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 swarms made-up of terrestrial and aerial robots

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Co-Tutor:
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Description:
The use of unmanned aerial vehicles (UAVs) is getting a lot of attention in robotics research, due to the new research challenges such vehicles pose: low-level control aspects, navigation in real-world conditions, mapping of large areas, real-time obstacle avoidance, just to name but few. When considering multi-vehicle scenarios, also involving unmanned ground vehicles (UGVs), such challenges become even more difficult to face.

In the literature, different approaches have been discussed to implement control strategies for heterogeneous systems involving UGVs and UAVs. However, most approaches are focused on low-level control aspects, and much less is present in the literature regarding advanced behaviours in non-stationary environments, and their implications for high-level representation and reasoning processes, such as those involved in hybrid continuous/discrete frameworks such as PDDL+ based planners.

With this PhD proposal, we want to investigate two orders of challenges: on the one hand, we want to implement a number of UAV-related behaviours, such as the autonomous transportation of objects, 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 swarms of heterogeneous robots to quickly reconfigure in order to achieve a given task, such as rendezvous and coordinated exploration.

Prospective PhD students will be involved in:

- the development of UAV-based scenarios in which the task requires the online identification of a number of robots' model parameters, e.g., transporting objects between different locations in the environment, which implies a change in the robot's weight;
- the design of coordination strategies between heterogeneous vehicles, such as UAVs and UGVs, e.g., to allow for cooperative exploration or rendezvous.

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. These robots will be able to **adapt how they behave and speak to the culture, customs and manners** of the person they assist. CARESSES' innovative approach will translate into care robots that are designed to be **sensitive to the culture-specific needs and preferences of elderly clients,** while offering them a safe, reliable and intuitive system, specifically designed to support active and healthy ageing and reduce caregiver burden. CARESSES' culturally aware solution will expand the capabilities of the Pepper robot, which is designed and marketed by Softbank Robotics, a partner of the project. **Culturally aware robot capabilities will include**:

- communicating through speech and gestures;
- moving independently;
- assisting the person in performing everyday tasks (e.g. helping with to-do lists and keeping track of bills, suggesting menu plans);
- providing health-related assistance (e.g. reminding the person to take her medication);
- providing easy access to technology (e.g. internet, video calls, smart appliances for home automation);
- providing entertainment. (e.g. reading aloud, playing music and games)

CARESSES involves researchers from different European countries and Japan, with backgrounds in Robotics, Human-Robot Interaction, Artificial Intelligence, Smart Home Automation, Transcultural Nursing, Social Psychology, Evaluation of Health- and Wellbeing-related Technology, along with a world leading Robotics Company, and a Network of Residential and Nursing Care Homes.

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.

References:

- 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. Obstacle Detection and Avoidance System for Unmanned Vessels

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Co-Tutor:
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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:
Unmanned Surface Vehicles (USVs) are autonomous boats that have different applications, ranging from patrolling and monitoring of the waterways for security reasons, to scientific applications such as sampling the water for pollution or biological investigations.

One of the major research theme to be tackled, for the widespread adoption of USVs, is the development of reliable obstacle *detection* and *avoidance* systems [1]. In particular, in this research project, the use of LIDAR sensors (Velodyne PUCK), together with IR and EO cameras is proposed as a mean for detecting obstacles in short proximity of the USV (around 100 m). Possible integration with a Solid-state Doppler Radar is foreseen as a successive step. A proper data fusion of all these sensors should lead to the development of a compact and reliable detection system, providing the required feedback for the control system.

For what concerns control algorithms for the avoidance, previous results are already available as a base for further developments [2], including the addition of constraints such as limited curvature radius of the USVs, as well as the addition of “rules of the road” (COLREGS).

ISME has developed an autonomous catamaran (3 m length x 1.8 m width), which can be used for gathering datasets and testing the detection and avoidance algorithms. ISME is involved together with CSSN (Italian Navy) in a joint research lab called Sealab, which allows access to a wide restricted marine area in La Spezia, where all the experimentation can take place.

Requirements:
Very good knowledge of C/C++ is required.
Basic knowledge of GPU processing, vision techniques, mechatronics, robotics and automatic control is a plus.

References:

- Sorbara, A., Odetti, A., Bibuli, M., Zereik, E., Bruzzone, G. Design of an obstacle detection system for marine autonomous vehicles. In OCEANS 15, Genova, 2015
- E. Simetti, S. Torelli, G. Casalino and A. Turetta. Experimental Results on Obstacle Avoidance for High Speed Unmanned Surface Vehicles. In OCEANS 14, St. John's, Canada, September 2014.

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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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