PhD Program in Bioengineering and Robotics

Curriculum Robotics and Autonomous Systems

Research themes

The goal of the Robotics and Autonomous Systems curriculum is to study, design and build robots, team of robots and, in general, autonomous systems able to exhibit a robust and predictable behavior while performing complex tasks in challenging indoor and outdoor environments. The focus is both on key methodologies and technologies (e.g., advanced robot control, robot coordination and cooperation, sensing, state estimation, knowledge representation, motion planning, real-time scheduling, human-robot interaction, design of macro/micro robot systems, design of sensors and actuators) as well as on specific robotic areas (e.g., underwater, aerial and space robotics, wheeled and legged robots, manipulation) and on different application scenarios (e.g., search & rescue, surveillance and monitoring, material handling and transportation).

Furthermore, 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 goals of meeting robustness and predictability requirements even in unknown, dynamically changing, or even hazardous environments.

The themes offered in this intake are supported by the Department of Informatics, Bioengineering, Robotics and System Engineering, University of Genoa.

The ideal candidates are students with a higher-level university degree, with a strong desire for designing and developing robot systems able to have a huge impact on the society in the upcoming future.

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

1. Approximate methods for active identification

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Description:
The research will focus on system identification methods with particular attention to the role of the control action to improve (on line) the performance in terms of identification accuracy over a finite time or time.

As for the system model, the so-called "black box" paradigm will be addressed. No specific structure for the system to be identified will be assumed. The use of parametrized approximation structures will be addressed whose complexity could be tuned a priori in order to reach a suitable trade-off between model accuracy and online computational requirement.

The parameters of the approximating structure will be tuned on line, when the control action will be used in order to improve the achieved model accuracy. Different control methods will be addressed, based on parameterization of the control laws as well as on approximate optimization methods.

Requirements:
- Skills in system Identification, machine learning, optimal control.

References:

- L. Scardovi, M. Baglietto, T. Parisini, "Active State Estimation for Nonlinear Systems: a Neural Approximation Approach", IEEE Trans. on Neural Networks, vol. 18, no. 4, pp. 1172-1184, 2007.
- A. Alessandri, M. Baglietto, G. Battistelli, M. Gaggero "Moving-horizon State Estimation for Nonlinear Systems Using Neural Networks", IEEE Trans. on Neural Networks, vol. 22, no. 5, pp. 768-780, 2011.

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2. Goal-based cooperation and reasoning models for heterogeneous robot teams made-up of terrestrial and aerial robots

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Description:
The use of teams of heterogeneous robots involving both unmanned terrestrial and aerial vehicles is getting a lot of attention in robotics research. Different research challenges emerges, including low-level control strategies, reliable navigation in real-world conditions, obstacle avoidance, concurrent mapping and localisation, as well as coordination and distributed task allocation and monitoring.

In the literature, a number of approaches have been introduced to allow teams of heterogeneous robots to operate taking both high-level directives and low-level control aspects into account, including distributed task allocation, coordination, and refinement. Most approaches are focused either on (distributed) task planning and allocation or on low-level control aspects. Much less is discussed in the literature regarding the integration of the two levels and the related implications for high-level representation and reasoning processes.

With this PhD proposal, we want to investigate two aspects: on the one hand, we want to implement a number of robot behaviours, such as autonomous exploration and area monitoring, and investigate how such behaviours affect low-level control aspects related to navigation and obstacle avoidance (on the basis of robot parameters to identify online), as well as high-level reasoning for mission planning and execution; on the other hand, we want to implement high-level coordination and reasoning behaviours allowing teams of heterogeneous robots to quickly reconfigure in order to achieve a given directive, such as context-based activity and coordinated exploration.

Prospective PhD students will be involved in:

- the development of scenarios where the tasks to be carried out require the online identification of a number of parameters related to robot models and/or the environment;
- the design of coordination strategies between heterogeneous vehicles, such as terrestrial and aerial robots, e.g., to allow for cooperative exploration or monitoring.

Requirements:

- Concepts related to robot modelling, system identification, action planning and reasoning.
- Software development in C/C++.

References:

- Ramaithitima, Whitzer, Bhattacharya, and Kumar, "Automated Creation of Topological Maps in Unknown Environments Using a Swarm of Resource-Constrained Robots," IEEE Robotics and Automation Letters, vol. 1, iss. 2, pp. 746-753, 2016.
- Charrow, Kumar, and Michael, "Approximate Representations for Multi-Robot Control Policies that Maximize Mutual Information," *Autonomous Robots*, vol. 37, iss. 4, pp. 383-400, 2014.

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3. Sensor based control of bi-manual robots for human-robot cooperative operations

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Description:
Innovative robot systems are expected to work and cooperate with other robots and humans for the execution of handling and manipulation tasks for industrial and service applications. To this aim bi-manual highly sensorized robots (e.g. Baxter from Rethinking Robotics, Frida from ABB, Justin from DLR-KUKA to name a few) are expected to execute highly coordinated motions to handle and manipulate rigid and flexible objects (e.g. cables, etc.) autonomously or in cooperation with other agents (either robots or humans). These operations must be executed properly reacting to unexpected events and to changes within their working envelope of the robot in order to ensure the reliable and safe (in case of interaction with humans) execution of the planned tasks. This involves the usage of highly sensorized robot systems or robot working cells (depending on context and application), typically featuring multiple camera sensors, range sensors, tactile and force/torque sensors, and possibly task specific sensing devices. These robot systems will enable the execution of demanding tasks like the handling and manipulation of non-rigid objects (e.g. articulated, deformable, flexible etc.), which are currently executed mostly by humans. Examples of relevant tasks of this class for industrial or service applications include, but are not limited to: handling of cables, assembly, packaging, co-operative human robot handling of non rigid/deformable objects, etc.

These research topics have been part of relevant international research projects (ROBOSKIN: www.roboskin.eu; CloPeMa: www.clopema.eu; RasoRoSo).

Requirements:
Applicants are expected to have a strong motivation for at least one of the following key topics in robotics: robot control, robot programming, mechatronics. Furthermore, good attitude for experimental work is mandatory. The candidates must have: very good programming skills with different languages (including C/C++, Python, Matlab/Simulink); confidence with electronic hardware and be capable to conduct experiments; attitude to problem solving, and be strongly
motivated to team working.

References:

- G. Cannata, S. Denei, F. Mastrogiovanni. Towards the creation of tactile maps for robots and their use in robot contact motion control. Robotics and Autonomous Systems 63(3): 293–308, 2015.

- S. Denei, F. Mastrogiovanni, G. Cannata. Parallel Force-Position Control Mediated by Tactile Maps for Robot Contact Tasks. Proceedings of the 2012 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2012), Vilamoura, Portugal, October 2012.
- A. Del Prete, S. Denei, L. Natale, F. Mastrogiovanni, F. Nori, G. Cannata, G. Metta. Skin spatial calibration using force/torque measurements. Proceedings of the 2012 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2012), Vilamoura, Portugal, October 2012.

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4. Tactile sensing technologies and perception

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Description:
Tactile sensing is one key topic for the development of future robots capable of complex interaction with humans and objects. Design of tactile sensors as well as tactile based sensing, perception and control are challenging research topics and University of Genova has gained a solid reputation in this area in the past few years, and has been involved in important international research projects related to this topic (ROBOSKIN: www.roboskin.eu; CloPeMa: www.clopema.eu).

Tactile data convey information about the characteristics of the contact between the robot and the manipulated objects. This information is fundamental to proper control the grasping and manipulation; furthermore, controlled manipulation can in turn be used to extract further information useful to recognize and classify objects and contacts.

The objective of the PhD program is to investigate techniques and methodologies for tactile data sensing, perception and interpretation. Furthermore, since tactile data are generated by active manipulation control another objective is the study of the mechanisms relating tactile based feedback robot control and tactile data perception.

Requirements:
Applicants are expected to have strong background and experience in at least one of the following topics: robot control, machine learning, system identification. The candidates must have: very good programming skills with different languages (including C/C++, Matlab/Simulink); experience with electronic hardware; be capable to conduct experiments and be strongly motivated to team working.

References:

- G. Cannata, S. Denei, F. Mastrogiovanni. Towards the creation of tactile maps for robots and their use in robot contact motion control. Robotics and Autonomous Systems 63(3): 293–308, 2015.
- P. Maiolino, M. Maggiali, G. Cannata, G. Metta, L. Natale. A Flexible and robust large scale capacitive tactile system for robots. IEEE Sensors Journal, vol. 13, no. 10, pp. 3910-3917, October 2013.
- L. Muscari, F. Mastrogiovanni, L. Seminara, M. Capurro, G. Cannata, M Valle. Real-time reconstruction of contact shapes for large area robot skin. Proceedings of the 2013 IEEE International Conference on Robotics and Automation (ICRA 2013), Karlsruhe, Germany, May 2013.

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5. Culture-Aware Robots and Environmental Sensor Systems for Elderly Support

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Co-Tutor(s):
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Description: Research will be performed within the Horizon2020 project CARESSES, a three years joint effort between EU and Japan aimed at designing **culturally aware** and **culturally competent** elder care robots, i.e., robots able to **adapt how they behave and speak to the culture, customs and manners** of the person they assist.

In this general framework, the specific objective of the research will be to design a system for the **automatic recognition of human activities** using the sensors on board the robot Pepper developed by SoftBank Robotics possibly complemented by smart sensors distributed in the environment (e.g., presence sensors that may detect the person in different areas of the house). The recognition of activities (e.g., eating, watching the TV, cleaning herself, sleeping, receiving visits, etc.) will then constitute the basis to recognize habits, i.e., activities that are repeatedly executed on regular basis, therefore allowing the robot to adapt its behavior to the person herself to improve the quality of the interaction.

Specifically, the algorithms for activity recognition shall be based on cloud services for the semantic labelling of images (e.g., CLARIFY: https://www.clarifai.com/) complemented by frameworks for knowledge representation (e.g., ontologies written in OWL2, http://www.owl2.it/) and for reasoning with uncertainty (e.g., Bayesian Networks in Netica, https://www.norsys.com/netica_api.html), shall take into account the cultural background of the person whose activities shall be recognized. Cultural information will be used, for instance, to consider

- differences in the environment (e.g., an old person lying on the floor during night is very likely to be sleeping on a tatami in Japan, whereas it is probably fallen to the floor in a western country);
- different times of the day when activities are typically performed (it is a well known fact that lunch and dinner happen at different times of the day in different countries: e.g., a person sitting at a table at 6pm is not very likely to have dinner in Spain, whereas this is much more likely in the UK).

After recognizing an activity, the system shall be able to verify, in partnership with the person, if the detected activity corresponds to the activity that the person is really

performing through dialogue. To this end, the PhD candidate will be encouraged to rely on Cloud-based services for Automatic Speech Recognition (e.g., Google ASR, https://cloud.google.com/speech/) as well as for Natural Language Processing (e.g., DialogFlow, https://dialogflow.com/). The evidence acquired by collecting the person's answers shall provide an input for updating the assumptions that the system has made, with the ultimate aim of tailoring the system's behaviour to the specific customs and habits of the person with whom the robot is interacting.

Requirements: The ideal candidate will have a strong motivation for working in an interdisciplinary and international group, a solid background in robotics and robot programming (Java and Python), and a specific interest in social robotics and human-robot interaction.

Specifically, the student will be requested to use the following tools

- OWL2 API for building and querying ontologies
- Netica API for Bayesian Networks
- API to access cloud services for the semantic tagging of images as well as for Automatic Speech Recognition and Natural Language Processing
- NAOqi API for sensorimotor control of the Pepper's robot

References:

- Barbara Bruno, Nak Young Chong, Hiroko Kamide, Sanjeev Kanoria, Jaeryoung Lee, Yuto Lim, Amit Kumar Pandey, Chris Papadopoulos, Irena Papadopoulos, Federico Pecora, Alessandro Saffiotti and Antonio Sgorbissa, Paving the Way for Culturally Competent Robots: a Position Paper, 2017 IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN), Lisbon, Portugal, August 2017
- Barbara Bruno, Fulvio Mastrogiovanni, Federico Pecora, Alessandro Saffiotti, Antonio Sgorbissa, Fuzzy Logic for Culture-aware Robotics, 3rd Workshop on Artificial Intelligence and Robotics (AIRO 2016), hosted AIxIA 2016.
- Cultural Robotics, First International Workshop, CR 2015, Held as Part of IEEE RO-MAN 2015, Kobe, Japan, August 31, 2015. Editors: Koh, J.T.K.V., Dunstan, B.J., Silvera-Tawil, D., Velonaki, M. (Eds.), Lecture Notes in Artificial Intelligence 9549, Springer.

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6. Surface and underwater deployment and docking systems for underwater autonomous vehicles.

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Co-Tutor(s):
Enrico Simetti

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The PhD proposal is offered jointly with the Interuniversity Centre of Integrated Systems for the Marine Environment (ISME).
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Description:
The theme of the PhD is the study and simulation of automatic rendezvous systems between Autonomous Underwater Systems (AUVs) and docking stations. The challenge is that the docking station is not necessarily moored to the seafloor, but could be towed by a surface vehicle and therefore floating underwater or near the sea surface. The rendezvous needs to be accomplished through cooperative control techniques between the docking station and the AUV itself, through the use of advanced sensors and data exchange among the two systems.

This research theme is extremely important in the field of marine robotics, where the need of such automatic systems is very high, since reliable and scalable launch and recovery systems are a necessary part toward the increase use of AUVs in the near future.

Requirements:
Very good knowledge of Matlab is required.
Good knowledge of C++ is also required.

References:

- Allen, B., Austin, T., Forrester, N., Goldsborough, R., Kukulya, A., Packard, G., Purcell, M. and Stokey, R., "Autonomous docking demonstrations with enhanced REMUS technology", in Proceedings of OCEANS'06 MTS/IEEE Conference, pp. 1–6, Boston, MA, USA, September 2006.
- Feezor, M., Sorrell, Y., Blankinship, P. and Bellingham, J., "Autonomous underwater vehicle homing/docking via electromagnetic guidance". IEEE Journal of Oceanic Engineering, Vol. 26, No. 4, pp. 515–521, October 2001.
- Granger, R., Smith, J., Somlyody, S., Thomas, B. and Labosky, J., "UUV docking and recharging station: Demonstration results and next steps", in Proceedings

of the American Society of Naval Engineers Launch and Recovery 2012 Symposium, Baltimore, MD, USA, November 2012

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7. Robots in the warehouse: methods and technologies for the next-generation warehouse logistics

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Description:
In the past few years, we assisted to the increasing use of mobile robot solutions in warehouses, specifically to transport goods between different areas, e.g., from storage to manual loading or unloading areas. Typically, these robots cannot be considered fully autonomous yet: either they rely on environmental cues, which have been purposely engineered for them, such as artificial beacons, coloured strips on the floor or markers of various shapes, or are designed as specialised goods transportation systems, or both.
We would like to investigate methods and technologies allowing fully autonomous vehicles in warehouses, able to transport goods between different areas without relying on modifications of the environment to work properly.
The topic has received much attention both in scientific literature and in the startup ecosystem: the Amazon Kiva system, the Knapp open shuttle, the Locus Robotics systems, the Swisslog CarryPick vehicle, the GreyOrange Butler, the solutions from Fetch Robotics, the Scallog system or the Hitachi Racrew are examples of commercial or quasi-commercial products for warehouse logistics automation. However, all theses systems represent specialised robot solutions, which do not share almost anything with current, human-based solutions for warehouse logistics. In other words, they are aimed at replacing current technological solutions and, as such, they constitute entry-level barriers to the widespread adoption of advanced robotic solutions in warehouses.
The PhD proposal aims at developing methods and technologies allowing common electric transpallets and forklift trucks to become fully autonomous. In particular, the student will:

- investigate methods for simultaneous localisation and mapping in warehouse scenarios, also including cooperative approaches;
- design and implement path planning, obstacle avoidance, and robot navigation behaviours in a warehouse environment;
- design and implement methods and solutions for acting on payloads (forking pallets, picking, detecting, interacting with operators and so on);
- design and implement suitable perception algorithms to recognise common warehouse objects, such as transportation pallets and other vehicles;

- integrate the single robot architecture with a distributed system for high-level action planning and scheduling;
- integrate the single robot architecture with future wider intelligent automatized systems in the warehouse, such as autonomous carriers and trucks, robot arms, non robotic displacement systems and similar).

The work will be tested in cooperation with SogeGross SpA, which is one of the top 10 Italian private groups working in large-scale organised logistics.

Requirements:

- Concepts related to mobile robotics, planning, reasoning.
- Software development in C/C++.

References:

- F. Mastrogiovanni, A. Sgorbissa, R. Zaccaria. Distributed sensing and human-aware robot reasoning mechanisms. In N. Y. Chong (Ed.) Networking humans, robots and environments, pp. 43-58, Bentham Publishers, 2013.
- L. Iocchi, E. Menegatti, A. Bonarini, M. Matteucci, E. Pagello, L. C. Aiello, D. Nardi, F. Mastrogiovanni, A. Sgorbissa, R. Zaccaria, R. Sorbello, A. Chella, M. Giardina, P. Zingaretti, E. Frontoni, A. Mancini, G. Cicirelli, A. Farinelli, D. G. Sorrenti. Development of intelligent service robots. Intelligenza Artificiale, vol. 7, no. 2, pp. 139-152, January 2013.
- F. Mastrogiovanni, A. Sgorbissa. R. Zaccaria. How the location of the range sensor affects EKF-based localisation. Journal of Intelligent & Robotic Systems, vol. 68, no. 2, pp. 121-138, 2012.

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8. Semi-autonomous defects inspection in shop-floor scenarios via human-robot cooperation processes

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Description:
According to the Industry 4.0 paradigm, it is expected that many manufacturing processes will undergo a decisive paradigm shift in the upcoming future, and such shift may involve the nature itself of industrial environments. One of the most relevant ideas put forth in smart factories is to close the gap between production and end user needs, improving their satisfaction via a high level in personalisation and just in time production. Such a fact will pose serious difficulties to human operators working in shop floor or warehouse environments, in so far as stress and fatigue (and therefore alienation) are concerned, with additional repercussions on job quality and the number of defected goods.

Among the guidelines to limit such drawbacks affecting human operators, it has been proposed that collaborative robots work closely with human operators to carry out tasks usually considered stressful, fatigue-prone or difficult. In such a scenario, this project aims at addressing a number of research and technological objectives shared between University of Genoa and Applied Tech Systems srl, a multinational company with a local branch in Genoa, and in particular:

1. Automated inspection processes using state of the art machine learning approaches. Solutions addressing this objective will have to maximise a series of Key Performance Indicators, e.g., decreasing the overall inspection time, reducing the number of false positives, limiting the stress and fatigue levels of human operators.

2. Integrate the inspection process with software and control architectures allowing for a natural cooperation between human operators and robots, and supporting collaborative inspection processes. Such integration will have to take into account the availability of wearable devices (e.g., for augmented reality or body tracking) to be used by human operators.

These objectives will be met via the analysis, design and a first development of a robot-assisted inspection architecture based on Deep Learning approaches, allowing collaborative robots to learn inspection procedures while interacting with human

operators. Such objectives entail a series of challenges as far as physical and cognitive aspects of the cooperation are concerned. Beside a number of basic considerations related to the safety of human operators, other key aspects include robot-based perception, human activity recognition, the definition of cooperation models appropriate to meet certain target performance levels in the cooperation process, action planning and execution strategies for robots while their workspace is shared with humans, just to name a few.

Requirements:

- Concepts related to human-robot cooperation, machine learning, planning, and reasoning, as well as human activity recognition.
- Software development in C/C++.

References:

- A. Capitanelli, M. Maratea, F. Mastrogiovanni, M. Vallati. On the manipulation of articulated objects in human-robot cooperation scenarios. arXiv preprint arXiv:1801.01757.
- D. Shah, E. Denicia, T. Pimentel, B. Bruno, F. Mastrogiovanni. Detection of bimanual gestures everywhere: why it matters, what we need and what is missing. Robotics and Autonomous Systems 99, pages 30-49, 2018.
- K. Darvish, F. Wanderlingh, B. Bruno, E. Simetti, F. Mastrogiovanni, G. Casalino. Flexible human-robot cooperation models for assisted shop-floor tasks. Mechatronics, *to appear*.

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