UNIVERSITÀ DEGLI STUDI DI PALERMO

DEPARTMENT	Ingegneria
ACADEMIC YEAR	2022/2023
MASTER'S DEGREE (MSC)	ELECTRICAL ENGINEERING
SUBJECT	MOBILE AND DISTRIBUTED ROBOTICS
TYPE OF EDUCATIONAL ACTIVITY	C
AMBIT	20923-Attività formative affini o integrative
CODE	21526
SCIENTIFIC SECTOR(S)	ING-INF/04
HEAD PROFESSOR(S)	FAGIOLINI ADRIANO Professore Associato Univ. di PALERMO
OTHER PROFESSOR(S)	
CREDITS	6
INDIVIDUAL STUDY (Hrs)	96
COURSE ACTIVITY (Hrs)	54
PROPAEDEUTICAL SUBJECTS	
MUTUALIZATION	MOBILE AND DISTRIBUTED ROBOTICS - Corso: CYBER-PHYSICAL SYSTEMS ENGINEERING FOR INDUSTRY MOBILE AND DISTRIBUTED ROBOTICS - Corso: INGEGNERIA DEI SISTEMI CIBER-FISICI PER L'INDUSTRIA
YEAR	1
TERM (SEMESTER)	1° semester
ATTENDANCE	Not mandatory
EVALUATION	Out of 30
TEACHER OFFICE HOURS	**FAGIOLINI ADRIANO** Tuesday 16:00 20:00 - Edificio 10, Viale delle Scienze, Ufficio Docente- Canale Teams

DOCENTE: Prof. ADRIANO FAGIOLINI

PREREQUISITES	Basic knowledge of Physics (in particular of Mechanics and Electromagnetism), Vector and matrix calculus fundamentals (sum, scalar and vector product, property of matrix operations, matrix determinant, trace, and eigenvalues), System Theory (state form, inputs, outputs, transfer functions), notions of automatic controls (simple proportional compensation networks, integral, derivative).
LEARNING OUTCOMES	The student will learn concepts and skills along the following lines: • basic knowledge and understanding: modeling of some physical systems characterized by non-linear dynamic behavior, analysis of the stability of equilibria, characterization of the non-linear controllability and observability properties of such systems, design of a stabilizing controller using the Lyapunov technique; • applied knowledge and understanding: identification and analysis of the kinematic constraints of a mobile robot, as well as derivation of kinematic and dynamic models with physically accessible state and inputs, design of a non-linear controller (static and dynamic) and evaluation of the validity local and global, modeling of a distributed robot and design of collaborative and decentralized control laws for coordination, training, and obstacle avoidance; • independent judgment: assessment of the actual goodness of a model and the controller adopted and identification of any necessary corrections; • communication skills: multidisciplinary collaboration with colleagues from their degree course and other courses, with experts and users of robots, through clear and concise expressions on the requirements, problems and advantages deriving from the use of such a robot ; • ability to learn (learning skill): ability to continue the study of existing and new robotic systems.
ASSESSMENT METHODS	The exam consists of the development and oral presentation of a project. The project is to be carried out in teams from home and consists of the study of one or more topics covered in the course and the realization of a demonstration using the mathematical and software tools introduced in the class. The topic of the project is agreed upon with the teacher during the course (at the beginning of the 3rd month of the course). The exam aims at assessing the technical competencies, the expression ability, and the correct use of technical jargon, as well as the student’s critical reasoning in the subject under study.
EDUCATIONAL OBJECTIVES	The first educational objective of the course is to provide the theoretical tools for the study of non-linear dynamic models, for the design of non-linear controllers, in conditions of nominal knowledge of the model, and for their validation with respect to model disturbances and uncertainty. As a second objective, the course aims to introduce some main software tools (Matlab / Simulink, ROS, Gazebo) for the simulation, implementation and verification of applications with mobile and distributed robots.
TEACHING METHODS	Class lessons, works, and laboratory
SUGGESTED BIBLIOGRAPHY	• Dispense fornite dal docente / Lecture notes provided by the teacher • L. Sciavicco, B. Siciliano, L. Villani, G. Oriolo, Robotica, McGraw-Hill, 3 a edizione, 2008, ISBN: 883866322X • Hassan K. Khalil , Nonlinear Systems, 3° edizione, Prentice Hall, ISBN: 9780130673893

SYLLABUS

Hrs	Frontal teaching
2	1.1 "Introduction to Mobile Robotics". Applications in the industry and for services.
3	1.2 "Recalls of analysis of nonlinear dynamic systems". State forms. Equilibria and stability. Lyapunov's methods, Babarshin-Krasovskii's Theorem. Variable gradient method. Invariant Sets and Krasovskii-Lasalle's Theorem. Limit Cycles.
5	1.3 "Control tools for nonlinear dynamic models". Lyapunov Control Functions. Backstepping. SISO exact input-output linearization.
6	1.4 "Wheeled Robots". Nonholonomic systems and canonical forms. Unicycle vehicles (kinematic and dynamic models, point-to-point motion control, control law for path following and trajectory tracking). Car-like vehicles (rear and front traction, rear and front reference kinematic models, dynamic models, controllers for path following and automatic parking).
4	2.1 "Race-cars". Mechanics of the wheel and tyre. Tire slips. Magic formula. Components of the vehicle model (kinematics, road-tyre interaction, load transfers, first-order suspension, insights on braking). Single track model (nonlinear). Linear control for constant forward speed and/or lateral wind gusts. Double track model. Control of roll motion and lateral velocity. Model predictive control (MPC) for classes of trajectories. Optimal trajectory planning (minimum length, minimum curvature, mixed solutions).
6	2.2 "Autonomous Aircrafts". Applications. Mechanics, underactuation, and dynamic model of a quadrotor. Linear cascade control of attitude and position at hovering. Recalls of nonlinear controllers for tracking acrobatic trajectories.
4	3.1 "Distributed Robots". Recalls on graph theory. Message-based cooperation. The linear consensus algorithm. Coordination for rendez-vous, coverage, and formation control. Voronoi partitions.

SYLLABUS

Hrs	Frontal teaching
2	3.2 "ROS (Robot Operating System)". Software architecture. MAVLINK protocol. Programming with Matlab/ Simulink and Software In The Loop (SITL).
4	3.3 "Advanced mathematical analysis and control tools. Reachability and observability for nonlinear systems, Lie products and brackets, involutive distributions. MIMO exact input-output linearization. Adaptive control and online parameter estimation. Backstepping adaptive control.
6	4.1 "Robots with embodied intelligence". Modeling of soft robots with pneumatic and electric actuation, in agonistic-antagonistic configurations. Robust and adaptive control of soft robots. Joint stiffness estimation via actuation-side and link-side approaches. Insights into Cartesian stiffness estimation.

Hrs	Practice
2	Stability analysis of equilibria for nonlinear systems of 2nd and 3rd order. Direct Lyapunov's method applied to wheeled mobile robots.
2	Model predictive control (MPC) of race-cars in TORCS. Quadrotors control in Matlab/Simulink.
2	Hardware in the loop emulation of control systems with ROS/Gazebo and fast prototyping boards (Arduino, ST-microelectronics, Raspberry).