needed to fit with the complexities of a real underwater intervention mission?

Contents:
Description of technological needs of a real underwater intervention mission. Specifications concerning the Work-class ROVs (Remotely Operated Vehicles). Specifications for I-AUVs. Main technologies evolved on for autonomous navigation, surveying, recognition, positioning and intervention (i.e. manipulation) associated with I-AUVs. Pros and cons of both kinds of systems (ROVs vs I-AUVs). Real examples through case studies and lessons learned from recent research projects and developed real missions.
Prerequisites: backgrounds in mathematics

Key skills acquired :
After completing this course the students will be able to:
- Understand the main properties around an underwater intervention mission
- Getting a general comprehension about the complexities inherent to nowadays underwater intervention systems
- Understand the main differences between Work-class ROVs and I-AUVs, and their pros and cons
- Distinguish the technological capabilities that better fits with a specific intervention mission
- Obtain a good comprehension about the state-of-the-art and historic evolution concerning the underwater intervention systems

Assessment:
100% continuous assessment

Recommended texts:
The notes of the course will be given by lecturer.

Further readings:
- P. Ridao, Carreras, M., Ribas, D., Sanz, P. J., and Oliver, G., “Intervention AUVs: The Next Challenge”, Annual Reviews in Control, vol. 40, 2015.
- “Underwater Robots” by Gianluca Antonelli. Springer Tracts in Advanced Robotics Vol (96), 2014.

# Autonomy in subsea operation - NTNU			
Credits: 1.5 Semester 2 Compulsory: Yes			
Format	Lecture: 15	Tutorial work: 0	Practical work: 0
Lecturers: Prof I. Schjølberg, Dr B. A. Haugaløkken and Dr A. Sans Muntadas (NTNU)			

Objectives:
The course will give insight into the development of autonomy in subsea operations. Autonomy contributes to more efficient operations for operators in planning and decision support during subsea operations. Autonomy is critical for operators to reduce risk and costs during operations. Methods and components within autonomy will be presented as well as many industrial examples.

Contents:
Introduction to the terms
Decision support models of robots, sensors and equipment
Intervention concepts and tasks
Development of efficient operations

Prerequisites:
Background in mathematics.

Key skills acquired :
- After completing this course the students will be able to:
- Develop a concept for autonomous underwater operations
- Provide solutions for autonomous marine robots
- Formulate and describe the challenge of autonomy in underwater operations

Assessment:
100% continuous assessment

Recommended texts:
The notes of the course will be given by lecturer.

Further readings:
Supplied during the course

# Cooperative robotics - IST-UL			
Credits: 1.5 Semester 2 Compulsory: Yes			
Format	Lecture: 15	Tutorial work: 0	Practical work: 0
Lecturers: Prof A. Pascoal (IST-UL)			

Objectives:
The last decade has witnessed tremendous progress in the development of marine technologies that are steadily affording scientists advanced equipment and methods for ocean exploration and exploitation. Recent advances in marine robotics, sensors, computers, communications, and information systems are being applied to the development of sophisticated technologies that will lead to safer, faster, and far more efficient ways of exploring the ocean frontier, especially in hazardous conditions. As part of this trend, there has been a surge of interest worldwide in the development of autonomous marine robots capable of roaming the oceans freely and collecting data at the surface of the ocean and underwater on an unprecedented scale. Representative examples are autonomous surface craft (ASC) and autonomous underwater vehicles (AUVs). The mission scenarios envisioned call for the control of single or multiple AUVs acting in cooperation to execute challenging tasks without close supervision of human operators.
Motivated by the above trends, this course will afford the students core theoretical tools required for the design and analysis of multiple autonomous systems connected via communication networks. Inspiring examples will focus on the use of multiple cooperative surface and autonomous for a number of scientific and commercial applications that include marine habitat mapping, seismic surveying, and inspection of critical infrastructures. Starting with representative mission examples and end-user specifications, the student will be guided through the steps required to go from mission to functional and technical specifications, as a means to clearly motivate the ensuing theoretical body of work that will be presented. The latter will be centered on the concepts and mathematical and simulation tools appropriate to the study of cooperative motion planning, navigation, and control of multiple heterogeneous vehicles exchanging data over hybrid aerial and underwater acoustic communication networks.

Contents:
The course will be structured as follows:
- Motivating problems and systems: from functional to technical specifications
- Review of key methods for single vehicle navigation, guidance, and control (NGC) with applications to pose control, path following, trajectory tracking, and path following.
- Network systems
  - Elements of graph and algebraic graph theory
  - Averaging systems and consensus
  - Networks with switching communication topologies
- Cooperative Control
- Cooperative Navigation
- Cooperative Motion Planning
- Introduction to computer-based tools for networked autonomous systems simulation and performance assessment.

Prerequisites:
Attendees are supposed to master the core concepts of linear algebra, signals, and systems, together a good understanding of control theory. Basic knowledge of estimation and filtering theory is also recommended.

Key skills acquired :
After completing this course the students will be able to:

- Have a general, well balanced vision of a multitude of scientific and commercial problems requiring the use of cooperative marine robots.
- Tackle and solve problems related to the design of cooperative navigation, control, and motion planning of multiple robots
- Understand the design constraints imposed by the underlying aerial, optical, and acoustic networks
- Read advanced references on cooperative robotics.

Assessment:
100% Continuous assessment.

Recommended texts:
The notes of the course will be provided by the lecturer. Representative papers will also be listed.

Further readings:

- T. Fossen, Handbook of Marine Craft Hydrodynamics and Motion Control, Wiley, 2011, ISBN-13: 978-1119991496.
- F. Bullo, Lectures on Network Systems, Edition 1.3, July 2019, Kindle Direct Publishing, ISBN-13: 978-1986425643.
- Chao Gao, Guorong Zhao, Hassen Fourati, Editors, Cooperative Localization and Navigation: Theory, Research, and Practice, 1st Edition, CRC Press, 2019, ISBN 9781138580619

BLOCK 3 - Applied marine intelligent robotics (7 ECTS)

Deep-sea vehicles and missions for ocean sciences			
Credits: 2 Semester 2 Compulsory: Yes			
Format	Lecture: 15	Tutorial work: 0	Practical work: 5
Lecturers: Ifremer – Dr Jan Opderbecke - Dr Lucie Somaglino- Dr Aurélien Arnaubec Dr Maxime Ferrera - Jennifer Greer - Dr Claire Dune-Maillard			

Objectives:
The objective of this lecture is to provide insight specific to deep-sea underwater vehicles and their operation. It gives an overview of existing underwater vehicles, observatories and operations procedures, with emphasis on the Underwater Systems developed and operated within the French Oceanographic Fleet. Sensors and equipment required for deep water submarine operations will be presented. A focus on acoustic communication necessary for the operation of AUVs (Autonomous Underwater Vehicles) will be carried out in terms of principle, strategies and equipment. Instrumental architecture and key principles of distributed multi-sensor acquisition systems will be exposed. Visual perception in deep-sea operations as well as 3D representation of natural structures on the ocean floor will also be deepened.

Contents:
- Overview of robotic systems for ocean sciences in the deep-sea (1h30 lecture, Jan Opderbecke)
  - Underwater vehicle systems in the French Oceanographic Fleet
  - Specific requirements for deeps-sea exploration and monitoring
  - Current projects : technologies and systems
  - Relevant research topics
- Acoustic communication for deep-sea vehicles (3h lecture, Lucie Somaglino)
  - Technologies and communication strategies with the vehicle(s)
  - Basic principles of communication (carrier waves, modulation schemes…)
  - Performance of underwater acoustic modems
- Visual perception for the exploration of the deep sea (1h30 lecture Maxime Ferrera + 1h30 lecture Aurelien Arnaubec)
  - Camera's images formation principles
  - Multi-view geometry for 3D reconstruction
  - Optical based 3D reconstruction from structure-from-motion and 2D mosaicking
- Multi-sensor and data acquisition systems (1h30 lecture, Jennifer Greer)
  - Multi-sensor hubs in vehicles and in observatories
  - Sensors
  - Intervention operations performed by ROVs

Prerequisites:
Underwater acoustics, Linear Algebra, Numerical Optimization, Fundamental knowledge in physics and fluid mechanics, Electronics and Industrial Computing.

Practical Work:
Data acquisition and student projects on acquired data.

Links with industry:
Lecturers are engineers and researchers from IFREMER (La Seyne-Sur-Mer center). Underwater vehicles and equipment use and references are from the industry or developed at IFREMER. Lecturers are experts in specific areas of deep-sea robotics, they contribute in numerous partnerships with industry and academia, as well as in research projects at national or European level.

Key skills acquired:

- Insight in the state-of-the-art in operational vehicle systems, specific concepts in vehicle categories, and applicative missions in the field of ocean sciences
- Principles of long distance acoustic communication for AUVs and evaluation of existing equipment
- Basics of Image Processing, Multi-view Geometry and optical 2D/3D reconstructions
- Notions of hardware and software architecture for multi-sensor acquisition systems and their web-based control interfaces, overview of operations performed by ROVs in observatories

Assessment:

Oral presentation of projects related to practical work

Recommended texts:

Lecturers will give the notes of the course.

Further readings:

E. Raugel, J. Opderbecke, M.C. Fabri, L. Brignone, Operational and scientific capabilities of Ariane, Ifremer's hybrid ROV, Proceedings of Oceans MTS-IEEE, Marseille-France, 17-20 June 2019.

R Hartley, A Zisserman, Multiple view geometry in computer vision - Vision, 2nd ed., New York: Cambridge, 2003.

Szeliski, Richard. Computer vision: algorithms and applications. Springer Science & Business Media, 2010.

Underwater acoustic sensors			
Credits: 1 Semester 2 Compulsory: Yes			
Format	Lecture: 10	Tutorial work: 0	Practical work: 0
Lecturers: Dr F. Mosca, Dr G. Jouve, Dr G. Matte. (iXBlue)			

Objectives:
This lecture will be devoted to the presentation of existing off-the-shelves acoustic sensor products for underwater vehicles such as DVL, lateral, frontal sonars, multibeam sonars, sonar imagery, integrated sensors with embedded inertial sensor units. The technology behind each type of sensor will be described to emphasize the difference in specifications and usage of the devices to be embedded on surface or underwater drones.

Contents:
Introduction to underwater acoustics :
- Principle of acoustic propagation
- Ocean acoustics
- Sonar architecture
- Underwater acoustics sensors for navigation :
- DVL/CVL technologies
- USBL/LBL
- Coupling with INS
- FLS technology
- Underwater acoustics sensors for payload & applications :
- SBES/MBES
- SSS/SAS
- SBP
- Other UWA sensors and ancillaries : ADCP, CTD/SVP, Split-beam, Acom
- Software suites for geophysical data acquisition and interpretation
- Trends and perspectives

Prerequisites:
Mathematics (distribution theory), wave physics, basics of electronics

Practical Work:
Remote controlled iXblue SeapiX multibeam echosounder implemented on cataraft for fish characterization in shoreline environments.
Links with industry: Using of iXblue systems in operational conditions + laboratory visit

Key skills acquired :
Underwater acoustic signal understanding, environmental monitoring and surveying using acoustic sensors, interest of acoustic sensors for industry & academic research.

Assessment:
100% continuous work

Recommended texts:
The notes of the course will be given by lecturer.

Further readings:
- Books:
  - An Introduction to Underwater Acoustics, Principles and applications, X. Lurton
  - Fisheries Acoustics, Simmonds, MacLennan
  - Computational Ocean Acoustics, Jensen, Kupperman, Porter, Schmidt.
- Articles :
  - Scientific potential of a new 3D multibeam echosounder in fisheries and ecosystem research, Mosca et al. Fisheries Research 178 (2016) 130–141, 2016
  - Low-frequency source for very long-range underwater communication, Mosca et al., The Journal of the Acoustical Society of America 133 (1):EL61-EL67, 2013

Entrepreneurship – Industry and research project			
Credits: 2 Semester 2 Compulsory: Yes			
Format	Lecture: 14	Tutorial work: 3	Practical work: 0
Lecturers: L. Delclos (STAT MARINE), Dr K. Pediaditi, Assoc Prof R. Marxer, Prof V. Hugel			

Objectives:
To develop the necessary skills of the business entrepreneur to generate and evaluate innovative ideas, to develop and materialize innovation in products and services, and to structure a business plan to incubate and explore technology based innovation, with a specific knowledge of market mechanisms, financement, and management. Research oriented skills in project proposal writing will also be developed.

Contents:
Using learning by doing methods students will be taught business planning particularly focusing on research and innovation projects. Research proposal writing will also be taught focusing on an overview of the different funding sources as well as the basic principles of proposal writing. Case studies and topics will be provided by industries and research labs.

Prerequisites:
Design thinking module

Practical Work:
Students will work on case studies with the aim of developing an innovative product or service or writing a proposal for a research project . They will have to work in groups and or individually depending on the topic selected and develop business plans and/or research proposals as well as present professionally their idea and plan to potential clients.

Links with industry:
where possible real cases studies from industries will be used and presentations made to industry representatives.

Key skills acquired :
After completing this course the students will be able to:

- Business plan development
- Proposal writing
- Professional presentation skills

Assessment:
100% continuous assessment

Recommended texts:
The notes of the course will be given by lecturer.

Intelligent robotics for seabed resources exploration			
Credits: 1 Semester 2 Compulsory: Yes			
Format	Lecture: 10	Tutorial work: 0	Practical work: 0
Lecturers: Prof R. Bachmayer (MARUM-UNI BREMEN)			

Objectives:
The objective of this course is to introduce the students to the specific considerations of designing and operating an intelligent system for unmanned seafloor exploration.

Contents:
The course will present the students with a number of selected key requirements for exploration. A focus will lie on underwater navigation from surface to the seafloor and will highlight some of the operational scenarios. The students will be introduced to a broad range of underwater sensing modalities and available sensors.
Since the underwater environment presents systems with formidable challenges for potential approaches and solutions special considerations will be given to the environmental factors, such as pressure, currents, visibility, expected seafloor terrain and how they might actually influence potential exploration strategies.
The second part of the course the students will go through a typical design and development cycle of such a system and follow through with an efficient multi-platform approach suitable for large scale (~10 square km) seafloor exploration down to targeted seafloor imaging. To conclude this part an outlook towards current developments of intelligent autonomous seafloor exploration will be given.
In the tutorials the students will be presented with a specific exploration task and as one or several groups will develop an efficient exploration strategy using an intelligent systems approach.

Prerequisites:
- Physics
- Basic knowledge of robotics: sensors, electromechanical Systems
- Links with industry: we will use webinars or particular science and industry study cases to introduce the students to the current state of the art exploration tools, including navigation and sensing.

Key skills acquired :
After completing this course the students will be able to:
- Understand the fundamental challenges for seabed exploration
- Develop a concept of an intelligent exploration system for specific challenges
- Understand the different sensing, navigation and control constraints between autonomous and tethered systems
- Understand the availability, limitations and suitability of different sensors for various exploration tasks

Assessment:
100% continuous assessment

Recommended texts:
The notes of the course will be given by lecturer.

Further readings:

- Hékinian, R., “Sea floor exploration : scientific adventures diving into the abyss”
- Whitcomb, Louis L., et al. “Navigation and control of the Nereus hybrid underwater vehicle for global ocean science to 10,903 m depth: Preliminary results.” 2010 IEEE International Conference on Robotics and Automation. IEEE, 2010.
- Hegrenaes, Øyvind, and Oddvar Hallingstad. “Model-aided INS with sea current estimation for robust underwater navigation.” IEEE Journal of Oceanic Engineering 36.2 (2011): 316-337.

Artificial intelligence and shipping			
Credits: 1 Semester 2 Compulsory: Yes			
Format	Lecture: 10	Tutorial work: 0	Practical work: 0
Lecturers: Prof N. Nikitakos (University of Aegean)			

Objectives:
Review of methods from artificial intelligence and their application to specific problems in maritime sector.

Contents:
- Fourth Industrial revolution and shipping
- Cyber physical systems – Big Data - Shipping 4.0 – Applications
- Brief Introduction to ships and port technology
- Ship's design characteristics, Navigation systems, Propulsion and Automations, Telecommunication systems, Ports Electronic Systems
- Introduction to AI and Agents
- Introduction to AI –Agents - brief history of AI – State of the art in shipping
- Search
- Problem-solving agents, Problem types, Problem formulation, Example problems, Basic search algorithms, Informed search algorithms, simulated annealing, Constraint Satisfaction Problems, Adversarial Search, Real time decisions. Maritime case study
- Logic
- Knowledge-based agents, Logic models and entailment, Propositional (Boolean) logic, Equivalence, validity, satisfiability, Inference rules
- Case study from maritime
- Planning
- Reinforcement Learning, Active and Passive reinforcement learning, Optimization: Least Squares, minimizing errors
- Uncertainty
- Probability, Markov Models, Hidden Markov Models, Particle Filters and Applications of HMMs. Maritime case study
- Learning
- Machine Learning , Naïve Bayes Case-Based Learning , Bayes' Nets , Case-Based Reasoning, Perceptrons, neural networks (classifiers, decision rules),
- Maritime case study
- Specific topics in maritime domain –autonomous ship

Prerequisites:
Elementary Technological and computer programming background, Basic knowledge of AI methods.

Practical Work:
Basic programming of AI application in shipping using Python.

Key skills acquired :
After completing this course the students will be able to:
- Define basic methods and algorithms from area of artificial
- Intelligence, as applied in shipping
- Demonstrate ideas behind different algorithms and their use,in practical maritime applications
- Select methods for specific shipping problems,
- Formulate problems in shipping as problems from area of artificial intelligence
- Evaluate applications and background algorithms used for their implementation in shipping issues

Assessment: 100% continuous assessment
Recommended texts: The notes of the course will be given by lecturer. **Further readings:** S. Russell and P. Norvig 'Artificial Intelligence: A Modern Approach 'Prentice Hall

YEAR 2

SEMESTER 3

UJI, SPAIN

STUDY TRACK 1:
Applied robotics for underwater intervention missions

UNIVERSITAT JAUME I

SEMESTER 3 - STUDY TRACK 1: APPLIED ROBOTICS FOR UNDERWATER INTERVENTION MISSIONS - UJI, SPAIN

Summary

While commercially available Autonomous Underwater Vehicles (AUVs) are routinely used in survey missions, a new set of applications exist which clearly demand intervention capabilities. The maintenance of permanent underwater observatories, submerged oil wells, cabled sensor networks, pipes and the deployment and recovery of benthic stations are but a few of them. Nowadays, these tasks are addressed using manned submersibles or work-class ROVs (Remotely Operated Vehicles), equipped with teleoperated arms.
Current Intervention-AUVs (I-AUVs) prototypes are usually big and complex systems exhibiting only a limited set of functionalities including docking and fixed based manipulation on a subsea panel, as well as search and recovery of simple objects. Underlying the main drawbacks found in these kinds of systems are the current technology limitations in several domains like wireless communications, human-robot interaction, multisensory based manipulation, networking, cooperative robots or different control strategies to mention but a few. Moreover, looking for increasing autonomy levels, cognition developments will also be a cornerstone, trying to replace dexterities associated with the human expert on the intervention domain by means of Artificial Intelligence (AI) procedures. In summary, all the aforementioned technologies will be the key contents assumed in this specialization.

Summary table of UJI study track modules

Module Title	Number of Teaching hours	Total ECTS 30
Perception and Manipulation	40	4
Multi-robot systems (previously cooperative robotics)	40	4
Cognitive processes	40	4
Wireless communication	40	4
Telerobotics and HRI	40	4
Robotic Intelligence	40	4
Transversal skills	40	4
Spanish as a foreign language	20	2

SEMESTER 3 : ANALYTICAL DESCRIPTION OF MODULES - STUDY TRACK 1

Perception and Manipulation			
Credits: 4 Semester 3 UJI Compulsory: Yes			
Format	Lectures 30	Examples 10	Private study 85h
Lectures: Prof P. J. Sanz			

This course is an indispensable piece of connection between robotic intervention systems and the real world, where physical interaction is crucial. The way we interact with the universe surrounding a robot, is strongly influenced by the ability of perception of the environment implemented in it. Thus, during the physical interaction related to the ability to manipulate their environment, the robot may incorporate more robust and efficient resources to the extent that it is capable to combine different types of sensory information from different perceptual channels. In summary, students will learn, at the end of this course, how a suitable feedback of different perceptual channels (i.e. vision, force, and tactile), is a powerful mechanism to solve complex problems, as underwater intervention missions, where physical interaction is a must.

Contents:

The following subjects will be treated:

- Introduction to Artificial Perception.
- Perception-Action Integration.
- The Robot Physical Interaction Framework.
- Introducing Learning Skills during the physical interaction process
- Sensory Fusion Technical Information in the Context of Robotic Grasp.
- Autonomous vs. teleoperated manipulation in underwater domains.
- Case Study-1: Service robotics.
- Case Study-2: Underwater Intervention Systems.

Objectives

- Train to solve real problems of perception-based robotic manipulation for dynamic unstructured environments.
- Facilitate and promote the development of programming robots to task level.
- Instruct both on remote-as autonomous systems for underwater intervention.
- Improving all aspects of sensory and motor integration, considering also the inspiration in biological systems.

Assessment:

80% continuous assessment, 20% Oral presentation.

Practical Work:

Project development

Multi-robot systems			
Credits: 4 Semester 3 UJI Compulsory: Yes			
Format	Lectures 30	Examples 10	Private study 85
Lectures: Assoc Prof E. Cervera			

The distribution of devices, sensors and actuators, among several mobile robots increases flexibility and robustness, and reduces the overall cost compared to monolithic solutions based on a single gifted robot. However, for efficient cooperation among a team of robots, it is necessary to address and solve challenges to efficiently manage devices and communications between them. They also represent a test for the allocation and planning of real tasks. Its applications range from exploration and / or efficient surveillance environments, to the assistance in underwater intervention missions.

Contents:
The following subjects will be treated:
- Introduction to cooperative robotics. In this issue the latest robotic technology network will be studied according to the IEEE Technical Committee on "Network Robotics".
- Literature review. This section provides a literature review of some significant articles were made in the field of cooperative robotics.
- Technology for cooperative robotics. Network technologies, both hardware and software, for enhancing the applications of cooperative robotics.
- Architectures and software platforms for cooperative robotics. In this section the design of platforms for cooperative applications are discussed. Examples of these platforms can be Jade, Player / Stage, or ROS.

Objectives:
After completing this course the students will be able to:
- Efficiently manage a team of robots.
- Schedule and distribute tasks.
- Exploiting Multiplicity to increase the capacities of perception and learning.

Assessment:
20% continuous assessment, 80% from end-of-semester examination.

Practical Work:
laboratory: multi-robot systems

Recommended texts:
- Tucker Balch, Lynne Parker, Robot Teams: From Diversity to Polymorphism, AK Peters, Ltd., 2002.
- Jiming Liu, Jianbing Wu, Multiagent Robotic Systems, CRC Press, 2001.
- Alan C. Schultz, Lynne E. Parker, Multi-Robot Systems: From Swarms to Intelligent Automata, Kluwer, 2002.
- Mohammad O. Tokhi and Gurvinder S. Virk (eds): Advances in Cooperative Robotics, World Scientific, 2016.

Further readings:
will be provided by the lecturer

Cognitive Processes			
Credits: 4 Semester 3 (UJI) Compulsory: Yes			
Format	Lectures 30	Examples 10	Private study 80
Lectures: Assoc Prof Ll. Museros			

Objectives:
The development of robotics has been directed toward the development of skills in robots, similar to those of human beings, regardless of the cognitive processes underlying human intelligent behavior. Probably the poor implementation of natural cognitive processes to robotics and artificial intelligence is because neuroscience, the discipline that should nurture knowledge on natural cognitive processes, has not been able so far to provide a generic explanation of behavior of our brain, which could be used for artificial intelligence and robotics. This course will approach the study of the latest discoveries in neuroscience of human brain function, and then move to the implementation of artificial cognitive processes. The course includes the learning of machine learning topics, and its applications to underwater robotic open problems.

Contents:
- Review about Artificial Intelligence and its areas of study.
- Natural Cognitive Processes
- Computational Cognitive approaches for Sensing and Perceiving Processes
- Computational Cognitive approaches for Attention, Memory, Language, Reasoning and Learning Processes
- Computational Cognitive approaches for Emotion, Self-Consciousness, Personality, an others
- Ethics and Artificial Intelligence
- Applied machine learning concepts

Abilities:
After completing this course the students will be able to:
- Know the natural cognitive processes that neuroscience has discovered. Define natural cognitive processes can be implemented in artificial cognitive processes and how.
- Know a few artificial cognitive processes for sensing and perceiving, attention, memory, language, reasoning, learning, emotion, self-consciousness, and personality.
- Know how to apply machine learning algorithms to solve underwater robotic problems.
- Know the latest trends related with ethics and Artificial Intelligence.

Assessment:
20% continuous assessment, 80% from end-of-semester examination through the development of a project.

Practical Work:
Exercises will be set, which will involve preparing and presenting a paper in scientific format of the project developed during the course.

Recommended texts:
Thagard, Paul (2nd, 2005). Mind : Introduction to Cognitive Science. Cambridge, MA: The MIT Press.

Further readings:
Specific readings will be provided by the lecturer each year.

Underwater Wireless Communication			
Credits: 4 Semester 3 (UJI) Compulsory: Yes			
Format	Lectures 30	Lab. 10	Private study 85
Lectures: Assoc Prof J.V. Martí			

Objectives:
The goal of the course is to enable students to understand and use the technologies involved in the underwater wireless communications.
In recent times, the capabilities of the AUVs (Autonomous Underwater Vehicles) have been considerably increased, allowing greater duration and distance in the interventions. The umbilical connection to the control center, through which energy and data are transmitted, is a binding that limits the action of the AUV. The underwater wireless communications allow to avoid this tie, but presents a series of difficulties and disadvantages that it is necessary to know and manage to implement a working system, allowing communication with both the base station and other AUVs in the vicinity.

Contents:
The following subjects will be discussed:
- Introduction. State of the art
- Physical and technological constraints to underwater wireless communications
- Acoustic communications: sonar
- Light communications: LED and laser
- Radiofrequency underwater communications
- Data transmission
- Localization

Abilities:
After completing this course the students will be able to:
- Understand and discuss the most relevant articles in related areas: Acoustic, light and RF underwater communications.
- Come up with new ideas, start innovative projects in this area.
- Develop and check underwater communications techniques and protocols using sonar, RF and light technologies.

Assessment:
60% continuous assessment, 40% oral presentation.

Practical Work:
Laboratory project.

Recommended texts:

- Marco Lanzagorta, "Underwater Communications", Morgan & Claypool Publishers, 2012.
- Camilla M.G. Gussen et al., "A Survey of Underwater Wireless Communication Technologies". Journal of Communication and Information Systems, vol. 31, no. 1, 2016.

Further readings:
Will be provided during the course

Telerobotics and HRI			
Credits: 4 Semester 3 (UJI) Compulsory: Yes			
Format	Lectures 30	Lab. 10	Private study 85
Lectures: Assoc Prof R. Marín			

Objectives:
The overall goal of this course is to study the processes and tools to design safe and efficient robotic systems for Tele-Manipulation in underwater environments, including advanced Human-Robot Interfaces.
Advances in information technologies, human interfaces and communications open new possibilities and interesting applications, in order to improve specific methods that enable the control of a mobile manipulator at a distance. Hazardous environments such as underwater, require advanced research activity to enable more efficiency and safety in robotic rescue operations, which cannot be performed by human experts directly. Remote control through communication networks (e.g. underwater radio frequency and sonar modems), and more specifically their interconnection as robot teams, including a human-supervisory control technique, enables the human operator to select the appropriate level of interaction according to the specific mission plan. For that, the user interface can enable the execution of semi-autonomous team behaviours, as well as low-level control of the robotic manipulator, according to the current specific necessity. In fact, hazardous environments present unexpected situations that need the human-operator in the loop, which can supervise and take control of the system according for example to the water currents and visibility conditions.

Contents:
The following subjects will be studied:
- Telerobotics for Tele-Manipulation in underwater and other hazardous environments.
- History of Telerobotics, Networked Robotics, Online Robots, and Human-Supervisory Control.
- Tools for the design of Tele-Manipulation Systems
- Design of Human-Robot Interfaces for Human-Supervisory Control.
- The communication network and its influence on the remote control.

Abilities:
After completing this course the students will be able to
- Learn the concept of telerobotic system for human-supervisory control.
- Know the facilities provided by the telerobotic systems in the past.
- To introduce the latest software and tools for the design of remote control systems.
- Study network architectures to design a telemanipulation system.
- Study the design of human-supervisory control interfaces for telemanipulation in hazardous environments.
- Study the impact of bandwidth and latency in the design of a telerobotic system.
- Remote control of real and simulated underwater robotic systems via ROS.

Assessment:
60% continuous assessment, 40% from end-of-semester examination.

Practical Work:
Laboratory exercises for controlling ROS-based underwater robots. Study of a simulation tool for experimenting communication effects in underwater telerobotics.

Recommended texts:

- T. Sherindan, Telerobotics, Automation, and Human Supervisory Control. Cambridge: MIT Press, 1992.
- K. Goldberg, Roland Siegward, Beyond Web Cams: An introduction to Online Robots, MIT Press, Massachusetts, 2001.
- N. Sarkar, Human Robot Interaction, Intech Open, 2007.

Further readings:
Will be provided during the course

Robotic Intelligence			
Credits: 4 Semester 3 UJI Compulsory: Yes			
Format	Lectures 30	Examples 10	Private study 85
Lecturer: Prof A. P. del Pobil			

Introduction to the topic of Machine Intelligence, understood as part of artificial intelligence that deals with those aspects of intelligence related to physical systems that interact in the real world. This intelligent behavior includes objectives such as: adaptation to a changing environment, active perception to interact with a partially unknown environment, explore, learn, etc.

Contents:

- The study of intelligence. Fundamentals and panoramic
- Robot intelligence: the basics
- Neural networks for adaptive behavior
- Braitenberg vehicles and arquitetura of Subsumption
- Development: From locomotion to cognition
- Evolution, genetic algorithms and self-organizing
- Design principles of autonomous robots

Objectives:
To acquire the basic principles and practices necessary skills to design and build a robotic system capable of displaying an appropriate and robust behavior in a realistic environment.

Assessment:
100% from student projects.

Practical Work:
Laboratory exercises on modelling and development of intelligent systems

Recommended texts:

- Rolf Pfeifer and Josh C. Bongard, How the Body Shapes the Way We Think - A New View of Intelligence, The MIT Press, 2006.
- Rolf Pfeifer and Christian Scheier, Understanding Intelligence, The MIT Press, 1999.
- Stuart J. Russell and Peter Norvig, Artificial Intelligence - A Modern Approach, Prentice Hall, Second Edition, New Jersey, 2003
- Michael A. Arbib, The Handbook of Brain Theory and Neural Networks, The MIT Press, 2nd ed., 2003.
- Ronald C. Arkin, Behavior-Based Robotics, The MIT Press, 1998.
- George A. Bekey, Autonomous Robots - From Biological Inspiration to Implementation and Control, MIT Press, 2005
- Cynthia L. Breazeal, Designing Sociable Robots, The MIT Press, 2004.
- Brooks, RA, Cambrian Intelligence - The Early History of the New AI, MIT Press, 1999
- Paco Calvo and Antoni Gomila (editors), Handbook of Cognitive Science: An Embodied Approach, Elsevier, Amsterdam, 2008.
- Kenneth A. De Jong, Evolutionary Computation - A Unified Approach, The MIT Press, 2006.

Further readings:
Will be provided by lecturer

Simulation, Middleware and Benchmarking			
Credits: 4 Semester 3 UJI Compulsory: Yes			
Format	Lectures 30	Practical 10	Private study 85
Lectures: Assoc Prof A. Morales			

Objectives:
The goal of this course is the study several general practical methodologies and tools which are applied on the development of every robot system and project. These are popular robotic middle-wares used the development and integration of robotic systems, simulation tools used to aid the development and visualization of running robotic systems, and the definition and application of benchmarks as a tool for the evaluation of robotics solutions.

Contents:
The following subjects will be studied:
- Robotic software middle-wares, principles and contents.
- Robot system architectures.
- Robotic simulation: tools and formats
- Benchmarking: concept and use
- Design of benchmarks

Abilities.
After completing this course, students will be able to
- Acquire the basic principles on the use of intermediate software in the general context of robotics.
- Handle the main simulation tools currently available.
- Understand, on a theoretical and practical level, the impact of benchmarking on the solutions found for any experiment / project in the context of robotics in real scenarios.

Assessment:
80% from student projects, 20% from oral presentation.

Practical Work:
project development

Recommended texts:
Will be provided by the lecturer

Further readings:
Will be provided by the lecturer

SEMESTER 3
NTNU, NORWAY

STUDY TRACK 2:
Safe autonomous subsea operations

SEMESTER 3 - STUDY TRACK 2: SAFE AUTONOMOUS SUBSEA OPERATIONS - NTNU, NORWAY

Summary

Subsea operations are being developed for increased autonomy in aquaculture, deep waters, and arctic areas. The next generation of autonomous operations requires an increased focus on safety and reliability to reduce costs and increase efficiency. An increased level of automation and autonomy in routine or otherwise tedious operations may improve safety, efficiency and performance, supporting the human operator in decision-making and supervision, and reducing human workload.
Currently, most subsea inspection, maintenance and repair operations (IMR) require support from a top-side vessel, marine robotic systems, tools and experienced human operators. Current industrial subsea operations are in general direct manually controlled, with little or no automatic control functions, nor autonomy. Efficiency in operations is highly dependent on the experience of the operators. Autonomy in operations is a stepping stone towards increasing the efficiency and thereby reducing the costs in subsea operations.
Navigation, positioning, and localization are critical technologies for enabling such autonomous operations as it is not possible to use Global Navigation Satellite Systems (GNSS's) under water. A number of other technologies are available, however, and will also be addressed in this semester.

Summary table of NTNU study track modules

Module Title	Number of Teaching hours	Total ECTS 30
Marine Control Systems, specialization course	30	7.5
Marine Control Systems, specialization project	30	7.5
Decision making under uncertainty for autonomous systems	30	7.5
Research-based Innovation Methodologies in Computer and Information Science or Safety and Asset Management, specialization course	30	7.5
Norwegian as a foreign language	30	-

SEMESTER 3 : ANALYTICAL DESCRIPTION OF MODULES - STUDY TRACK 2

Safety and Asset Management, specialization course			
Credits: 7.5 Semester 3 Compulsory: Yes			
Format weekly	Lectures 4	Practicals: 4	Private study: 4
Lecturers: NTNU			

Objectives:
The objective of the course is to learn advanced theory related to the risk modelling and advanced methods for risk analysis. Two modules, each 3.75 ECTS, have to be selected. The specialization modules are “Applied risk analysis” and “Advanced methods in risk analysis”. Both should be selected if relevant for the topic of the project and master thesis.

Contents:
- Risk related to autonomous systems
- Cyber risk
- Advanced methods in risk analysis, including event sequence diagrams (ESD) and event trees (ETA), fault tree analysis (FTA), Bayesian networks (BN)
- Hybrid Causal Logic (HCL) modeling
- The modules are given as lectures, exercises, project work, and self-tuition.

Practical Work:
project work

Industry collaboration:
Guest lectures will be given by industry partners on experience with risk management in autonomous operations.

Key skills acquired:
After completing this course the students shall be able to:
- Understand the challenges related to risk analysis for autonomous systems, including cyber risk.
- Analyze risk by use of the HCL method.
- Use applicable software.

Assessment:
Written or oral exams.

Recommended texts:
Lecture notes, journal articles, conference papers, text books, and assignment texts.

Marine Control Systems, specialization course			
Credits: 7.5 Semester 3 Compulsory: Yes			
Format weekly	Lectures 4	Practicals: 4	Private study: 4
Lecturers: Department of marine technology			

Objectives:
The objective of the course is to provide a general knowledge on autonomy in subsea operations using underwater vehicles. Two modules, each 3.75 ECTS, have to be selected, which are related to Underwater robotics in safe and autonomous subsea operations (3.75 ECTS), and marine mechatronics (3.75 ECTS).

Contents:
- Mathematical modelling of underwater vehicle manipulator systems for autonomous operations
- Sensor systems for navigation and localization
- Basics of autonomy in marine robotics
- Risk envelopes for autonomous operations
- Specialized vessels for underwater operations
- Underwater operations

Practical Work:
Field work with research vessel R/V "Gunnerus", environmental surveys, seabed mapping, underwater operations. Data acquisition and processing.

Industry collaboration:
Guest lectures will be given by collaborators from the industry. Specifically focus on experience on the use of underwater vehicles and sensors.

Key skills acquired:
After completing this course the students shall be able to:
- Perform field work
- Have knowledge of sensors for autonomous operations
- Navigation and localization in autonomous operations
- Modeling for autonomy of marine robots
- Risk handling

Assessment:
Written or oral exam.

Marine Control Systems, specialization project
Credits: 7.5 Semester 3 Compulsory: Yes
Department of marine technology

Objectives:
The student shall further in the project develop the ability to get familiar with a specific topic within marine control systems by the use of scientific methods. This includes collecting information and gaining insight by studies of relevant literature and other sources of information, and combining this information with his/her own knowledge.
Moreover, the student shall be trained in carrying out an extensive project, by developing a project plan with milestones, reporting intermediate results of his/her work and completing a project report according to recognized standards.
The project will consist of theoretical studies and analysis, computer-based simulations and in some cases experimental work.
The project work may be the basis for the MSc thesis.

Contents:
The topic for the project thesis and the chosen combination of subjects should be consistent. The supervisor of the project thesis should approve the choice of subjects.
The students have to attend a mandatory introduction seminar to the project thesis beyond the established ECTS. The seminar consists of lectures and assignments which has to be passed for the students to be allowed to hand in the project thesis. The content of the seminar prepares the student for writing their thesis; such as searching for literature, writing reports, scientific publishing and ethics.

Key skills acquired:
After having completed the introduction seminar to the project thesis the student shall:
- Know and understand the importance of ethical research practices.
- Be able to take an active role in their own skills development and learning.
- Understand the importance of conducting thorough literature reviews.
- Be able to perform detailed scientific literature reviews, including searching in literature databases.
- Be acquainted with the desirable quality and content of independent research.
- Be able to conduct accurate report writing, and thesis preparation.
- Know how to increase the effectiveness of their individual research.
- Know how to write concise scientific reports, including structuring, referencing, and avoiding plagiarism.
- Manage their project schedule and resources, managing expectations and change.
- Be able to define a project description and project plan.

Assessment:
3-4 mandatory exercises. 4 h exams.

Recommended texts:
Guideline for writing report and lecture notes.
Background material to be agreed with supervisor.

Recommended texts:

- Hegde, Jeevith; Utne, Ingrid Bouwer; Schjølberg, Ingrid; Thorkildsen, Brede.
- A Bayesian approach to risk modeling of autonomous subsea intervention operations. Reliability Engineering & System Safety 2018 ; V 175. s. 142-159
- Hedge, Jeevith, Utne, Ingrid B., Schjølberg, Ingrid. Development of collision risk indicators for autonomous subsea inspection maintenance and repair. Journal of Loss Prevention in the Process Industries 2016 (44) s. 440-452
- Haugaløkken, Bent Oddvar Arnesen; Jørgensen, Erlend Kvinge; Schjølberg, Ingrid.
- Experimental Validation of End-Effector Stabilization for Underwater Vehicle-Manipulator Systems in Subsea Operations. Robotics and Autonomous Systems 2018 ;V 109. s. 1-12
- Schjølberg, Ingrid; Gjersvik, Tor Berge Stray; Transeth, Aksel Andreas; Utne, Ingrid Bouwer.
- Next Generation Subsea Inspection, Maintenance and Repair Operations. IFAC-PapersOnLine 2016 ; V. 49.(23) s. 434-439,
- Jørgensen, Erlend Kvinge; Johansen, Tor Arne; Schjølberg, Ingrid.
- Enhanced Hydroacoustic Range Robustness of Three-Stage Position Filter based on Long Baseline Measurements with Unknown Wave Speed. IFAC-PapersOnLine 2016 ; V 49.(23) s. 61-67
- Eidsvik, Ole Alexander; Haugaløkken, Bent Oddvar Arnesen; Schjølberg, Ingrid.
- SeaArm - A Subsea Multi-Degree of Freedom Manipulator for Small Observation Class Remotely Operated Vehicles. I: 2018 European Control Conference (ECC). IEEE 2018 ISBN 978-3-9524-2698-2. s. 983-990
- Allmendinger, E. E., A. Society of Naval and E. Marine (1990). Submersible vehicle systems design. Jersey City, N.J, Society of Naval Architects and Marine Engineers.
- Brighenti, A. (1990). "Parametric analysis of the configuration of autonomous underwater vehicles." Oceanic Engineering, IEEE Journal of 15(3): 179-188.
- Gade, K. (2005). "NavLab, a generic simulation and post-processing tool for navigation."
- Hegrenaes, O., T. O. Sabo, P. E. Hagen and B. Jalving (2010). Horizontal mapping accuracy in hydrographic AUV surveys. Autonomous Underwater Vehicles (AUV), 2010 IEEE/OES.
- Jalving, B. (1999). Depth accuracy in seabed mapping with underwater vehicles. Oceans '99. MTS/IEEE. Riding the Crest into the 21st Century. Conference and Exhibition. Conference Proceedings (IEEE Cat. No.99CH37008).
- K. B. Anonsen, O. K. Hagen, O. Hegrenaes and P. E. Hagen (2013). The HUGIN AUV terrain navigation module. 2013 OCEANS - San Diego.
- Ludvigsen, M. and A. J. Sørensen (2016). "Towards integrated autonomous underwater operations for ocean mapping and monitoring." Annual Reviews in Control 42: 145-157.
- Sørensen, A. J., F. Dukan, M. Ludvigsen, D. De Almeida Fernandes and M. Candeloro (2012). Development of Dynamic Positioning and Tracking System for the ROV Minerva.
- Further Advances in Unmanned Marine Vehicles. G. N. Roberts and R. Sutton. Stevenage, UK Institution of Engineering and Technology: 113-128.

Decision making under uncertainty for autonomous systems			
Credits: 7.5 Semester 3 Compulsory: Yes			
Format weekly	Lectures 4	Practicals: 4	Private study: 4
Lecturers: Assoc Prof A. Lekkas			

Objectives:
This specialization course will present an introduction to autonomous robots from both the academic and industrial viewpoints. For the academic part, emphasis will be given to recent advances in deep reinforcement learning, which combines deep neural networks with reinforcement learning to provide a framework for discovering suitable control actions (policies) and addressing complex tasks without explicit programming. For the industry-focused lectures, aspects of artificial intelligence and autonomous robotics systems will be considered from industrial domain perspectives as inspection and maintenance.

Contents:
- Definition of autonomy. A brief description of the modules comprising autonomy. An overview of recent developments within robotics.
- An introduction to reinforcement learning and its connection with dynamic programming. Value iteration and policy iteration algorithms for optimal policies in discrete environments.
- Demonstration of how deep reinforcement learning can be used for controlling continuous systems. Case studies using highly-nonlinear models of marine vessels, drones, and robotic manipulators will be used.
- Artificial intelligence in autonomous robotics systems: what is an actionable definition in an industrial setting. Different levels of autonomy. Hierarchical architecture (Sense-plan-act and behavior based substrates) and autonomy layers. A control theory approach to planning and action – Model Predictive Control.
- Autonomous mobile robotics systems – environment perception vs mission sensors, localization and mapping, navigation and sense & avoid. Considerations on implementing autonomous systems in industrial applications as: system integration, ethics concerns, solutions fit to existing organization and systems, data management and intellectual property aspects.
- An application of AI to autonomous decision making in a technical and industrial context.

Practical Work:
A number of assignments, where the goal will be to get practical experience on the presented algorithms, will be given. Guidance sessions will also be carried out.

Industry collaboration:
A number of lectures will be given by industry. Specifically, related to autonomous operations offshore and subsea.

Key skills acquired:
After completing this course the students shall be able to:
- Understand the main modules required for designing an autonomous system.
- Understand the role machine learning can play in increasing the level of autonomy.
- Improve their skills in machine learning by getting hands-on experience with state-of-the-art algorithms
- Become familiar with the challenges of deploying an autonomous system in an industrial setting.

Assessment:
3-4 mandatory exercises. 4 h exams.

Recommended texts:

- R.S. Sutton and A.G. Barto. Reinforcement Learning:An Introduction. Second Edition, in progress. MIT Press, Cambridge, MA, 2017
- Wiering, Marco, and Martijn van Otterlo, eds. Reinforcement Learning: State-of-the-Art. Vol. 12. Springer Science & Business Media, 2012.
- Puterman, Martin L. "Markov Decision Processes: Discrete Stochastic Dynamic Programming (Wiley Series in Probability and Statistics)." (2005)
- Russell, Stuart J., and Peter Norvig. Artificial intelligence: a modern approach. Malaysia;Pearson Education Limited, 2016.
- A collection of papers, which is updated annually.

Research-based Innovation Methodologies in Computer and Information Science			
Credits: 7.5 Semester 3 NTNU Compulsory: No			
Format weekly	Lectures 2	Practical 10	Private study
Lectures: Assoc Prof B. A. Farshchian, Assoc Prof E. Parmiggiani			

Objectives:
The candidate will acquire knowledge of: basics of design of scientific studies, principles for selection of data collection and analysis methods, basic definitions of research-based innovation.

Contents:
The course will give insight in the most important challenges for research and innovation methods in computer science, as well as theories of science. Challenges of research design and presentation of results will be covered. The course gives insight in the most used empirical research methods: Case studies, design science and surveys, with emphasis on qualitative methods. The course will also teach students to conduct methodological hypothesis testing in a given market.
Lectures, self-study, group-based individual assignments.

Practical Work:
group-based individual assignments

Key skills acquired:
- Planning and conducting research projects.
- Collecting and analyzing research data.
- Foreseeing and reducing threats to validity of research designs.
- Critically evaluate the quality of qualitative studies in computer science.
- Conduct empirical studies.

Assessment:
100% coursework

Recommended texts:
Articles and book which will be presented at the start of the semester.

* Choose one of three.

SEMESTER 3

IST-UL, PORTUGAL

STUDY TRACK 3:
Cooperative marine robotics for scientific and commercial applications

TÉCNICO LISBOA

SEMESTER 3 - STUDY TRACK 3: COOPERATIVE MARINE ROBOTICS FOR SCIENTIFIC AND COMMERCIAL APPLICATIONS - IST-UL, PORTUGAL

Summary

We are entering a new era where the use of groups of autonomous marine robots working in cooperation, networked via aerial, acoustic, and optical links will dramatically improve the means available for ocean exploration and exploitation at unprecedented temporal and spatial scales. New theoretical frameworks and cutting-edge technologies are required to bring about this revolution in the field of marine robotics, “leveraging on the transformative advances and growth of the fields of machine learning and artificial intelligence”. This leap forward will hinge on the availability of a new breed of research engineer with the capacity to master the concepts and techniques required to design, implement, and field test advanced systems for multiple robotic vehicle operations, with a view to increase the safety, efficiency, and efficacy of operations at sea in a multitude of scientific and commercial scenarios.

At the core of the systems required for cooperative multiple vehicle operations are those in charge of cooperative motion planning with temporal and energy cost criteria, cooperative navigation and control, and networked operations that are often enabled via acoustic communication links that exhibit low bandwidth and are plagued with latency and temporary communication losses. The study track proposed by IST-UL, entitled Cooperative Marine Robotics for Scientific and Commercial Applications, leverages on the know-how and experience of its staff members, and aims to afford students the expertise required to advance R&D in this challenging and promising area of work.

The study track includes a number of modules that are key to the design and implementation of advanced robotic systems, effectively bringing together tools from a number of fields that include autonomous systems, optimization theory, computational systems, distributed decision and control systems, and computer communications. The students will be given the opportunity to select, for their MSc dissertation, one topic out of a pool of multifaceted topics addressing challenging problems in the general area of cooperative robotic systems.

Summary table of IST-UL study track modules

Module Title	Number of Teaching hours	Total ECTS 30
2nd Cycle Integrated Project in Electrical and Computer Engineering	14	6 (mandatory)
Artificial Intelligence and Decision Systems	49	6 (mandatory)
Control of Cyber-Physical Systems	49	6 (mandatory)
Image Processing and Vision	49	6 (mandatory)
Real-Time Systems	49	6 (option*)
Performance Evaluation and Dimensioning of Networks and Systems	49	6 (option*)
High Speed Networks	49	6 (option*)
Portuguese as a foreign language	weekly	-

SEMESTER 3 - STUDY TRACK 3: COOPERATIVE MARINE ROBOTICS FOR SCIENTIFIC AND COMMERCIAL APPLICATIONS - IST-UL, PORTUGAL

Analytical module description

2nd Cycle Integrated Project in Electrical and Computer Engineering		
Credits: 6 Semester 3 IST-UL Compulsory: Yes		
Format (hours)	Tutorial hours 14	Private study 154

Contents:
The project is initially defined by the supervisors or under the supervisors´ guidance. It can be carried out individually or in groups, and take place at IST or outside IST (universities, research centers or companies). The following modalities are possible:

- Scientific project: an in-depth and academically rigorous analysis of a scientific, technological or management challenge. May include experimental and/or computational work.
- Company project: individual project focused on a specific challenge posed by a host company that requires a solution or analysis targeted for short term implementation.
- SCOPE project: multidisciplinary team work based on real and complex problems/challenges posed by companies or other institutions that require inputs from students from different courses of IST or the University of Lisbon.

Objectives:
The integrated project may fall within one of three modalities: 1. Scientific project, 2. Company project and 3. SCOPE project. Learning objectives will depend on the specific project, but in general students should:

- apply the knowledge acquired during their degree to undertake a project of a scientific, technological or management nature.
- extend their knowledge to areas not covered in their degree.
- search, obtain, compile and summarize information (scientific, technical, legislation, interviews, polls) relevant to the project - plan and execute experiments, analyse and interpret data, develop mathematical models, perform computer simulations
- develop Critical and Innovative Thinking, Intrapersonal and Interpersonal Skills. - write and orally present and discuss a technical report.

Assessment:
For project types 1 and 2 a report must be submitted for evaluation and discussion by a juri of (at least) two professors.

Recommended texts:

- Depend on the project.

Artificial Intelligence and Decision systems		
Credits: 6 Semester 3 IST-UL Compulsory: Yes		
Format (hours)	Theoretical and Practical 49	Private study 119
Lecturers: Assist. Prof. Rodrigo Ventura		
Contents: Introduction to Artificial Intelligence. Intelligent Agents. Rational Agents. Environment properties. Agents' architectures. Problem solving. Search methods: non-informed and informed, heuristics. Adversarial search. Constraint satisfaction problems. Knowledge representation and reasoning. Propositional logic, and first-order logic. Quantification. Inference. Resolution. Planning, PDDL, GraphPlan. Uncertainty. Bayesian networks, Decision Theory, Markov models.		
Objectives: Provide background on basic notions about fundamental methodologies in the field of Artificial Intelligence. Introduce the concept of intelligent agent. Study methods of problem solving, knowledge representation and reasoning, planning and inference under uncertainty. Understand the techniques used in decision systems, covering both symbolic and probabilistic approaches.		
Assessment: 50% continuous, 50% non-continuous evaluation.		
Recommended texts: Artificial Intelligence: A Modern Approach: Stuart Russell, Peter Norvig, Pearson Int., Third Edition		

Control of Cyber-Physical Systems			
Credits: 6 Semester 3 IST-UL Compulsory: Yes			
Format (hours)	Theoretical 28	Laboratorial 21	Private study 119
Lecturers: Prof João Lemos and Assist Prof Pedro Batista			

Contents:

- Part 1 - Models and identification: Linear models in Computer Control and the Z transform. Sampling. Introduction to the stability of discrete linear systems. Noise models and interaction between linear systems and stochastic processes. ARX and ARMAX models. System identification and parameter estimation by least squares and maximum likelihood. Recursive Identification.
- Part 2 - Controllers Design: Design of linear controllers for deterministic pole placement systems and reference model. Robustness cionditions. Dynamic programming and discrete time LQG control. Linear prediction. Stochastic control of linear systems (minimum variance and minimum detuned variance). State estimation. Adaptive control. Fault tolerant control.

Objectives:

After successfully attending this course, students will be able to identify mathematical models for dynamic systems and, based on them, design computer-based controllers, integrating physical and computational systems.

Assessment:

50% continuous, 50% non-continuous evaluation.

Recommended texts:

- Digital Control of Dynamic Systems. G. F. Franklin, J. D. Powell and M. Workman. Addison Wesley, 3rd ed., 1998.
- Computer Controlled Systems. K. J. Astrom and B. Wittenmark. Prentice Hall, 3rd ed. 1997.

Image Processing and Vision			
Credits: 6 Semester 3 IST-UL Compulsory: Yes			
Format (hours)	Theoretical 28	Practical 21	Private study 119
Prof José Santos-Victor			

Contents:

- Motivation and Introduction;
- Camera Model: Image acquisition/formation, projective model, camera calibration;
- Image alignment: Image transformations, point correspondence and robust estimation (RANSAC);
- Stereo Vision / 3D reconstruction: Geometry of triangulation, Essential and Fundamental Matrices, 3D reconstruction;
- Image Processing: Topological relations, Image operations, Linear/Non-linear filtering;
- Optical flow: Camera motion, motion field and optical flow computation;
- Image features: Concept of image feature, Hough Transform, keypoints (SIFT);
- Segmentation and object recognition: Introduction to image segmentation and object recognition concepts

Objectives:
Introductory techniques for image analysis and 3D perception from images. Introduce geometric models for imaging devices and key visual processes to extract information from images: image filtering, feature extraction, matching, motion analysis and 3D reconstruction. Basic techniques and references for object recognition.

Assessment:
50% continuous, 50% non-continuous evaluation.

Recommended texts:

- Computer Vision: Algorithms and Applications: Richard Szeliski, 2010, Springer,http://szeliski.org/Book/
- Multiple View Geometry: Richard Hartley and Andrew Zisserman, 2004, Cambridge Ac Press

Real-Time Systems			
Credits: 6 Semester 3 IST-UL Compulsory: No			
Format (hours)	Theoretical 28	Laboratoria 21	Private study 119
Lecturers: Assist Prof Carlos Almeida			

Contents:
Introduction to embedded systems and real-time systems. Types of real-time systems. Temporal restrictions: source and characterization; problems associated with incorrect temporal behaviour. Paradigms for state capture: event-triggered and time-triggered; characterization; implementation using interrupt routines and a multitasking kernel. Scheduling concepts: models of tasks with explicit temporal restrictions; task scheduling taxonomy. Periodic task scheduling: cyclic static scheduling; dynamic task scheduling using fix and dynamic priorities. Aperiodic/sporadic task processing: fixed priority servers; dynamic priority servers. Access to shared resources: priority inversion problem; priority inheritance; priority ceiling protocols. Real-time operating systems: internal structures of multitasking kernels; task management. Other applications of real-time scheduling: traffic scheduling in shared buses; task scheduling on multiprocessors.

Objectives:
Familiarization with embedded and real-time systems, including aspects related to specification, implementation and test.

Assessment:
50% continuous evaluation, 50% non-continuous evaluation.

Recommended texts:
- Real-time Operating Systems Book 1: The Theory (The engineering of real-time embedded systems): Jim Cooling, 2019. Independently published.
- Real-time Operating Systems Book 2 - The Practice: Using STM Cube, FreeRTOS and the STM32 Discovery Board (The engineering of real-time embedded systems): Jim Cooling, 2017. Independently published

Performance Evaluation and Dimensioning of Networks and Systems			
Credits: 6 ECTS Semester 3 IST-UL Compulsory: No			
Format (hours)	Theoretical 28	Laboratorial 21	Private study 119
Lecturers: Prof Rui Valadas			

Contents:

- Stochastic modelling and queuing systems: discrete and continuous-time Markov chains, renewal and Poisson processes, Little's law, PASTA property, Markovian queues, M/G/1 queue, traffic models.
- Simulation of discrete events: programming techniques, generation of distributions and stochastic processes, statistical analysis of simulation results.
- Server farms: task assignment policies, dimensioning.
- Network performance evaluation: models for multiple access, packet scheduling, routing in packet and circuit-switched networks, congestion control, and service guarantees; economic principles of traffic management.
- Optimization: mathematical programming models for network and system optimization involving routing, dimensioning, traffic protection, server location, and critical node detection; heuristic algorithms.

Objectives:

To address the problem of resource management in computer networks and systems, introduce the main techniques of performance analysis and dimensioning (stochastic modelling, discrete event simulation and optimization) and their use in the context of networks and systems. Students must acquire the following skills: (i) be able to evaluate the performance of networks and services; (ii) be able to efficiently dimension networks and services using optimization techniques; (iii) understand the performance/cost tradeoff in the resource management of networks and services; (iv) be able to apply queuing theory in network performance analysis and understand its limitations; (v) be able to properly handle network and service simulators. The course aims at training performance and planning engineers.

Assessment:

50% continuous, 50% non-continuous evaluation.

Recommended texts:

- Performance Modeling and Design of Computer Systems, Mor Harchol-Balter, 2013, Cambridge University Press.
- Simulation Modeling and Analysis, Averill M. Law, 5th edition, 2014, McGraw-Hill Education.
- Routing, Flow, and Capacity Design in Communication and Computer Networks, Michal Pióro, Deepankar Medhi, 2004, Morgan Kaufmann.
- Data Networks, Dimitri Bertsekas, Robert Gallager, 2nd edition, 1992, Prentice-Hall.

High Speed Networks			
Credits: 6 ECTS Semester 3 IST-UL Compulsory: No			
Format (hours)	Theoretical 28	Practical 21	Private study 119
Lecturers: Assist Prof João Pires			

Contents:

- Introduction: Functions of a telecommunications network; Transmission, multiplexing and switching; Traffic and services; Landmarks on telecommunications evolution
- Network fundamentals: Network characterization (physical and logical topologies, traffic modelling); Routing algorithms and capacity dimensioning; Network planes and classification
- Service networks: Telephone and cellular networks; Ethernet and IP/MPLS networks; CATV networks; Data centres structure and interconnections
- Transport Networks: Network synchronism; Basic aspects of SDH; Optical Transport Networks; Optical network elements; Network protection; Planning optical transport networks
- Access networks: Structure of conventional access networks; X-DSL broadband networks; Optical network access architectures; Access network dimensioning

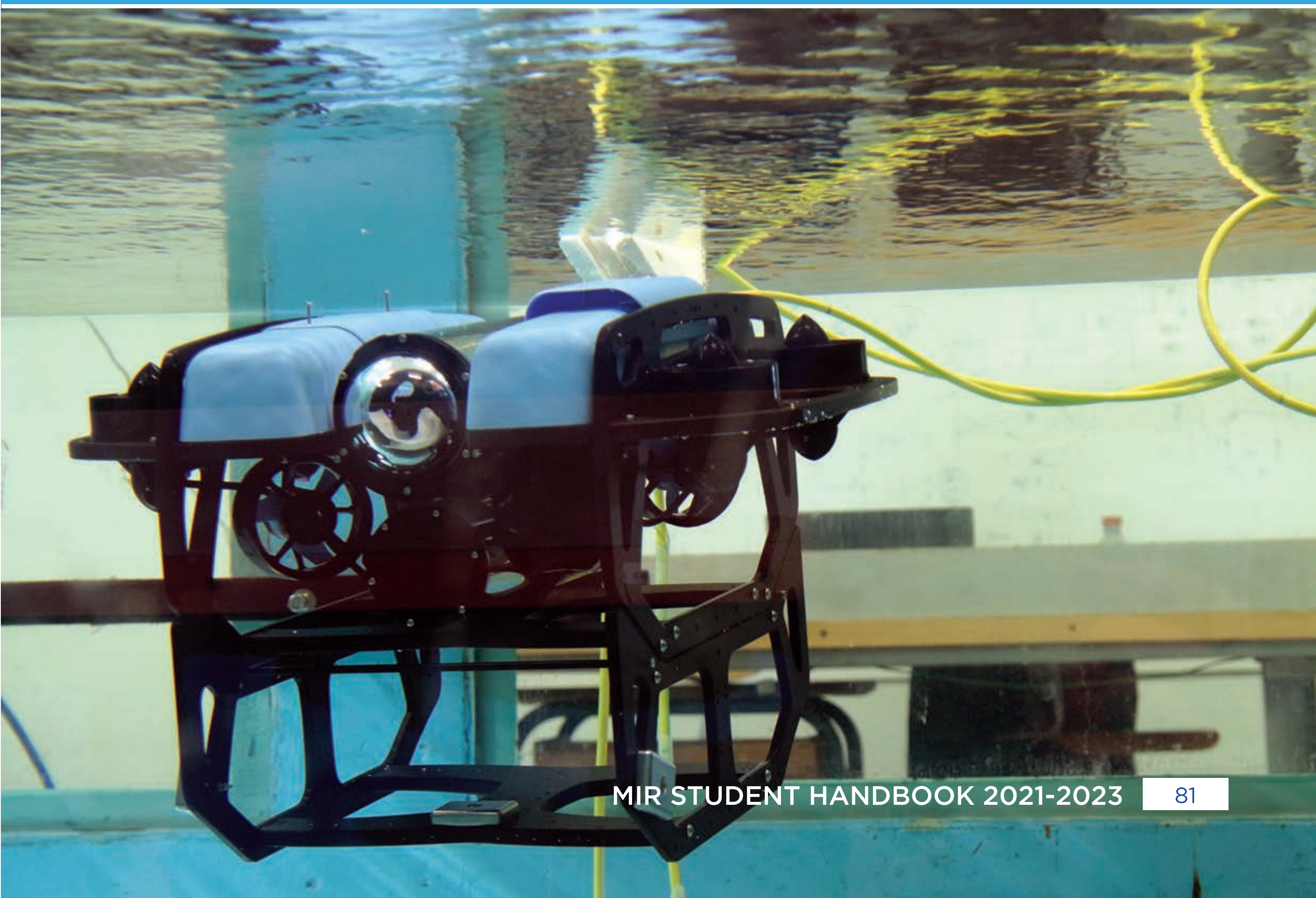
Objectives:
Introduce some of the fundamental concepts of high speed telecommunication networks and provide a general and integrated overview of these networks. Study the network technologies and architectures. Introduce methodologies for planning and performance analysis.

Assessment:
50% continuous, 50% non-continuous evaluation.

Recommended texts:

- Sistemas e Redes de Telecomunicações, João Pires, IST 2006
- Next Generation Transport Networks, M. Ellanti, S. Gorshe, L. Raman, W. Grover, Springer 2005
- FTTX concepts and applications, Gerd Keiser, John Wiley& Sons, 2006
- Course slides provided by the lecturer

SEMESTER 4
Thesis



SEMESTER 4 (30 ECTS)

MIR Thesis

Thesis work is an integral part of the MIR Master programme and is credited for 30 ECTS. All students undertake their thesis work during the fourth semester. During the 4th semester, students carry out their thesis research or internship in accordance with the regulations of their host institution. Each student will be jointly supervised by a minimum of two supervisors from two different institutions (the principal supervisor being from the hosting programme partner institution). Students can conduct their thesis at associated academic partner institutions, however, the students' principal supervisor will be from one of the 4 programme partner institutions. Students also have the possibility and are encouraged to conduct their thesis as part of an internship with one of the numerous associate industry partners of the consortium. In this case a student is assigned one industry supervisor and at least one academic supervisor, who will be the main supervisor. The principal supervisor has to be from one of the main partner universities of the MIR programme. IST can have a maximum of 2 supervisors so in the case of an industry or associate partner co-supervision, the 2nd main partner role will be of voluntary informal participation.

Students work independently albeit under supervision of their thesis supervisors and when relevant their industry promoters. The MSc thesis will be written and examined in accordance with the formal requirements set out by the S4 hosting main partner institution. The other institution will then recognize the completion of the MSc thesis at the institution where it was formally written. This does not exclude representatives of the partner institutions to be part of the examination process.

Thesis selection

In the beginning of February of the first academic year MIR students are provided with a provisional thesis research lines catalogue, jointly developed by IST, NTNU, UJI and UTLN. The thesis research lines catalogue enables students to find a thesis research line (broad topic area) that suits their interests and is relevant to their study track. Students can contact potential thesis supervisors and finalise a research topic from the catalogue associated with their study track.

Students can also suggest their own thesis topics by making use of an electronic form on the MIR website.

Thesis project descriptions include a title, an abstract, a work plan, contact details of supervisor and, if applicable, the industrial promoter, and an agreement of the industrial promoter to welcome the student for the particular thesis subject. During the 1st year Annual Symposium, thesis topics will be reviewed for approval by the MIR.

Thesis topic selection is determined in S3 at the latest.

Thesis preparation

Students can start with the preparation of the thesis (for example literature review, introduction, etc) during the second and third semesters. However, this must not interfere with the students other courses in these semesters. In principle, the fourth semester is fully available for the thesis work and submission. Therefore, these activities have to be supervised by the thesis supervisors. A minimum of 6 individual tutoring hours per student are foreseen during the 4th semester. The students will be encouraged to organise their thesis work in a way that enables them to submit the thesis in the first session exam period. During their studies, students receive guidance on research methods and scientific writing providing the necessary skills to prepare their thesis proposal and conduct their thesis to the highest scientific standards.

Thesis format

The thesis report must be written in English and should ideally have the format of a scientific publication. Precise guidance on thesis format and evaluation procedures will vary according to the regulations of each hosting institute.

The final written dissertation developed in the scope of the MSc programme shall not contain missing fragments and must consist in a coherent text, all of this aiming at the dissertation fulfilling the following requirements: (1) being the basis for the attribution of the degree; (2) being an adequate public statement of the reasons for the attribution of degree.

In the case where confidentiality clauses are stipulated by the nature of the subject or the potential industry partner, these will be regulated according to the thesis hosting/ principal supervisor institutes regulations.

Thesis defence

Within the framework of the MIR Consortium, the local rules of each institution apply for the assessment of the MSc. In addition to defending their thesis at the partner institution of the principal supervisor and hosting institution, students also present and discuss their results at the MIR Annual Symposium.

Precision regarding Thesis Mobility for Students in Study Track 2

Regarding study track 2 EMJMD scholarship holder students, half of them will do their thesis and be hosted at NTNU and the other half at UTLN. Attribution of mobility location and supervisor in Semester 4 will be determined based on thesis topic approved and following the decision of the Joint Management Committee in June of Semester 2.

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