I-RIM

PhD Course in

ROBOTICS AND INTELLIGENT MACHINES

Curriculum: Robotics and Intelligent Machines for Inspection and Maintenance of Infrastructures

Research themes

The main goal of the Robotics and Intelligent Machines Inspection and Maintenance of Infrastructures curriculum is to train scientists and researchers capable of working in multidisciplinary teams on topics related to state-of-the-art solutions for Inspection and Maintenance of Infrastructures tasks. Robotics has a high potential in the technological innovation process of inspection and maintenance processes to reduce costs, improve the quality of services, as well as safety and environmental impact. The impossibility of adapting existing plants and infrastructures to the capabilities of common industrial robots, combined with the growing autonomy of the most advanced technological solutions, has created the right conditions for the development of specific service robotics solutions for civil and industrial inspection and maintenance applications.

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. Autonomous Interaction Control for High Fidelity Surface Polishing Tasks – Istituto Italiano di Tecnologia

Curriculum: Inspection and maintenance of infrastructures

Hosting Institution:
Istituto Italiano di Tecnologia

Department:
Humanoid and Human Centred Mechatronics Research line (https://hhcm.iit.it/)

Tutor(s):
Nikos Tsagarakis, nikos.tsagarakis@iit.it

Description:
Surface treatment operations such as wall sanding require careful control of the motion trajectories and forces applied by the robotic end-effector tools on the surface, imposing a high level challenge for achieving consistent surface polishing quality.
At the same time, visual perception of imperfection features on the surface to be treated and the closed-loop use of this information during the sanding task execution is vital for enabling the autonomous execution of these operation through the continuous regulation of the robot -surface interaction achieved by the modulation of the motion and force profiles.
This research topic will develop control and perception strategies that allow robots to safely perform sanding and polishing operation on surface imperfections, exploiting customized end-effector tools used by human to perform these operations manually. The robot controller will have to track the desired motion, impedance and force trajectories that are modulated on the basis of an off-line-set of parameters as well as through online guidance using visual perception cues. To this aim, impedance control and hybrid motion-force control will be investigated. For the tuning of the off-line set of parameters data driven methods will be explored from data collected during the operation. If needed to collect data for learning the surface polishing interaction (force & motion parameters) , the possibility of asking human operators to directly operate the robotic manipulation system in kinesthetic teaching mode will be considered. At the interaction control level the developed tools shall permit the autonomous regulation of the motion/velocity profile, the regulation of the applied force on the surface to be treated as well as enable the reasoning and replanning when additional cycles of the process are needed to achieve the desired quality of surface. The developed tools will be demonstrated in tangible industrial use-cases scenarios related to wall sanding and car body grinding operations.

Requirements:
This topic lies in the intersection of Robot control and visual perception. Ideal applicants should have excellent C++ and Python programming competences. Strong competences in robot control and computer/robotic vision skills are required. Knowledge of motion planning tools and Robot Operating System (ROS) will be a plus. The applicants should be fluent in English and team players.

References:

- Yingxin Huo et al, Model-Free Adaptive Impedance Control for Autonomous Robotic Sanding, IEEE Trans. On Automation Science and Engineering, Vol. 19, No. 4, 2022.
- B. Maric et al, “Collaborative human-robot framework for delicate sanding of complex shape surfaces,” IEEE RAL, vol. 5, no. 2, pp. 2848–2855, 2020.
- Y. Dong et al, “Contact force detection and control for robotic polishing based on joint torque sensors,” Int. J. Adv. Manuf. Technol., vol. 107, pp. 2745–2756, Mar. 2020.

Number of positions available: 1

Main Research Site
Center for Robotics and Intelligent Systems (CRIS), IIT, Genova

Contacts:
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Scholarship Amount:

- Fascia 4: 19,500 €/year

2. Methods and techniques for robotized grab ship unloaders – University of Genoa and Tenova SpA

Curriculum: Inspection and maintenance of infrastructure

Hosting Institution
University of Genoa

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

Tutor(s):
Fulvio Mastrogiovanni

Description:
Grab ship unloaders (GSUs) have been used for many decades in trans-shipment processes. They are adopted in ports discharging bulk materials of different particle types and size, as grabs, when used with unloading bridges, prove to be very flexible and reliable also with materials of differing physical characteristics.
Even though GSUs can be considered a consolidated technology, they still suffer from several limitations, which limit their effectiveness and potential. Most notably, they are operated by a human operator located in a control cabin aboard the GSU itself, typically at a given height from the ground, and therefore they are characterized by a low safety level. Consequently, the human operator must sustain a possibly high level of cognitive stress during operations, which require large volumes of material to be unloaded in a short amount of time. A single human error in operating a GSU may jeopardize the whole discharging process.
The goal of this research theme is to design and develop technologies to accelerate the transition towards fully autonomous robotic GSUs, that is, carrying out the unloading operations without the need for a human operator working in the GSU cabin.
The task of operating a fully autonomous robotic GSU characterized by industry-level standards is a great challenge. In fact, there are multiple scientific and technical challenges to address. Currently, human operators must operate a trolley along a trail to position the grab; then the grab must descend through a hatch to grab the material; finally, the grab must be moved above a collector, and opened so that the material can be poured on a conveyor belt. An autonomous, robotic GSU must be able to carry out all these actions reliably.
This PhD thesis proposal has three general objectives: O1) develop a "sense-plan-act" control architecture for the GSU to support its autonomous operation; O2) embed in it a digital twin replica of the GSU for knowledge representation and reasoning purposes; O3) modelling relevant traits of the behavior of human operators, with the aim of inferring relevant operational strategies for the GSU. In particular, the PhD student will carry out one or more of the following research activities.

1. Design a develop a sensing and perception sub-system to detect and model the workspace in real-time, specifically adopting 3D sensing techniques. Semantic mapping approaches [1] will be adopted and properly adapted to task, with the aim of automatically labelling relevant parts of the workspace (for example, detecting bulk material or the ship hatch) to inform GSU's operations. This information will be fed to the digital twin replica of the GSU to align it with the current state of the workspace.
2. Design and develop a knowledge representation sub-system to decide the tasks to be carried out by the GSU, as well as to plan its operations. The knowledge representation module will ground the necessary information to model perceptions,

states, events, actions and plans to be carried out by the GSU, with the aim of monitoring their proper execution. The PhD student will evaluate the use of deterministic as well as probabilistic approaches to knowledge representation. It will be possible to encode and reason about plans (that is, sequence of atomic operations) to be carried out by the GSU and monitor their execution using data from the sensing and perception sub-system. The PhD student will adopt advanced modelling techniques, such as for example PDDL+, to model discrete and time-varying, continuous quantities (for example, the grab oscillating behavior) [2].

3. Adopt and integrate a suitable task and motion planning approach to reliably execute the planned sequence of operations [3]. It will be necessary to model and consider exogenous events and processes, such as for example the oscillations of the grab during its motions, or the particle dynamics of the bulk material to be grabbed. To this aim, the grab will be provided with sensors (for example inertial measurement units - IMUs) to estimate its pose in real-time. The grab's pose estimate will be fed to the digital twin replica, and its oscillation predicted in real-time to adapt its motions reactively.
4. While the knowledge representation sub-system will act as a framework to support possible sequences of GSU operations, and the task and motion planning sub-system will support their execution, one possible approach to select the best operational policy will be learning it from human operators [4]. The PhD student will investigate methods and approaches to learn human behaviors to control the GSU and link it to GSU operations. The result will be a set of normative policies, learned from data collected using the deployed sensing and perception infrastructure, to be encoded in the PDDL+ models.

Requirements:

Applicants are expected to have a background in robotics, mechatronics, computer science and engineering, and related disciplines. They are also expected to be proficient in software design, software development, and control theory. Outstanding candidates have experience in software frameworks for robots, machine learning, knowledge representation and planning for robots, robot motion control, and human behavior modelling. Exceptional candidates have carried out research activities related to robot perception using 3D vision and IMUs, digital twin technologies, task and motion planning.

References:

1. J. McCormac, A. Handa, A. Davison, S. Lautenegger. SemanticFusion: dense 3D semantic mapping with convolutional neural networks. Proc. 2017 IEEE International Conference on Robotics and Automation (ICRA), Singapore, May 2017.
2. F. Percassi, E. Scala, M. Vallati. A practical approach to discretised PDDL+ problems by translation to numerical planning. J. Artificial Intelligence Research, vol. 76, January 2023.
3. H. Guo, F. Wu, Y. Qin, R. Li, K. Li, K. Li. Recent trends in task and motion planning for robotics: a survey. ACM Computing Surveys, vol. 55, issue 53, pages 1-36, July 2023.
4. J. S. Park, J. O'Brien, C. J. Cai, M. Ringel Morris, P. Liang, M. S. Bernstein. Generative agents: interactive simulacra of human behavior. Proc. 36th Annual ACM Symposium on User Interface Software and Technology (UIST), San Francisco, CA, November 2023.

Company name and link (for industrial projects):

Tenova SpA (www.tenova.com)

Number of positions available:

1
Main Research Site Department of Informatics, Bioengineering, Robotics, and Systems Engineering, University of Genoa, Italy.
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Scholarship Amount: • Fascia 2: 17,500 €/year