I-RIM

PhD Course in

ROBOTICS AND INTELLIGENT MACHINES

Curriculum: Robotics and Intelligent Machines for Industry 4.0

Research themes

Summary

For larger companies, robotics has been a key productivity factor for many years; nowadays, thanks to the development of the new enabling technologies of Industry 4.0, such as collaborative robotics and artificial intelligence, robotics is also becoming increasingly relevant for smaller industries, which are crucial for Italy's production and employment capacity. Many drivers are pushing the adoption of robotic technology in industry, such as the need of products customization, the increase in competitiveness in the global market and the progressive penetration of cobots in human-centred manufacturing scenarios.

The introduction and spread of the Industry 4.0 production paradigm has given more boost to the use of robots, since they are interconnected, highly digitized autonomous agents, equipped with a digital twin, able to improve their performance based on the analysis of data collected in production systems. On the other hand, as also highlighted by the European Economic and Social Committee (EESC), the next transition to Industry 5.0 will be characterized by the shift from coexistence to full cooperation, physical and social, between machines and people.

All these topics are addressed with an integrated and multidisciplinary approach by the projects proposed in this curriculum; they represent cutting-edge technological challenges that can certainly be tackled due to the scientific and technological background of the proposing institutions and the experience of the involved researchers.

The main goals of the Industry 4.0 curriculum are:

- Encourage technology transfer from research to industry, particularly in the industrial sectors that can best exploit the use of robotics.

- Give industry the opportunity to help direct the research of PhD students, as demonstrated by the high number of scholarships in the curriculum funded or co-funded by companies
- Give PhD students the opportunity to spend some time within the companies participating in the training project

The ideal candidates are students with a Master (or equivalent/higher) degree in a STEM field: a specific background in Robotics or Mechatronics will be appreciated.

The students will perform their research project at the hosting institution (as described in the research project sheet). Interested students can contact the tutors and/or the Unit's Principal Investigators for clarifications before submitting their documentation.

International applications are encouraged, and the participants will receive logistic support with visa issues, relocation, etc.

1. Large Language Models in the Field of Industrial Automation – Università di Genova (*)

Curriculum: Industry 4.0	
Hosting Institution Universita' di Genova	
Department: DIBRIS	
Tutor(s): Prof. Davide Anguita	

Description:
The application of "Large language models" in the field of industrial automation offers an unprecedented opportunity to improve the understanding and processing of data, allowing the creation of predictive models and the optimization of production processes. This represents a significant qualitative leap towards the integration of artificial intelligence technologies in the industrial context. In particular, the PhD course is based on an innovative methodology that uses artificial intelligence and machine learning for data collection and analysis. The use of the LLMs in the industrial context, which is still unexplored today, will be innovative for the development of advanced design methodologies.

Requirements:
Applicants must have a good knowledge of AI and machine learning fundamentals. Applicants are also expected to have good programming skills (including Python, C/C++, Matlab/Simulink) and a strong attitude to problem solving.

References:
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Company name and link (for industrial projects):
Saie s.r.l. - Savona

Number of positions available:
1

Main Research Site
DIBRIS – Universita' di Genova
Saie s.r.l. - Savona

Contacts:
Email: davide.anguita@unige.it

Funding Scheme: This doctorate grant is co-funded by Saie s.r.l. and Regione Liguria (PR Liguria FSE+ 2021-2027)

2. Robotics and AI for electronic waste recycling– Università degli Studi di Genova (*)

Curriculum: Industry 4.0	
Hosting Institution University of Genoa	
Department: DIBRIS, Department of Informatics, Bioengineering, Robotics and Systems Engineering	
Tutor(s): Carmine Recchiuto, Antonio Sgorbissa, Davide Labolani, Jacopo Iottero	

Description:
This Ph.D. work foresees a pioneering approach that combines artificial intelligence with robotics to address a growing challenge: E-Waste recycling [1],[2]. The issue of sorting batteries is very topical and relevant, given the growing diffusion of electric or hybrid vehicles and the consequent need to dispose of batteries that have reached the end of their life. Although this is a research topic in continuous development, at the moment there are no fully automated systems for the disassembly and disposal of heterogeneous batteries, also due to the lack of production standards. To date, the disassembly of the batteries is carried out almost entirely by hand by a specialized operator and it involves poor ergonomics and a high degree of risk for the operator, as the batteries contain toxic and dangerous substances and may contain residual charge [3]. Furthermore, given the monotony of the disassembly process and the high weight and bulk of the batteries of electric vehicles, this process is mentally and physically stressful for the operator. The implementation of artificial intelligence and planning algorithms, together with the interaction between robots and human operators, offers an unprecedented opportunity to increase efficiency and safety in the process of disassembling electric vehicle batteries [4],[5]. In particular, the Ph.D. student is expected to study, design and implement artificial intelligence strategies for the semi-automatic disassembly of electric vehicle batteries through human-robot and robot-robot interaction, using advanced collaborative robots (e.g. Universal Robots) and industrial systems.

The work will be partially performed at HIRO Robotics, an innovative startup based in Genoa that operates in the automation branch for the disassembly of electrical and electronic waste.
In particular, HIRO Robotics has developed various automation lines suitable for the disposal and sorting of WEEE waste such as flat screen monitors and electronic boards, thanks to the use of artificial intelligence algorithms and proprietary adaptive robot control. The company also holds several patents in this area.

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.

References:

- [1] Grau Ruiz, M. A., & O'Brolchain, F. (2022). Environmental robotics for a sustainable future in circular economies. *Nature Machine Intelligence*, *4*(1), 3-4.
- [2] Kristensen, C. B., Sørensen, F. A., Nielsen, H. B., Andersen, M. S., Bendtsen, S. P., & Bøgh, S. (2019). Towards a robot simulation framework for e-waste disassembly using reinforcement learning. *Procedia Manufacturing*, *38*, 225-232.
- [3] Tarrar, M., Despeisse, M., & Johansson, B. (2021). Driving vehicle dismantling forward-A combined literature and empirical study. *Journal of Cleaner Production*, *295*, 126410.
- [4] Johnson, M., Khatoon, A., & Fitzpatrick, C. (2022, November). Application of AI and Machine Vision to improve battery detection and recovery in E-Waste Management. In *2022 International Conference on Electrical, Computer, Communications and Mechatronics Engineering (ICECCME)* (pp. 1-6). IEEE.
- [5] Choux, M., Marti Bigorra, E., & Tyapin, I. (2021). Task planner for robotic disassembly of electric vehicle battery pack. *Metals*, *11*(3), 387.

Company name and link (for industrial projects):
HIRO Robotics: https://www.hirorobotics.com/en/home/

Number of positions available:
1

Main Research Site
The research will be performed at the DIBRIS department in the "Laboratorium/Social Robotics Lab," a fully equipped facility for software development with ground robots (quadruped and wheeled), humanoid robots for socially assistive applications, and aerial robots, and at the HIRO Robotics laboratories, equipped with collaborative robots.

Contacts:

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Funding Scheme: This doctorate grant is funded by HIRO Robotics and Regione Liguria (PR Liguria FSE+ 2021-2027)

3. Sensor-based control of robots for human-robot cooperative operations – University of Genova

Curriculum: Industry 4.0

Hosting Institution
UNIGE

Department:
DIBRIS

Tutor(s):
Prof. Giorgio Cannata

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. During collaborative tasks robots are controlled using feedback from cameras, force/torque sensors, tactile sensors, proximity sensors etc. which allow the robot to localize itself and interact safely with humans and objects.
The PhD project has the goal of developing robot system capable to physically interact with a human to collaborate to execute jointly operations. The scientific objective is to investigate human-robot interaction control strategies based on sensor feedback from cameras, tactile and proximity sensors (multimodal sensing) mounted on the robot arm, enabling safe interaction and touch based robot guidance
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 applicatioans, sharing the space with a human operator to complete a series of operations involving contact of the robot with the environment.
This PhD research theme is part of the activities of the European project *HE Sestosenso* (www.sestosenso.eu)

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:

- . Albini, F. Grella, P. Maiolino and G. Cannata, "Exploiting Distributed Tactile Sensors to Drive a Robot Arm Through Obstacles," in IEEE Robotics and Automation Letters, vol. 6, no. 3, pp. 4361-4368, July 2021, doi: 10.1109/LRA.2021.3068110.
- Albini A, Cannata G. Pressure distribution classification and segmentation of human hands in contact with the robot body. The International Journal of Robotics Research. 2020;39(6):668-687. doi:10.1177/0278364920907688
- F. Grella, A. Albini and G. Cannata, "Voluntary Interaction Detection for Safe Human-Robot Collaboration," 2022 Sixth IEEE International Conference on Robotic Computing (IRC), Italy, 2022, pp. 353-359, doi: 10.1109/IRC55401.2022.00069.

Company name and link (for industrial projects):

n.a.
Number of positions available: 1
Main Research Site DIBRIS Department, Bioengineering Lab, Via Opera Pia 13, Genova, Italy.
Contacts: Email: giorgio.cannata@unige.it
Funding Scheme: This doctorate grant is fully funded by the University of Genova.

4. Machine learning and control for robot autonomy in contact-rich tasks- Italian Institute of Technology

Curriculum: Industry 4.0
Hosting Institution: Istituto Italiano di Tecnologia
Research Lab: Human-Robot Interfaces and Interaction - HRI^2 https://hri.iit.it/it/home
Tutor(s): Arash Ajoudani – arash.ajoudani@iit.it
Description: The research focuses on the development of control (e.g., adaptive and robust controllers) and machine learning (e.g., deep reinforcement learning) for control of mobile collaborative robots in interactive tasks, in particular with humans. The aim is to boost robot interaction autonomy by exploiting the potential of ML and classical control techniques in synergy in contact rich manipulation and co-manipulation tasks.
Requirements: The successful candidate must have an MSc degree with a strong background in Robotics, Machine Learning and/or physical human-robot interaction. The successful candidate should have: • Good skills on C++ and Python • Experience with ROS • Confidence with version control tools (specifically git) • Good communication skills and ability/willingness to integrate within a multidisciplinary international research group • Good knowledge of written and spoken English
References: [1] Zhao, Jianzhuang, et al. "A hybrid learning and optimization framework to achieve physically interactive tasks with mobile manipulators." IEEE Robotics and Automation Letters 7.3 (2022): 8036-8043. [2] Merlo, E., Lagomarsino, M., Lamon, E. and Ajoudani, A., 2023. Automatic Interaction and Activity Recognition from Videos of Human Manual Demonstrations with Application to Anomaly Detection. arXiv preprint arXiv:2304.09789.
Number of position available: 1
Main research site: Center for Robotics and Intelligent Systems, Italian Institute of Technology Via San Quirico 19D, 16163
Contacts: Arash Ajoudani@iit.it
Funding scheme: This doctorate grant is funded by IIT

5. Advanced robot perception for precision harvesting – Politecnico di Milano

Curriculum: Industry 4.0

Hosting Institution
Politecnico di Milano

Department:
Department of Electronics Information and Bioengineering

Tutor(s):
Prof. Matteo Matteucci

Description:
The deployment of harvesting robots has the potential to help significantly in mitigating problems such as labor shortages and workforce-related costs. Developing robots that can reliably and efficiently harvest fruit, however, poses many challenges. From the standpoint of perception, robots are expected to robustly recognize the presence of fruits despite the rapid environmental changes that characterize crops and orchards. These include, but are not limited to, variations in the weather conditions, lighting, and occlusions caused by foliage. Moreover, the harvesting problem requires that methods are devised to effectively estimate the ripeness of fruit so that each fruit is picked at the most appropriate time. As such, in addition to perceptual capabilities, harvesting robots also ought to be equipped with higher-level reasoning capabilities to make decisions based on the current state of the environment and on knowledge about the plant life cycle. From the standpoint of manipulation, methods are also needed for picking fruit without causing any damage that may compromise the quality of the harvest.

During the Ph.D., the candidate will develop a robot prototype for automated harvesting and evaluate the devised prototype in real agricultural environments. At first, the candidate will explore the use of state-of-the-art methods based on Deep Learning (DL) for fruit instance segmentation and detection and extend these existing methods - e.g., through the introduction of methods based on symbolic reasoning, to maintain a persistent model of the environment that can account for change and facilitate decision making. The candidate will also leverage a digital environmental model to simulate possible robot actions. A physics-based 3D rendering engine will indeed be used to reason about the consequences of complex grasping actions such as picking fruit and placing them in collection containers. This allows for collecting episodic memories of previous grasping actions so that decisions can be refined as the robot gains expertise. The advantage of this setup is that actions are simulated before causing actual damage to the fruit. The solution will be tested on a real-world task to assess "the reality gap".

Requirements:
Applicants are expected to have a background in robotics and computer science. Computer vision and perception is a plus.

References:

- Bac, C.W.; Henten, E. van; Hemming, J.; Edan, Y. Harvesting Robots for High-value Crops: State-of-the-art Review and Challenges Ahead. Journal of Field Robotics 31, (2014), 6, 888 - 911. https://doi.org/10.1002/rob.21525

- Kootstra, G., Wang, X., Blok, P.M. et al. Selective Harvesting Robotics: Current Research, Trends, and Future Directions. Curr Robot Rep 2, 95–104 (2021). https://doi.org/10.1007/s43154-020-00034-1
- Mail, M.F.; Maja, J.M.; Marshall, M.; Cutulle, M.; Miller, G.; Barnes, E. Agricultural Harvesting Robot Concept Design and System Components: A Review. AgriEngineering (2023), 5, 777-800. https://doi.org/10.3390/agriengineering5020048
- Rajendran, V., Debnath, B., Mghames, S., Mandil, W., Parsa, S., Parsons, S. et al. (2023) Towards autonomous selective harvesting: a review of robot perception, robot design, motion planning and control. Journal of Field Robotics, 1–33. https://doi.org/10.1002/rob.22230

Company name and link (for industrial projects):
ENI Progetti (www.eni.com)

Number of positions available:
1

Main Research Site
Artificial Intelligence and Robotics Laboratory (AIRLab)
Department of Electronics Information and Bioengineering
Politecnico di Milano, via Ponzio 34/5, 20133, Milan (Italy)

Contacts:
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Funding Scheme: This doctorate grant is [fully] funded by Politecnico di Milano.