PhD Program in Bioengineering and Robotics

Curriculum: Robotics and Autonomous Systems

Research themes

INTERNATIONAL APPLICATIONS ARE STRONGLY ENCOURAGED AND WILL RECEIVE LOGISTIC SUPPORT WITH VISA ISSUES AND RELOCATION. 1

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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.

Hierarchical, multi-domain reasoning models for autonomous robots

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Project Description

In the past few years, we have witnessed the rise of advanced reasoning capabilities in intelligent systems based on Large Language Models (LLMs). When used with robots, such models are subject to significant constraints. Among them, the availability of appropriate datasets, the embedding of robot-specific capabilities, the resulting model size, the ability to reason about multiple – yet related – domains, and inference time. At TheEngineRoom, we explored the use of fine-tuned LLMs to generate robot plans which actions can be streamlined and executed while the plan is being generated. This allows us to simultaneously plan and execute actions, with relevant capabilities in terms of sensorimotor, in-the-loop replanning. The fine-tuning process is based on synthetic data generated using optimal or heuristic PDDL-compatible logic-based planners, which ensure that logic constraints are implicitly encoded in the resulting model via examples. Our first model, which we refer to as Teriyaki [1], suffers from two major limitations. The first is the use of a “big”, cloud-based LLM, which hinders the embeddability of the overall robot software architecture. The second is the fact that Teriyaki can only generate intrinsically single-domain reasoning models. While the first limitation has been partially addressed in our second reasoning model, called Gideon, which is based on a “small” LLM, the need arises to work on a principled, second iteration of Teriyaki characterized by the following capabilities:

1) small memory footprint, with the purpose of embedding the model into computational machinery aboard the robot’s body, which requires the use of small LLMs;

2) inference time compatible with robot operations in real-world environments to enforce sensorimotor, in-the-loop continuous re-planning;

3) hierarchical reasoning, whereas a full hierarchy of reasoning models can be orchestrated, possibly using a specifically designed reasoning model, or in fully decentralized mode;

4) multi-domain reasoning, whereas each model is capable of reasoning on one or more (related) domains, depending on the context.

Relevant scenarios will be those where mobile robots must carry out tasks involving the (location-specific) manipulation of objects, and their transportation to other locations. While high-level reasoning will be based on approaches aimed at fine-tuning LLMs to generate a hierarchy of multi-domain reasoners, low-level robot motions will be achieved using Vision-Language-Action models, such as for example OpenVLA [2].

The work to be done may include at least the following activities:

- Analysis of state-of-the-art literature to understand current approaches and limitations in hierarchical architectures for robots, and in the use of LLM-based reasoning models.
- Design and synthesis of a fully LLM-based, hierarchical robot architecture, for example taking inspiration from previous work done at TheEngineRoom [3].

- Design and implementation of software tools to obtain domain- and robot-specific, synthetic data, related to the reasoning domains of interest.
- Implementation of interacting multi-domain reasoning models.
- Unit and system testing in a selected number of scenarios.

Requirements:

[1] A. Capitanelli, F. Mastrogiovanni. A framework for neurosymbolic robot action planning using Large Language Models. Frontiers in Neurorobotics 18, 1342786, 2024.

[2] M. J. Kim, K. Pertsch, S. Karamcheti, T. Xiao, A. Balakrishna, S. Nair, R. Rafailov, E. Foster, G. Lam, P. Sanketi, Q. Vuong, T. Kollar, B. Burchfiel, R. Tedrake, D. Sadigh, S. Levine, P. Liang, C. Finn. OpenVLA: an open-source vision-language-action model. arXiv:2406.09246, 2024.

[3] H. Karami, A. Thomas, F. Mastrogiovanni. A task and motion planning framework using iteratively deepened AND/OR graph networks. Robotics and Autonomous Systems 189, 104943, 2025.

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Dual Arm Manipulation for human-robot cooperative operations

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Project Description

Collaborative robots (COBOTS) are used in industrial and service applications to accomplish tasks where human-robot cooperation (i.e. sharing a common space) or collaboration (i.e. physically interacting to complete a common action) is required. Between the different approaches to perform Human-Robot Cooperation, Bi-manual or multi-arm manipulation becomes the predominant technique for this type of applications. The advantages of implementing Bi-manual or Dual arm manipulation (DAM) refers to the ability of transfer the skill of the human entity-operator to the robot in a more intuitive way, and in dual arm coordinated tasks, the use of dual arm manipulation allows to combine the task flexibility and dexterity of serial links, with the stiffness and strength of parallel manipulation while holding objects. (closed chain mechanism).

The PhD project has the goal to implement a dual arm/Bi manual control approach for coordinated tasks, while overcoming the principal issues when performing dual-arm manipulation, such as generating feasible configurations connected through each other (motion planning), internal forces acting while arms are holding objects, manipulators breaking and reinitializing contact with a common object(regrasping), among others.

The experimental scenario is based on a dual-arm robot (sensorized using cameras, tactile and proximity sensors) mounted on a mobile platform for assistive or domestic applications, sharing the space with a human operator to complete a series of operations involving contact of the robot with the environment

Requirements:

Applicants must have a good knowledge of robotics fundamentals and robot programming. Applicants are also expected to have good programming skills (possibly including Python, C/C++, Matlab/Simulink), confidence with electronic hardware and be capable to conduct experiments, and a strong attitude to problem solving

References :

Zhang, J., Xu, X., Liu, X., & Zhang, M. (2018, December). Relative dynamic modeling of dual-arm coordination robot. In *2018 IEEE International Conference on Robotics and Biomimetics (ROBIO)* (pp. 2045-2050). IEEE.

Wang, J., Liu, S., Zhang, B., & Yu, C. (2019). Inverse kinematics-based motion planning for dual-arm robot with orientation constraints. *International Journal of Advanced Robotic Systems*, *16*(2), 1729881419836858.

Xian, Z., Lertkultanon, P., & Pham, Q. C. (2017). Closed-chain manipulation of large objects by multi-arm robotic systems. *IEEE Robotics and Automation Letters*, *2*(4), 1832-

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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 capabilities are crucial, the thesis will offer the student the freedom to explore one or both of the following options:

- Using the quadruped robot SPOT by Boston Dynamics, equipped with a custom manipulator.
- Using the lighter quadruped robot GO1 from Unitree.

In both cases, the thesis will explore strategies for managing all the necessary aspects that enable a quadruped to exhibit fully autonomous behavior aimed at locomotion, navigation, and manipulation—from sensor acquisition to controlling the robot's kinematics and dynamics to perform observations and interact with the environment.

These aspects will require investigating the robot's capabilities in terms of autonomous perception and locomotion in various scenarios, including rocks, grass, sand, garbage, pipes, 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 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.

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 (2014) Intelligent Service Robotics, 7 (2), pp. 67 – 77

[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, (2020) IEEE Robotics and Automation Letters, 5 (4), art. no. 9134727, pp. 5409 - 5416

[3] Philip Arm, Mayank Mittal, Hendrik Kolvenbach, Marco Hutter, Pedipulate: Enabling Manipulation Skills using a Quadruped Robot's Leg, arXiv:2402.10837

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Aerial Drones for Monitoring Large Photovoltaic Plants

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Project Description

This PhD position, fully funded by the University of Genova, will perform research in parallel with SOLARIS European project (https://solaris-heu.eu/) in which the University of Genova is involved. SOLARIS aims to foster the development and integration of Photovoltaic (PV) systems in Europe and beyond. The project focuses on developing and demonstrating a comprehensive set of physical and digital tools for improved forecasting, operational performance, and maintenance, resulting in high-performance indices (90%) and availability (>98%) of PV plants.

Among other functionalities, SOLARIS will equip operators with automated multispectral PV inspection using drones. The University of Genoa will **develop strategies that enable drones to inspect PV plants more efficiently and reliably, operating in complete autonomy**. Please notice that the University of Genoa has gained relevant experience in this field from previous collaborations [1] To address these issues, the PhD candidate will explore GPS-based navigation as well as innovative real-time visual segmentation and servoing techniques for navigation and control, addressing current limitations in the state of the art [2]. This includes the capability to fly at variable heights from the ground (providing higher resolution images) and accommodating scenarios where PV panels may not be parallel to the terrain. Furthermore, the candidate will investigate path planning and optimization techniques [3] to ensure that the path taken by drones over PV panels maximizes the number of panels inspected on a single charge.

More specifically, for navigation and control, the candidate will explore solutions based on real-time visual segmentation and servoing, combined with GPS navigation for navigating between PV rows. The following steps are expected to be considered: 1) Real-time segmentation of PV panels from acquired images. 2) Utilization of filtering techniques (e.g., Extended Kalman Filter) to merge visual information obtained in successive steps, reducing the impact of errors in image segmentation. 3) Visual servoing to maintain drone alignment along PV panel rows while maintaining a forward velocity. All these developments will first be validated using drone simulation and visualization software (NViz & Gazebo).

For path optimization, the candidate will explore innovative solutions, with the following steps expected to be considered: 1) Satellite image acquisition: obtaining georeferenced satellite images, such as those from Copernicus ; 2) PV panel and PV panel row segmentation through an ML tool, trained with a large dataset of satellite images (e.g., Detectron) to accurately segment PV panels and PV panel rows from the image background. 3) Subarea clustering: to simplify the subsequent optimization problem, subareas in the PV plant will be clustered by identifying subsets of PV panel rows and waypoints that can be inspected with a single battery charge. 4) Optimization: solving a Traveling Salesman Problem for each subarea.

Requirements: The ideal candidate is a robotic scientist or a computer engineer with a strong background in programming and control. Previous experience with aerial drones will be positively considered.

References:

[1] Morando, L., Recchiuto, C.T., Calla, J., Scuteri, P., Sgorbissa, A. Thermal and Visual Tracking of Photovoltaic Plants for Autonomous UAV Inspection, (2022) Drones, 6 (11).

[2] Aghaei, M.; Dolara, A.; Leva, S.; Grimaccia, F. Image resolution and defects detection in PV inspection by unmanned technologies. In Proceedings of the 2016 IEEE Power and Energy Society General Meeting (PESGM), Boston, MA, USA, 17–21 July 2016; pp. 1–5. 15.

[3] X. Luo, et al., "Optimal path planning for UAV based inspection system of large-scale photovoltaic farm," in Proc. of the CAC. Jinan, PRC: IEEE, Oct. 2017, pp. 4495–4500.

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LLM-Based approaches for diversity awareness applied to social robots in the educational sector

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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 the other things, children learn a second language or to deal with children's special needs, but also as an instrument for inclusion, thanks to the development of robots that may consider the different cultural background (e.g., social norms, preferences, religious habits) of persons during the 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, potentially through fine-tuning of generative language models (LLMs), 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 (ML) techniques that periodically gather and analyze vast datasets, with the goal of gaining deeper insights into the person and their environment, but common approaches also include robots that interact with diverse groups and people using a priori knowledge and behave in a way that is most likely to work for most people it interacts with, rather than trying to adapt to individual differences. This approach has been usually followed in the education sector, where, however, diversity-awareness has been so far limited to the cultural dimension [3].

his PhD program aims at overcoming the current limitations at the state-of-the-art, by developing a software framework for social robot in the educational sector that can be really diversity-aware, combining a priori knowledge with the learning and adaption capability offered by LLM. The software framework is expected to be deployed in various contexts, including interaction with children with diverse developmental needs.

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] 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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Multiparty Human-Robot Interaction

Tutors: Carmine Tommaso Recchiuto

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Project Description: In recent years, the field of Human-Robot Interaction (HRI) has increasingly shifted from dyadic, one-on-one interactions to more complex multiparty settings, where multiple humans and multiple robots engage in verbal communication. Such scenarios are particularly relevant in domains like education, healthcare, and collaborative work, where robots are expected to function not as isolated tools but as **socially aware agents** capable of managing group dynamics, turn-taking, attention, and conversational context.

Verbal interaction in these settings presents unique challenges, including **speaker identification, role recognition, coordination across participants, and the maintenance of coherent dialogue threads** across different agents. As an example, accurately identifying the active speaker may involve combining audio and visual cues developing smoother interactions in environments where multiple participants speak in rapid succession or simultaneously [1].

The main goal of this PhD program lies in the development of ***multi-robot***, ***multi-users*** interaction strategies, capable of understanding the active speaker, but also the person(s) or robot(s) whom the person is addressing during the interaction, so that the robot(s) can properly interpret conversational intent and respond appropriately. Moreover, the robots should be able to correctly interpret speech, so that it can intervene only when it is appropriate, and respond in ways that are contextually appropriate and socially sensitive [2, 3]. Finally, the presence of **multiple robotic agents** adds an additional layer of complexity, requiring each robot to manage its own role in the dialogue while being aware of the contributions and actions of the others.

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] Appiani, A., & Beyan, C. (2025). VAD-CLVA: Integrating CLIP with LLaVA for Voice Activity Detection. *Information*, *16*(3), 233.

[2] Moujahid, M., Hastie, H., & Lemon, O. (2022, March). Multi-party interaction with a robot receptionist. In *2022 17th ACM/IEEE International Conference on Human-Robot Interaction (HRI)* (pp. 927-931). IEEE.

[3] Grassi, L., Recchiuto, C. T., & Sgorbissa, A. (2023, October). Robot-induced group conversation dynamics: a model to balance participation and unify communities. In *2023 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)* (pp. 3991-3997). IEEE.

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Multi-drone load transportation

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Project Description

The use of multiple Unmanned Aerial Vehicles (UAVs) offers the possibility to study different applications in complex environments, from cooperative task assignments such as monitoring wide areas to formation control and cooperation for a mutual goal, including autonomously transporting a payload [1].

New controlling techniques should be developed for a system composed of multiple UAVs (quadrotors) transporting a payload by flexible rods [2][3].

Utilizing more agents enables carrying heavier payloads during mid to-long-term missions, reducing battery energy consumption per robot in the team. Despite these advantages, cooperative transportation poses several challenging situations, which can be explored related to (among others): coordinated takeoff and landing, recovery strategies in case of a UAV failure, cooperative formation control and reconfiguration basing on onboard sensors.

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.

[2] K. Sreenath, V. Kumar, "Dynamics, Control and Planning for Cooperative Manipulation of Payloads Suspended by Cables from Multiple Quadrotor Robots", Robotics: Science and Systems, 2013.

[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.

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