I-RIM

PhD Course in ROBOTICS AND INTELLIGENT MACHINES

Curriculum: Robotics and Intelligent Machines for Hostile and unstructured environments

Research themes

The main goal of the curriculum "Robotics and Intelligent Machines for Hostile and unstructured environments" is to address problems related to the study and development of enabling technologies and complex systems that will allow robots and intelligent machines to work in situations where the environment is dynamic, partially or totally unknown, hard to predict in advance, and possibly very challenging. The general objective of the curriculum is to form scientists and research technologists capable of working in multidisciplinary teams on projects where the interaction with a complex environment play a crucial role in technological development and design.

The eight fellowships offered this year by the Istituto Italiano di Tecnologia, Università degli Studi di Catania, Università degli Studi di Genova, Università degli Studi di Milano-Bicocca, and Università di Pisa in cooperation with Bosch as part of this curriculum will be assigned to the best applicants to each of the eight themes offered.

Theme number 1 addresses the problem of developing new learning capabilities for robots. The assumption is that a robot endowed with rich sensory systems should be informed by the law of physics that governs the physical world. Therefore, learning can be made more efficient by leveraging temporal or spatial regularities in the training data.

Theme number 2 addresses the problem of obstacle detection and tracking for robotic vehicles moving on the sea surface and below the sea surface, a problem which is made very complex by the fact that the sea is a harsh and hostile environment due to limited visibility and adverse weather conditions.

Theme number 3 aims to advance the capabilities of commercial robots (e.g., vacuum cleaning and lawn mowers) to operate in open contexts without human intervention. The goal will be to provide formally grounded model-based design strategies that can accommodate the

ability of the robot to learn from previous mistakes to avoid difficult situations while navigating the environment more effectively to perform their tasks.

Theme number 4 addresses the problem of validation and verification of autonomous systems in complex environments, by studying model-driven approaches and to develop a complete toolchain to model and develop software with adaptive deliberation functions that incorporate formal verification from the lowest level (i.e. components and middleware) up to the deliberative level (task models, i.e. finite state machines or behavior trees).

Theme number 5 explores interactions with humans and other agents in unstructured environments, which typically pose high challenges due to the variety of conditions and sensory limits such as occlusions and limited FOV. The work will focus on the study and development of systems that can perceive others' states and predict their actions, intentions, and beliefs.

Theme number 6 has the objective of designing and building a new generation of soft bio-robots with growing abilities capable of exploring and acting in extreme environments (e.g., the soil) for several applications, including agriculture, remediation, or digging.

Theme number 7 will investigate soft robotics' principles and fundamental nature to design and develop functional devices that embody part of their control logic in the form of "mechanical intelligence," with application in various fields ranging from collaborative industrial robotics to prosthetics.

Theme number 8 addresses autonomous navigation for mobile robots in unstructured environments such as volcanoes, agriculture fields, and caves, requiring specific methodologies for properly executing tasks, including perception and decision-making.

The ideal candidates are students with a higher level university degree willing to invest extra time and effort in blending into a multidisciplinary team. Depending on the theme selected, a specific competence in computer vision and machine learning (themes 1, 2, 4, 5, and 8), formal methods and software architectures (theme 3), control theory, mechatronics, and robot design (themes 6 and 7), as well as the capability to design and evaluate experiments with people (theme 5) may play an important role.

The students will perform their research project at the Hosting Institution (described in the research project sheet).

International applicants are encouraged and will receive logistic support with visa issues, relocation, etc.

1. AI methods for Robots in Unstructured Environments – Italian Inst. of Technology

Curriculum: Hostile and unstructured environments

Hosting Institution
Istituto Italiano di Tecnologia

Department:
Humanoid Sensing and Perception
https://www.iit.it/it/web/humanoid-sensing-and-perception

Tutor(s):
Lorenzo Natale, Massimiliano Pontil

Description:

AI and Machine Learning methods are particularly useful for robotics in all applications in which it is difficult to obtain accurate models of the environment, the robot body and its sensors. Examples include visual and tactile perception, but also control in complex, scenarios and unstructured environment, such as dexterous manipulation of unknown or deformable objects or agile locomotion. The application of modern AI methods remain however limited to those cases in which computing power is not an issue, and large datasets are available, either through online datasets, rendering or simulation. Training is often performed off-line, with a strong separation between exploration and exploitation. Although the state-of-the-art has been progressing at a constant pace, today's performances are still insufficient to guarantee that robots can perceive and react effectively and adaptively in dynamic environments. In such situations, however, robotics offers opportunities that can be leveraged to ease learning. Robots operate in the physical world, in which object interactions are governed by the laws of physics. They interact with the environment to actively extract training data, in absence or with partial human intervention. Finally, robots are endowed with rich sensory systems, and can sense the world through their body using, diverse and redundant, sensory modalities.

In this project we seek to advance learning capabilities of robots that operate in unstructured environments, by developing new machine learning algorithms that are more efficient and robust leveraging on temporal or spatial regularities in the training data, knowledge acquired while solving different tasks or structure in the data that can be derived from the integration of different sensory modalities, as well as the robot embodiment. Topics include:

- Machine learning and continual learning in robotics for object and scene perception;
- Active and self-supervised strategies for efficient learning and knowledge transfer;
- Multi-modal learning;
- Reinforcement learning techniques with application to object grasping and in-hand object manipulation using visual and tactile feedback;
- Bio-inspired, event-driven sensing and efficient learning architectures algorithms for perception.

Requirements:

The ideal candidate would have a degree in Computer Science, Engineering or related disciplines, with a background in Robotics, Computer Vision and/or Machine Learning. They would also be highly motivated to work on robotic platform and have computer programming skills.

References:

- Ceola, F., Maiettini, E., Pasquale, G., Meanti, G., Rosasco, L., and Natale, L., Learn Fast, Segment Well: Fast Object Segmentation Learning on the iCub Robot, IEEE Transactions on robotics, 2022.
- Piga, N., Onyshchuk, Y., Pasquale, G., Pattacini, U., and Natale, L., ROFT: Real-time Optical Flow-aided 6D Object Pose and Velocity Tracking, IEEE Robotics & Automation Magazine, vol. 7, no. 1, pp. 159-166, 2022.
- Maiettini, E., Tikhanoff, V., and Natale, L., Weakly-Supervised Object Detection Learning through Human-Robot Interaction, in Proc. International Conference on Humanoid Robotics, Munich, Germany, 202

Number of positions available:

1

Main Research Site
Istituto Italiano di Tecnologia, Genova

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Funding Scheme: This doctorate grant is fully funded by the proponent research institution.

2. Detection and tracking of obstacles for autonomous marine vehicles – Univ. Genova

Curriculum: Hostile and unstructured environments

Hosting Institution
University of Genoa

Department:
Department of Informatics, Bioengineering, Robotics and Systems Engineering

Tutor(s):
E. Simetti, F. Odone

Description:
The sea is a harsh and hostile environment, which makes the employment of robots very challenging. Despite this fact, there is an increasing interest in the development of marine robots both for civil and military purposes. One of the main challenges is the development of a reliable obstacle detection and tracking capability, which is a prerequisite for implementing any obstacle avoidance task. On the surface, the variety of weather conditions, such as sea fog, variable lighting conditions, and water reflection, have a great impact on the performance of the perception system. Below the surface, the visibility is often very limited and acoustic sensors such as forward-looking sonar needs to be employed.

The goal of this PhD proposal is twofold. On the one hand, research in multi-sensor detection and tracking for surface vehicles is needed. Previous works have started lying down a possible detection and tracking pipeline based on a camera and a LiDAR sensor [1], and the idea is to also include a thermal camera and to close the loop between 3D and 2D tracking [2]. For underwater vehicles, the processing of forward-looking sonar data should be developed. On the other hand, once the tracking is performed, the vehicle should take this information into account to autonomously avoid the obstacle [3]. The proposal can exploit available dataset in the literature and the ULISSE catamaran for experimentation.

Requirements:
Applicants are expected to have good programming skills (Python and C++) and have good background knowledge in computer vision and machine learning.

References:

[1] Mina Sorial, Issa Mouawad, Enrico Simetti, Francesca Odone, Giuseppe Casalino, Towards a Real Time Obstacle Detection System for Unmanned Surface Vehicles, OCEANS 2019, Seattle

[2] J. Han, Y. Cho, J. Kim, J. Kim, N.-s. Son, and S. Y. Kim, “Autonomous collision detection and avoidance for aragon usv: Development and field tests,” Journal of Field Robotics, vol. 37, no. 6, pp. 987–1002, 2020.

[3] Casalino, G., Turetta, A., & Simetti, E. (2009, May). A three-layered architecture for real time path planning and obstacle avoidance for surveillance USVs operating in harbour fields. In Oceans 2009-Europe (pp. 1-8). IEEE.

Number of positions available:

1

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Funding Scheme: This doctorate grant is co-funded by the proponent research institutions and by the Italian Ministry of Research, under law D.M. 351/2022 (PNRR).

3. End-to-end structured design methodologies for safe adaptive robots – Univ. Genova

Curriculum: Hostile and unstructured environments

Hosting Institution
University of Genoa

Department:
Department of Informatics, Bioengineering, Robotics and Systems Engineering

Tutor(s):
Armando Tacchella

Description:

The results developed in this research will be deployed to advance the capabilities of Bosch commercial robots (e.g., vacuum cleaning and lawn mowers) to operate in open contexts without human intervention. The goal will be to provide structured design methodologies that can accommodate the ability of the robot to learn from previous mistakes to avoid difficult situations while navigating the environment more effectively to perform their tasks.

The research will be carried out in the context of the CONVINCE project (Horizon EU project coordinated by IIT and with UniGe as partner), whose target is to develop a toolchain to support formally grounded model-based design in robotics. In addition, the research will be about evaluating how the adoption of the toolchain developed for the CONVINCE project will improve the robustness of the software and reduce the need for field tests. CONVINCE technology will also be used to design and research novel concepts for interacting with the environment by lightweight manipulators to clear the way of small obstacles and to clean corners and edge areas, which cannot be reached by the main suction unit. This particularly requires advanced coverage planning algorithms for the new, complex kinematics. The methodological and fundamental algorithmic research for this use case will be carried out by Bosch Corporate Research, in close collaboration with the relevant business unit (BSH) in an internal cross-sectional project house. This ensures access to prototypes of the next generations, early and frequent feedback from business unit developers as well as access to standardized test environment and measurement systems].

Requirements:
Applicants are expected to have a strong background in at least one of the following, and a reasonable knowledge of all three:

- Applications of formal methods to robotics and automation
- Model-based design for control software
- Software architectures for robotics

References:

- Tobias Blaß, Arne Hamann, Ralph Lange, Dirk Ziegenbein, Björn B. Brandenburg: Automatic Latency Management for ROS 2: Benefits, Challenges, and Open Problems. RTAS 2021: 264-277

- Michele Colledanchise, Giuseppe Cicala, Daniele E. Domenichelli, Lorenzo Natale, Armando Tacchella: Formalizing the Execution Context of Behavior Trees for Runtime Verification of Deliberative Policies. IROS 2021: 9841-9848
- Jan Kristof Behrens, Karla Stépánová, Ralph Lange, Radoslav Skoviera: Specifying Dual-Arm Robot Planning Problems Through Natural Language and Demonstration. IEEE Robotics Autom. Lett. 4(3): 2622-2629 (2019)

Company name and link (for industrial projects):

Bosch Gmbh – Bosch Center for Artificial Intelligence - https://www.bosch-ai.com/

Number of positions available: 1

Main Research Site
Bosch Center for AI – Renningen – Germany

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Funding Scheme: This industrial doctorate grant is fully funded by companies on behalf and proponent research institution.

4. Social perception in unstructured environments – Univ. Milano Bicocca

Curriculum: Hostile and unstructured environments

Hosting Institution: Università degli Studi di Milano – Bicocca

Department: Psicologia

Tutor(s): D. Ognibene, D. G. Sorrenti, E. Datteri

Description:

In the last 10 years, with the advent of modern deep learning methodologies, substantial performance improvement has been observed in perception for robots and other artificial systems. However, interactions with unstructured environments pose high challenges due to the variety of conditions and crucial sensory limits, such as occlusions and limited FOV. This position will focus on the study and development of systems that can perceive others' states in unstructured environments and predict their actions, intentions and beliefs.

A possible line of research would focus on adaptive and social active perception mechanisms that enable to dynamically deal with sensory limits and have received limited attention but play a crucial role in human perception (Ognibene & Demiris, 2013, Lee, Ognibene et al. 2015). It has been recently shown that such mechanisms may substantially improve learning performance other than execution efficiency and even enable online adaptation to new environments [Ognibene & Baldassarre, 2015], however, these properties have not been fully scaled to social conditions yet. Moreover, active perception also plays a crucial role also when interacting with other agents who add relevant scene dynamics and may occlude important information. At the same time agents may have their own sensory limits and active perception strategies that must be scrupulously parsed to support effective social interaction [Ognibene, Mirante et al, 2019], e.g. false beliefs and theory of mind [Bianco & Ognibene 2020]. Most importantly, social interaction increases the demand for integration of information about task and context, i.e. simultaneous perception of the states of other agents, their effectors and other scene elements which can be strongly affected by the limited field of view and challenging for active perception due to the necessity to focus on the right element at the right time [Ognibene, Chinellato, et al 2013] and adapt to different types of interaction. The work may not only focus on advancing technical performance but on understanding and modeling how humans perform and adapt social perception or on how to design active social perception to improve the perceived quality of human-robot interactions.

Requirements:

Applicants are expected to have good programming skills and interest in further improving them.

Knowledge of statistics, control systems theory, artificial intelligence, computer vision, as well as machine learning methodologies and libraries would be an important plus. Similarly, the ability to understand and design psychological tasks as well as use statistical methods to evaluate experimental results and human-robot interaction effectiveness would be valuable. Experience with real-time 3d engines and/or VR platforms, such as Unity3D, Unreal and similar, or with robotic platforms will also be considered positively.

References:

- Bianco, F., & Ognibene, D. (2020, March). From psychological intention recognition theories to adaptive theory of mind for robots: Computational models. In Companion of the 2020 ACM/IEEE International Conference on Human-Robot Interaction (pp. 136-138).
- Ognibene, D., Mirante, L., & Marchegiani, L. (2019, November). Proactive intention recognition for joint human-robot search and rescue missions through Monte-Carlo planning in POMDP environments. In International Conference on Social Robotics (pp. 332-343). Springer, Cham.
- Lee, K., Ognibene, D., Chang, H. J., Kim, T. K., & Demiris, Y. (2015). Stare: Spatio-temporal attention relocation for multiple structured activities detection. IEEE Transactions on Image Processing, 24(12), 5916-5927.
- Ognibene, D., Chinellato, E., Sarabia, M., & Demiris, Y. (2013). Contextual action recognition and target localization with an active allocation of attention on a humanoid robot. Bioinspiration & biomimetics, 8(3), 035002.
- Ognibene, D., & Demiris, Y. (2013). Towards active event perception. In Proceedings of the 23rd International Joint Conference of Artificial Intelligence (IJCAI 2013).

Number of positions available:

1

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Funding Scheme: This doctorate grant is co-funded by the proponent research institutions and by the Italian Ministry of Research, under law D.M. 351/2022 (PNRR).

5. Soft growing and adaptable robots for exploration of extreme environments – Italian Inst. of Technology

Curriculum:
Hostile and unstructured environments

Hosting Institution
Fondazione Istituto Italiano di Tecnologia

Department:
Bioinspired Soft Robotics

Tutor(s):
Barbara Mazzolai

Description:

The PhD proposal is part of the EU-funded I-Wood (ERC) project [1], which investigates the plant-fungus interactions to inspire a new generation of physical robotic networks controlled by new paradigms of artificial intelligence to target exploration, monitoring and remediation of ecosystems in both agriculture and natural environments. These robotic systems implement growing abilities in response to environmental signals and exchange information through the implementation of plant-inspired behavioral rules.

Growing, adaptable robots are a novel class of robots able to move and explore the environment through apical growth [2,3,4].

The major objective of the research is to design and build a new generation of bio-robots capable to explore and act in extreme environments, e.g., soil, for several applications, including agriculture, remediation, or digging.

The candidate will design and develop a growing robot able to advance the state of the art performance by combining additive manufacturing techniques, functional materials, and control strategies

Requirements:

The successful candidate must have an MSc degree in Mechanical engineering, Mechatronic engineering, Robotics, Manufacturing engineering, or a related field. She/he should have a strong knowledge of solid modelling tools, mechanical engineering basis and analytical reasoning. The multidisciplinarity of the project requires good communication skills, good knowledge of written and spoken English, and capabilities to work in a team.

References:
[1] https://cordis.europa.eu/project/id/101003304
[2] Del Dottore, E., Sadeghi, A., Mondini, A., Mattoli, V., & Mazzolai, B. (2018). Toward growing robots: a historical evolution from cellular to plant-inspired robotics. Frontiers in Robotics and AI, 5, 16.
[3] Sadeghi, A., Mondini, A., & Mazzolai, B. (2017). Toward self-growing soft robots inspired by plant roots and based on additive manufacturing technologies. Soft robotics, 4(3), 211-223.
[4] Sadeghi, A., Del Dottore, E., Mondini, A., & Mazzolai, B. (2020). Passive morphological adaptation for obstacle avoidance in a self-growing robot produced by additive manufacturing. Soft robotics, 7(1), 85-94.

Number of positions available:

1

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Funding Scheme: This doctorate grant is fully funded by the proponent research institution.

6. Traversability for Mobile Robots in Hostile and Unstructured Environments – Univ. Catania

Curriculum: Hostile and unstructured environments

Hosting Institution
Università degli Studi di Catania

Department:
Dipartimento di Ingegneria Elettrica Elettronica e Informatica

Tutor(s):
Prof. G. Muscato

Description:
Autonomous navigation in unstructured environments as volcanoes, agriculture fields, caves, requires specific methodologies for properly executing tasks.

Both perception and decision-making levels of the robotic system infrastructure are crucial in such demanding scenarios. The ideal candidate should be able to address these aspects and to learn and develop methods and their implementation on real systems.

First year of the project will be devoted to improving the knowledge on the state of the art and to get acquainted with the available robotic platforms. Second year will address the development of strategies and solutions. The third year will deal with the on-field validation and testing of the proposed methods. The PhD will also include a six-month internship abroad.

The Robotic Systems Group (Rosy) of the University of Catania has been involved in several national and European projects on this topic and many ground vehicles are available for the experimental development of the proposed strategies. The group has strong connections with several international robotic research Universities and companies.

Catania is a welcoming city with many historical and natural touristic attractions and wonderful climate and food. The Laboratory is in a Campus well connected with the main facilities.

https://rosysgroup.github.io/ www.muscato.eu

Requirements:
Applicants are expected to have background on control methods, robotics, and mechatronics. Expertise on software programming, deep learning methods and computer vision is a plus.

References:

- Guastella, D.C.; Muscato, G. Learning-Based Methods of Perception and Navigation for Ground Vehicles in Unstructured Environments: A Review. Sensors 2021, 21, 73. https://doi.org/10.3390/s21010073
- Guastella, D. C., Cantelli, L., Longo, D., Melita, C. D., & Muscato, G. (2019). Coverage path planning for a flock of aerial vehicles to support autonomous rovers through traversability analysis. ACTA IMEKO, 8(4), 9-12.
- Palazzo, S., Guastella, D. C., Cantelli, L., Spadaro, P., Rundo, F., Muscato, G., ... & Spampinato, C. (2020). Domain adaptation for outdoor robot traversability estimation from RGB data with safety-preserving Loss. In 2020 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS) (pp. 10014-10021). IEEE.

- Muscato, G., Bonaccorso, F., Cantelli, L., Longo, D., & Melita, C. D. (2012). Volcanic environments: Robots for exploration and measurement. IEEE Robotics & Automation Magazine, 19(1), 40-49.

Number of positions available:

1

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Funding Scheme: This doctorate grant is co-funded by the proponent research institutions and by the Italian Ministry of Research, under law D.M. 351/2022 (PNRR).