PhD Program in Bioengineering and Robotics

Curriculum: Robotics and Autonomous Systems

Research themes

The main goal of the PhD curriculum in *Robotics and Autonomous Systems* is to study, design and build novel solutions and behaviors for robots, teams of robots and, in general, autonomous systems capable of exhibiting a high degree of autonomy and intelligence when performing highly complex tasks in challenging real-world environments.
The focus of the curriculum is two-fold: on the one hand, on key, innovative and disruptive methodologies and technologies, including such topics as sensing, state estimation, knowledge representation, software architectures for robots, real-time scheduling, motion planning, advanced robot control, robot coordination and cooperation, human-robot interaction and collaboration, design of macro/micro robot systems, design of sensors and actuators; on the other hand, on specific areas, e.g., underwater operations, aerial and space, or Industry 4.0, as well as on such diverse application scenarios as manufacturing, material handling and transportation, search & rescue, surveillance and monitoring, ambient assistive living). The curriculum enforces research practices and education methodologies based on cutting-edge best practices at the international levels, and all the aspects outlined above are dealt with by focusing on the study and the adoption of theoretically sound methodologies and the design of experimentally verifiable solutions, with the goal of meeting robustness and predictability requirements even in unknown, dynamically changing, or even hazardous environments. The ideal candidates are students with a higher-level University degree, with a strong desire for investigating, designing and developing robot-based systems which can have a huge, disruptive, impact on the society in the upcoming future.

International applications are strongly encouraged and will receive logistic support with visa issues and relocation.

Adaptive Emotional Planning for Social Robots in Sensitive Human Contexts

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Project Description

Social robots are promising tools as long-term companions and assistants in sensitive human contexts, such as healthcare, elderly care, and inclusive education. However, in these domains, i.e., with vulnerable users, Human–Robot Interaction requires not only technical robustness, but also social intelligence, emotional awareness, and the ability to act in ways that are understandable, predictable, and supportive.

For example, social robots have demonstrated great potential in assisting people affected by neurodegenerative diseases [1]. Previous works indicate that this kind of robot can reduce caregiver workload, promote positive emotions, and improve users' well-being. However, to be effective, these systems must be equipped with empathetic, context-aware interaction strategies. This is particularly true when dealing with critical situations such as delusions, which are common in Alzheimer's disease and involve misinterpretations of reality (e.g., beliefs of theft, infidelity) [2]. Clinical practice shows that supportive strategies based on emotional validation and gentle redirection are appropriate in this context.

Moreover, in this scenario, emotions play a fundamental role: they can be used for goal selection, decision-making, and for defining the most appropriate social behavior. As it happens in humans, emotional processes can be considered to regulate interactions, anticipate consequences, and respond appropriately to complex situations. Social robots operating in close interaction with humans, especially in assistive contexts, may integrate emotional mechanisms into planning and decision-making [3].

For all these reasons, the project aims to combine:

- emotional planning and decision-making mechanisms, inspired by models of human affective cognition, with
- perception and reasoning modules capable of detecting emotionally salient situations, such as delusional statements or signs of distress, or other types of relevant situations, and selecting appropriate supportive responses.

In the proposed PhD project, emotions will be considered not only as outputs of the robot but also as internal drivers, influencing action selection and interaction strategies. For example, if the robot detects a delusional belief, the robot should not only recognize the situation but also reason about its emotional implications and choose a response strategy that supports the user's well-being.

The project will build upon existing work in affective computing and socially assistive robotics, extending it through the development of an emotion-based planning architecture that allows the robot to reason over alternative strategies and adapt its responses based on emotional context and the history of the interaction. The proposed architecture will be implemented on a humanoid social robot (e.g., NAO, Pepper, or Navel) and evaluated in representative interaction scenarios

Requirements:

Applicants are expected to have good programming skills (C++, Java, or Python) and a profound interest in cutting-edge research in autonomous robotics. Previous experience

with Artificial Intelligence techniques and Human-Robot Interaction strategies will be considered.
When applying for the Ph.D. scholarship, the student will be encouraged to propose solutions to address one or more of the aspects described in the proposal.

References:

[1] Karami, V., Yaffe, M. J., Gore, G., Moon, A. J., & Abbasgholizadeh Rahimi, S. (2024). Socially Assistive Robots for patients with Alzheimer's Disease: A scoping review. Archives of Gerontology and Geriatrics, 123, 105409. https://doi.org/10.1016/j.archger.2024.105409

[2] Rao, V., & Lyketsos, C. G. (1998). Delusions in Alzheimer's Disease. Journal of Neuropsychiatry and Clinical Neurosciences, 10(4), 373–382. https://doi.org/10.1176/jnp.10.4.373

[3] Maroto-Gómez, M., Alonso-Martín, F., Malfaz, M., Castro-González, Á., Castillo, J. C., & Salichs, M. Á. (2023). A systematic literature review of decision-making and control systems for autonomous and social robots. International Journal of Social Robotics, 15(5), 745–789. https://doi.org/10.1007/s12369-023-00977-3

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LLM- and RAG-Based Approaches for Diversity-Aware Social Robots in Education

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Project Description

According to a broadly accepted definition, "diversity is about what makes each of us unique and includes our backgrounds, personality, life experiences and beliefs, all of the things that make us who we are. (...) Diversity is also about recognizing, respecting, and valuing differences based on ethnicity, gender, age, race, religion, disability, and sexual orientation. (...) Inclusion occurs when people feel, and are valued and respected regardless of their personal characteristics or circumstance (...) Equal opportunity means that every person can participate freely and equally in areas of public life (...) without disadvantage or less favorable treatment due to their unique attributes." [1].

On the other hand, social robotics has recently shown its potential applications both as a powerful tool in the educational sector, to help, among other things, children learn a second language or support children with special educational needs, but also as an instrument for inclusion, thanks to the development of robots that may consider the different cultural backgrounds (e.g., social norms, preferences, religious habits) of people during interaction [2].

For all these reasons, the main goal of this PhD program lies in the development of human–robot interaction strategies that leverage initial information about users to implement interaction patterns that are aware of diversity, with a particular focus on the educational field. In this context, the program foresees the use of generative language models (LLMs), potentially through fine-tuning, which can be employed both to improve user understanding and task evaluation, as well as to achieve smoother, more varied, and user-adaptive interactions.

Indeed, in AI and robotics research, significant efforts have been made to tackle the challenge of personalizing robots to suit individual needs. One strategy is to employ machine learning techniques that periodically gather and analyze large datasets in order to gain deeper insights into the person and their environment. Other common approaches include robots that interact with diverse groups using a priori knowledge and behave in a way that is most likely to work for the majority of users, rather than explicitly adapting to individual differences. This latter approach has typically been followed in the educational sector, where diversity awareness has so far been limited mainly to the cultural dimension [3].

This PhD program aims to overcome the current limitations at the state of the art by developing a software framework for social robots in the educational sector that can be truly diversity-aware, combining a priori knowledge with the learning and adaptation capabilities offered by LLMs. In particular, the framework will incorporate Retrieval-Augmented Generation (RAG) mechanisms to support persistent, structured, and context-aware memory management.

More specifically, RAG-based approaches will be used to equip the robot with a long-term, dynamic memory of interaction-relevant information, such as individual learning profiles, interaction history, preferences, cultural references, and teacher-provided contextual knowledge.

In the educational context, this memory-aware architecture is particularly crucial, as it allows the robot to maintain continuity across repeated interactions with the same learners and teachers, and adapt its communicative strategies over time based on observed needs and responses.

By integrating RAG-based memory management with LLM-driven interaction capabilities, the proposed framework aims to support both short-term adaptivity and long-term personalization, with robotic systems embedded in real classroom practices and aligned with pedagogical goals.

References:

[1] The Victorian Government commitment to diversity and inclusion (D&I), https://bit.ly/3DbTzlJ

[2] Papadopoulos, C., Castro, N., Nigath, A., Davidson, R., Faulkes, N., Menicatti, R., ... & Sgorbissa, A. (2022). The CARESSES randomised controlled trial: exploring the health-related impact of culturally competent artificial intelligence embedded into socially assistive robots and tested in older adult care homes. *International Journal of Social Robotics*, *14*(1), 245-256.

[3] Kim, Y., Marx, S., Pham, H. V., & Nguyen, T. (2021). Designing for robot-mediated interaction among culturally and linguistically diverse children. *Educational Technology Research and Development*, *69*, 3233-3254.

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Social robots for domestic assistance: perception, planning, and adaptive interaction

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Project Description

Social robots are increasingly considered a promising solution for supporting people in domestic environments, particularly in the context of aging populations and the growing demand for autonomous living assistance. Robots such as Pepper by SoftBank Robotics combine communication capabilities, mobility, and multimodal sensing, making them suitable platforms for long-term interaction with users in home environments [1]. Recent advances in Vision-Language Models (VLMs) now make it possible to envision robots capable not only of interacting socially with humans, but also of autonomously understanding and reasoning about the state of their environment in order to support users in everyday activities.

The objective of this thesis is to develop a cognitive architecture for a social robot based on Pepper or a similar social robot, capable of perceiving and understanding a domestic environment through multimodal sensing and VLMs, reasoning on the state of the world through symbolic planning techniques, and autonomously executing and monitoring plans in dynamic environments.

A first component of the project will concern the use of VLMs for extracting semantic information from observations acquired through the robot's sensors. Recent VLM architectures have demonstrated remarkable capabilities in scene understanding, object recognition, visual question answering, and semantic grounding [2]. In the proposed system, these models will be used to identify objects, infer their likely locations, recognize relevant environmental conditions, and build symbolic representations of the environment suitable for high-level reasoning.

A second component will focus on automatically instantiating the domain and problem definition of a PDDL-based symbolic planner from the semantic information extracted by the perception system. The robot will therefore be able to generate planning problems dynamically from observations of the environment and user requests [3]. The planner will then compute sequences of actions aimed at achieving specific goals while considering environmental constraints and the current state of the world.

The thesis will also address the execution and monitoring of plans. In particular, the robot will execute planned actions while continuously monitoring their outcome through sensor observations. Changes in the environment, failures during execution, or unexpected user actions may invalidate the assumptions of the current plan. In such situations, the robot will update the symbolic representation of the environment, reformulate the planning problem, and autonomously replan [4]. Particular attention will be devoted to the integration of perception, symbolic reasoning, action execution, and human-robot interaction into a coherent adaptive architecture.

The proposed framework will be validated in domestic-assistance case studies involving older adults living independently. One scenario will concern user-triggered assistance functionalities, such as helping users remember where objects are likely located based on previous observations acquired by the robot. For example, the user may ask the robot where a pair of glasses, a medicine box, or a mobile phone was last observed. The robot will combine semantic memory, probabilistic reasoning, and symbolic planning to search for the object and guide the user accordingly.

A second scenario will concern event-triggered assistance in emergency situations. For example, the robot may detect that the user answered the doorbell or telephone while forgetting to switch off the gas cooker. In such situations, the robot will autonomously reason about the evolving state of the environment, plan appropriate intervention strategies, interact verbally with the user, and possibly execute actions aimed at reducing risk conditions.

Requirements: The ideal candidate is a robotic scientist or a computer engineer with previous experience in robot software architectures, artificial intelligence, computer vision, machine learning, symbolic planning, and human-robot interaction.

References:

[1] Pandey A.K., Gelin R., A mass-produced sociable humanoid robot: Pepper: The first machine of its kind, IEEE Robotics and Automation Magazine, 25(3), pp. 40–48, 2018.

[2] Radford A. et al., Learning Transferable Visual Models From Natural Language Supervision, Proceedings of the 38th International Conference on Machine Learning (ICML), 2021.

[3] Ghallab M., Nau D., Traverso P., Automated Planning: Theory and Practice, Morgan Kaufmann, 2004.

[4] Kaelbling L.P., Lozano-Pérez T., Hierarchical Task and Motion Planning in the Now, IEEE International Conference on Robotics and Automation (ICRA), 2011.

[5] Brohan A. et al., RT-2: Vision-Language-Action Models Transfer Web Knowledge to Robotic Control, Proceedings of the 7th Conference on Robot Learning (CoRL), 2023.

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Autonomous quadruped robots: new challenges in hostile and unstructured environments

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Project Description

While wheeled robots were the predominant choice for outdoor navigation and exploration in the past, legged robots with varied kinematics and locomotion capabilities are now gaining popularity. These robots are increasingly favored for their ability to operate in complex environments where traditional wheeled robots are ineffective [1]. They are especially useful in scenarios such as emergency interventions in natural or environmental disasters and the inspection of industrial plants, with potential applications in other areas as well.

Consider, for example, a large solar plant that needs inspection for potential damage. Typically, this task is performed using flying drones. However, drones have limitations concerning the resolution of images taken from above and cannot inspect areas obscured beneath solar panels. In such cases, a quadruped robot equipped with a manipulator arm could efficiently explore the area and possibly take preliminary action before human operators are directly involved, such as removing vegetable residues that can clog the solar panels.

In light of this general scenario, where autonomous navigation and interaction capabilities are crucial, the thesis will focus on the quadruped robot Spot by Boston Dynamics, integrated with a manipulator. The goal will be to investigate how a legged mobile manipulator can autonomously perceive, navigate, plan, and act in hostile and unstructured environments.

The thesis will explore strategies for managing all the necessary aspects that enable Spot to exhibit fully autonomous behavior aimed at locomotion, navigation, perception, and manipulation—from sensor acquisition to controlling the robot's kinematics and dynamics to perform observations and interact with the environment. Particular attention will be devoted to the integration of perception, high-level decision making, locomotion control, and manipulation skills into a coherent autonomous architecture.

A further objective will be to investigate the use of Vision-Language-Action models (VLAs) for planning sequences of actions given multimodal sensor data and task objectives. VLA models such as RT-2 have been proposed to connect visual perception, language-conditioned reasoning, and robotic action generation within a unified framework [4]. In this project, such models may be exploited to transform sensor observations, semantic scene descriptions, and mission goals into sequences of navigation and manipulation actions, while delegating low-level execution to dedicated locomotion and manipulation controllers.

The development and training process will also consider the use of NVIDIA Isaac Sim and Isaac Lab. Isaac Sim provides physically based robotic simulation, testing, and synthetic data generation capabilities, while Isaac Lab is designed to support robot-learning workflows such as reinforcement learning, learning from demonstrations, and motion planning [5]. These tools may be used to build realistic simulated environments, generate training data, train locomotion and manipulation policies, evaluate VLA-based action planners, and support sim-to-real transfer before deployment on the physical Spot platform.

These aspects will require investigating the robot's capabilities in terms of autonomous perception, locomotion, and manipulation in various scenarios, including rocks, grass, sand, garbage, pipes, narrow passages, cluttered industrial areas, and steep slopes, both uphill and downhill. This, in turn, raises theoretical and technological issues that go beyond the typical problems faced by wheeled manipulators in indoor, office-like environments [2], including whole-body loco-manipulation and the possibility to "pedipulate" objects with legs [3]. The student will have the opportunity to address these challenges by proposing original solutions that advance beyond the current state of the art.

Requirements: The ideal candidate is a robotic scientist or a computer engineer with previous experience in legged robot locomotion, software architectures and simulation of legged robots, kinematics and dynamics control for manipulation, and machine-learning methods for robot perception, planning, and control.

References:

[1] Bazeille S., Barasuol V., Focchi M., Havoutis I., Frigerio M., Buchli J., Caldwell D.G., Semini C., Quadruped robot trotting over irregular terrain assisted by stereo-vision, Intelligent Service Robotics, 7(2), pp. 67–77, 2014.

[2] Hooks J., Ahn M.S., Yu J., Zhang X., Zhu T., Chae H., Hong D., ALPHRED: A Multi-Modal Operations Quadruped Robot for Package Delivery Applications, IEEE Robotics and Automation Letters, 5(4), pp. 5409–5416, 2020.

[3] Arm P., Mittal M., Kolvenbach H., Hutter M., Pedipulate: Enabling Manipulation Skills using a Quadruped Robot's Leg, arXiv:2402.10837.

[4] Zitkovich B. et al., RT-2: Vision-Language-Action Models Transfer Web Knowledge to Robotic Control, Proceedings of the 7th Conference on Robot Learning, PMLR 229, pp. 2165–2183, 2023.

[5] Mittal M. et al., Isaac Lab: A GPU-Accelerated Simulation Framework for Multi-Modal Robot Learning, arXiv:2511.04831, 2025.

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Sensing, Perception and Control for Human-Robot Physical Interaction

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Description:
Human-robot interaction (HRI) is a key research topic in collaborative robotics, assistive systems, service robotics, and industrial automation. Robots are expected to operate in unstructured and shared environments where safe, adaptive, and intuitive interaction with humans is required. The proposed PhD activity aims to contribute to the development of next-generation collaborative robotic systems capable of natural, safe, and intelligent interaction with humans. The project is expected to generate scientific contributions in robotics sensing, AI-enhanced perception, and physical interaction control, leveraging the expertise developed at the University of Genoa (UNIGE) within the recent European projects *COLLABORATE* and *SESTOSENSO*. The candidates can choose to focus one or more of the following research threads:

1. Design of Proximity and Tactile Sensors

- Large-area distributed tactile and proximity sensing skins for robot bodies.
- Miniaturized tactile sensors for robot hands and dexterous manipulation.
- Flexible and soft sensing technologies.
- Embedded electronics and real-time data acquisition systems.
- Sensor calibration, robustness, and reliability.

2. Physical Interaction Control

- Compliant and impedance/admittance control strategies.
- Human-robot collaborative manipulation.
- Robot-robot cooperative interaction.
- Sensor fusion for interaction-aware control.
- Safety and adaptive control in shared environments.

3. AI-Based Tactile and Proximity Perception

- AI methods for tactile and proximity gesture recognition.
- Touch-based object recognition and classification.
- Proximity-based exploration of the robot surrounding space.
- Deep learning and multimodal sensor fusion.

Self-supervised and adaptive learning approaches for HRI.

Requirements:
The ideal candidate should possess:

- Strong background in robotics, control systems, embedded systems, or machine learning.
- Knowledge of programming languages such as C/C++, Python, and MATLAB/Simulink.
- Familiarity with robotic frameworks and middleware (e.g., ROS/ROS2).
- Basic knowledge of tactile sensing technologies, signal processing, or AI methods for perception is appreciated.
- Experience in experimental robotics and hardware/software integration is considered a plus.
- Good analytical skills, autonomy in research activities, and motivation for interdisciplinary research.

Good written and spoken English.

References:

Grella F., Albini A., Cannata G., Maiolino P. (2025) IEEE International Conference on Automation Science and Engineering, pp. 1998 - 2004.
Borelli S., Giovinazzo F., Albini A., Grella F., Cannata G. “Generating Whole-Arm Avoidance Motion Through Localized Proximity Sensing” (2025) IEEE/ASME Transactions on Mechatronics, 30 (5), pp. 3988 - 3999.
Giovinazzo F., Grella F., Sartore M., Adami M., Galletti R., Cannata G., “From CySkin to ProxySKIN: Design, Implementation and Testing of a Multi-Modal Robotic Skin for Human–Robot Interaction” (2024) Sensors, 24 (4).

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Multi-drone load transportation

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Project Description

The use of multiple Unmanned Aerial Vehicles (UAVs) opens new possibilities for exploring a wide range of applications in complex and dynamic environments. These include cooperative task assignments such as large-scale area monitoring, search and rescue operations, infrastructure inspection, and precision agriculture. Beyond observation and surveillance, multi-UAV systems also enable advanced coordination tasks such as formation flight and collaborative manipulation [1].

In such cooperative missions, the development of novel control strategies becomes essential, particularly when the system consists of multiple quadrotors connected to a common payload through flexible rods or cables [2][3]. These mechanical couplings introduce additional dynamics and constraints that significantly increase the complexity of the overall system, requiring controllers capable of handling underactuation, coupling effects, and time-varying disturbances.

Using more UAVs enables heavier payload transport over longer distances while distributing effort among agents, reducing individual energy consumption and extending mission endurance. However, cooperative transportation also introduces challenges such as coordinated takeoff and landing, recovery from UAV failures [2], maintaining stable formation control under disturbances, and autonomous reconfiguration based on sensor feedback.

Requirements:

- Classical Control/Optimal Control
- State estimation and Filtering
- familiarity with ROS/ROS2 environment
- C++/Python
- Matlab/Simulink
- PX4 (optional)

References:

[1] D. K. D. Villa, A. S. Brandão, R. Carelli and M. Sarcinelli-Filho, "Cooperative Load Transportation With Two Quadrotors Using Adaptive Control", in IEEE Access, vol. 9, pp. 129148-129160, 2021, doi: 10.1109/ACCESS.2021.3113466.
[2] A. Delbene and M. Baglietto, "On Formation Control Strategies in a Failure-Prevention Scenario for Multi-UAV Payload Transportation," 2025 IEEE 21st International Conference on Automation Science and Engineering (CASE), Los Angeles, CA, USA, 2025, pp. 185-191, doi: 10.1109/CASE58245.2025.11163951.
[3] M. Tognon, C. Gabelleri, L. Pallottino, A. Franchi, “Aerial Co-Manipulation with Cables: The Role of Internal Force for Equilibria, Stability, and Passivity”, IEEE Robotics and Automation Letters, vol. 3 no. 3, pp. 2577-2583, 2018, doi: 10.1109/LRA.2018.2803811.

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