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 behaviour while autonomously 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, design of human-robot interfaces, 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).

Moreover, all the aspects above are faced by putting a special emphasis on the study and the adoption of theoretically founded methodologies and the design of experimentally verifiable solutions, to the end of meeting the robustness and predictability requirements even in unknown, dynamically changing, or even hazardous environments.

The themes offered this year as part of this curriculum are supported by the Department of Informatics, Bioengineering, Robotics and System Engineering (DIBRIS) of University of Genova.

The ideal candidates are students with a higher level university degree, with a strong desire for designing and developing the robotic systems impacting on the society in the close future.

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

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1. Advanced Autonomy and Cooperation for Unmanned Marine Systems

Tutors: Enrico Simetti, Giuseppe Casalino

Department: DIBRIS (University of Genova)
http://www.dibris.unige.it

Description: The GRAAL lab (www.graal.dist.unige.it), which is part of ISME (Interuniversity center on integrated system for the marine environment, www.isme.unige.it) is currently involved in two research areas involving autonomous marine vehicles.

The first one is the navigation and obstacle avoidance aspects, mainly involving surface vehicles. This topic is a key one for the future use of surface vehicles in unrestricted areas. The second research topic is the cooperation between a team of

marine vehicles, often in form of distributed algorithms. The cooperation has been studied for topics such as patrolling or adaptive sampling, both for surface and underwater vehicles.

Currently, the GRAAL lab is involved in the on-going H2020 WiMUST project. The WiMUST proposal aims at conceiving, designing, and engineering an intelligent, manageable, distributed and reconfigurable underwater acoustic array that could drastically improve the efficacy of the methodologies used to perform geophysical and geotechnical acoustic surveys at sea.

This PhD program will thus investigate these two main topics. The PhD program will exploit different hardware resources for its experimental results: 10 small scale unmanned surface vehicles, 2 eFolaga AUVs.

Part of these researches will be carried out in cooperation with the SEALab, a joint laboratory between ISME and CSSN (Center for naval experimentation support) of the Italian Navy. The SEALab has direct access to a vast restricted navigation area inside the port of La Spezia were field experiments will be done.

Requirements: Applicants are expected to have strong background and experience in at least one of the following topics: mechatronics, control theory, robotics. The candidates must have: strong programming skills (C/C++, Matlab/Simulink); attitude to problem solving, to conduct experiments, and finally be motivated to work within a research team in collaborative projects.

Reference: 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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2. Biologically inspired approaches to perception, knowledge representation and action in Robotics

Tutors: Fulvio Mastrogiovanni

Department: DIBRIS (University of Genoa)
http://www.dibris.unige.it

Description (MAX 1500 char):
During the past few years, many approaches have been pursued to define computational models of reasoning, specifically for the integration between action and motion planning in robots. The main problem is the huge amount of concepts, objects and their relationships a robot should consider if it had to carry out real-world tasks.

We argue that it is necessary to solve a representation problem. We put forth a novel computational planning theory that is heavily inspired by how such mammals as monkeys behave.

Within this context, the student is expected to carry out the following research activities.

- Design, develop and validate a bio-inspired framework allowing a bi-manual robot to learn bio-inspired, neural-based representation structures related to real-world objects using, force, vision and proprioceptive information.
- Use the developed representation structures to assess knowledge coded in suitable neural spaces, in order to reason about goals, plans and actions. Representation structures refer to capabilities (i.e., what a robot gain in considering them) and affordances (i.e., what possible actions they entails).
- Carry out planned actions monitoring their execution at run-time in order to implement advanced and multi-modal sensory-motor couplings. Each action execution reflects back as sensory information, thereby allowing the system to continuously update relevant representation structures.

The framework will be tested in a bi-manual mobile manipulation scenario.

Requirements: Interests in knowledge representation, perception, reasoning, biologically-inspired robot architectures for perception and control, developmental aspects, category learning.

Reference: F. Mastrogiovanni, A. Sgorbissa. A biologically plausible, neural-inspired planning approach which does not solve "The gourd, the monkey and the rice" puzzle. Biologically Inspired Cognitive Architectures 2:77-87, October 2012.

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3. Heterogeneous robots capable of autonomous behavior in complex, unstructured environments.

Tutor: Antonio Sgorbissa

Department: DIBRIS (University of Genoa)
http://www.dibris.unige.it

Description (MAX 1500 char):
The focus of this research theme is on the development of heterogeneous teams of robots (flying multirotors, wheeled-robots, slithering robots, etc.) and human first responders (equipped with wearable sensors, actuators and computers embedded in clothes) operating in hazardous scenario. One of the possible application domains is search & rescue after earthquakes: the hosting laboratory is involved in the two projects PRISMA and DIONISO for robotic intervention after a seismic event, together with other Italian and International partners.

The capability to operate in complete autonomy in unstructured environments is probably the most important feature required by successful robotic systems able to cooperate with humans in the accomplishment of complex tasks. Autonomy include the capability to acquire and interpret sensor data in real-time, building representations (e.g., maps) of the environment, compute one's position, taking decisions to plan a course of actions, coordinate with team members, executing actions, monitoring action execution, etc.

In the last two decades, the robotic community has spent a significant research effort on some of these issues, for instance in the attempt to solve the so-called SLAM problem, i.e., the problem of building and iteratively updating a map, and computing the position of the robot in such a map. Now, times are mature to reconsider the problem of autonomous behavior in a wider perspective, facing issues both related to low-level control and to higher-level cognitive functions in a novel, integrated way.

In this spirit, the purpose of the research will be to provide shared solutions enabling teams of heterogeneous robots (i.e., whose morphology and capabilities can be extremely different from robot to robot) to exhibit an autonomous, goal-oriented behavior in complex, unstructured environments. Within this context, the student is expected to carry out the following research activities.

- Study the relevant Literature in the field;
- Define and implement new algorithms to perform such activities as data fusion, 2D and 3D map building, localization, planning, etc;
- Define a real-time software architecture for managing all the concurrent activities to be executed;
- Test the proposed solutions in simulation and on real robots.

Requirements: Very good programming skills; interests in studying and developing new SW solutions to design autonomous robotic systems.

Reference: A. Sgorbissa, R. Zaccaria, "Planning and obstacle avoidance in mobile robotics", ROBOTICS AND AUTONOMOUS SYSTEMS 60(4), 628:638 (2012)

M. Baglietto, A. Sgorbissa, D. Verda, R. Zaccaria, "Human navigation and mapping with a 6DOF IMU and a laser scanner" ROBOTICS AND AUTONOMOUS SYSTEMS vol. 59 1060:1069 (2011)

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4. Manufacturing of robot sensors and functional components for robotics using 3D printing and rapid prototyping technologies

Tutors: Giorgio Cannata

Department: DIBRIS (University of Genova)
http://www.dibris.unige.it

Description (MAX 1500 char):
Rapid prototyping technologies. and 3D printing in particular are becoming more and more popular and cost effective. They enable the possibility of develop mechanical parts featuring high geometrical complexity; furthermore, by reducing the manufacturing time and cost allow the fast evolutionary development of new parts, and finally make possible the production of small series. Most of the 3D printing technologies are based on additive material deposition processes, however, advanced machines allowing additive synthesis and subtractive precise re-working are emerging allowing to increase the accuracy and the finishing quality of the parts.

In the robotics domain miniaturized and highly integrated sensors (e.g. force/torque, tactile, etc.) sensors represent key technologies for the execution of advanced tasks. The objective of this activity is to study and implement 3D printing manufacturing solutions making possible the embedding of functional elements (typically transducers) during the construction process.

This research topic is emerging from the activities performed at DIBRIS during recent international project (ROBOSKIN: www.roboskin.eu; CloPeMa: www.clopema.eu)

Requirements: Applicants are expected to have strong background and experience in at least one of the following topics: mechatronics, mechanical engineering, robotics. The candidates must have: good mechanical design capability, good programming skills (preferably: C/C++, Matlab/Simulink); knowledge of FEM software simlation tools; attitude to problem solving, to conduct experiments, and finally be motivated to work within a research team in collaborative projects.

References: Maiolino, P., Galantini, F., Mastrogiovanni, F., Gallone, G., Cannata, G., Carpi, F., "Soft dielectrics for capacitive sensing in robot skins: Performance of different elastomer types", Sensors and Actuators, A: Physical, 226, 9066, 2015.
Loi, A., Basiricò, L., Cosseddu, P., Lai, S., Barbaro, M., Bonfiglio, A., Maiolino, P., Baglini, E., Denei, S., Mastrogiovanni, F., Cannata, G., "Organic bendable and stretchable field effect devices for sensing applications", IEEE Sensors Journal, 13, 12, 2013.

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5. Real-time control architectures for robot control

Tutors: Giorgio Cannata

Department: DIBRIS (University of Genova)
http://www.dibris.unige.it

Description (MAX 1500 char):

The execution of complex robot tasks is based on sophisticated control algorithms involving multiple feedback loops from ethereogenous sensors (typically cameras, tactile, force/torque sensors, etc.). Although, the theoretical foundation of these control schemes has been extensively investigated, their implementation is very often a critical issue. As a matter of fact most of the existing middleware for robot programming do not provide support for the implementation of real-time sensor based task level control algorithms and do not provide support for control software design for embedded controllers which are becoming more and more used in innovative robotic control architectures. The goal of this activity is to investigate software design solutions which allow to extend ROS (Robot Operating System – presently a de-fact standard) with functionality making possible the real-time implementation of closed loop sensor based control algorithms over distributed control architectures, possibly including networked control.

This research topic is part of past or ongoing relevant international research projects where DIBRIS has been involved (ROBOSKIN: www.roboskin.eu; CloPeMa: www.clopema.eu)

Requirements: Applicants are expected to have strong background and experience in at least one of the following topics: robot control, real-time systems, software engineering. The candidates must have: excellent programming skills with different languages (including C/C++, Python, Matlab/Simulink); knowledge of major operating systems and network protocols; attitude to problem solving, to conduct experiments, and finally be motivated to work within a research team in collaborative projects.

References: Youssefi, S., Denei, S., Mastrogiovanni, F., Cannata, G. "A middleware for whole body skin-like tactile systems", Proceedings of 2011 IEEE-RAS International Conference on Humanoid Robots.
Youssefi, S., Denei, S., Mastrogiovanni, F., Cannata, G., "A real-time data acquisition and processing framework for large-scale robot skin", Robotics and Autonomous Systems. Volume 68, June 2015, Pages 86–103.

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6. Sensor based task planning and control of bi-manual robots

Tutors: Giorgio Cannata

Department: DIBRIS (University of Genova)
http://www.dibris.unige.it

Description (MAX 1500 char):
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 are expected to execute highly coordinated motions properly reacting to unexpected events and to

changes within their working envelope in order to ensure the reliable and safe (in case of interaction with humans) execution of the planned tasks.

Furthermore, the usage of highly sensorized robot systems typically featuring multiple camera sensors, tactile and force/torque sensors, or even new task specific sensors, 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 are part of past or ongoing relevant international research projects where DIBRIS has been involved (ROBOSKIN: www.roboskin.eu; CloPeMa: www.clopema.eu)

Requirements: Applicants are expected to have strong background and experience in at least one of the following topics: robot control, robotics, mechatronics. The candidates must have: very good programming skills with different languages (including C/C++, Python, Matlab/Simulink); experience with electronic hardware and be capable to conduct experiments; attitude to problem solving, and finally be motivated to work within a research team in collaborative projects.

Reference: Cannata, G., Denei, S., Mastrogiovanni, F., "Towards the creation of tactile maps for robots and their use in robot contact motion control", 2015Robotics and Autonomous Systems, Volume 63, Part 3, January 2015, Pages 293–308

Del Prete, A., Denei, S., Natale, L., Mastrogiovanni, F., Nori, F., Cannata, G., Metta, G., "Skin spatial calibration using force/torque measurements", IEEE International Conference on Intelligent Robots and Systems IROS 2011.

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7. Optimal control for Identification and state estimation

Tutors: Marco Baglietto

Department: DIBRIS (University of Genova)
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Description: Methods for state and parameters estimation will be addressed, with particular attention to identification problems and fault diagnosis applications.

Many techniques have been proposed in the literature in these fields, but the role of control for such purposes has not been completely addressed. In fact, while

concepts such as persistence of excitation has been considered, an aspect that has been largely disregarded is how to design an appropriate controller (or a set of controllers) such that some control performance is guaranteed while also preserving suitable estimation performance.

The focus of this program will be the study of control design methods in connection with suitable estimation techniques able to guarantee both some prescribed control performance as well as suitable convergence of the estimation error.

Different control methods will be addressed based on parameterization of the control laws as well as on approximate optimization methods. As to the estimation, the so called moving horizon paradigm will be first considered.

Requirements: background in Control Theory, Identification and Estimation is needed.

Reference: A. Alessandri, M. Baglietto, G. Battistelli, "Moving-horizon state estimation for nonlinear discrete-time systems: New stability results and approximation schemes", Automatica, vol. 44, no. 7, pp. 1753-1765, 2008.

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8. Robotics for Intervention

Tutors: Giuseppe Casalino, Enrico Simetti

Department: DIBRIS (University of Genova)
http://www.dibris.unige.it

Description: Robotics for intervention is certainly a very active topic of research and indeed mobile manipulation and bimanual operations will be key research topics for the factory of the future, as well as a very challenging topic for deep underwater operations.
The GRAAL lab (www.graal.dist.unige.it), which is part of ISME (Interuniversity center on integrated system for the marine environment, www.isme.unige.it), has been involved in many projects involving autonomous manipulation, both in ground and underwater scenarios.
Recently, it has been involved in the EU FP7 project TRIDENT, which has successfully completed the first steps in underwater autonomous floating intervention and in the MARIS national project, which aims at extending the TRIDENT results to cooperative underwater intervention. Currently, it is involved in the on-going H2020 DexROV project (http://www.dexrov.eu/), which aims at increasing the autonomous capabilities of work class ROVs to enable their tele-operation from remote sites (i.e. not from the support ship).

The PhD program will start from some of the results of these projects and its main objective will be the definition of a uniform control methodology able to encompass most if not all of the aforementioned operative scenarios. The program will thus mainly involve the following areas of research: force control, dynamic control of the coupled vehicle/manipulator system, task-priority based control, multi-robot cooperation, tele-operation with latencies.

The PhD program will exploit different hardware resources for its experimental results: a crawler mobile manipulator for outdoor environments, two youBot platforms, and the experimental setups of the DexROV project.

Requirements: Applicants are expected to have strong background and experience in at least one of the following topics: mechatronics, control theory, robotics. The candidates must have: strong programming skills (C/C++, Matlab/Simulink); attitude to problem solving, to conduct experiments, and finally be motivated to work within a research team in collaborative projects.

Reference: E. Simetti, G. Casalino, S. Torelli, A. Sperinde and A. Turetta. Floating Underwater Manipulation: Developed Control Methodology and Experimental Validation within the TRIDENT Project. *Journal of Field Robotics*, volume 31(3):364--385, May 2014

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9. Spatial, temporal and commonsense reasoning in robots

Tutors: Fulvio Mastrogiovanni

Department: DIBRIS (University of Genova)
http://www.dibris.unige.it

Description (MAX 1500 char):
In the past few years, we witnessed a growing interest in applying spatial, temporal and commonsense (also ontology-based) knowledge representation and reasoning techniques in robots to make sense of incoming perceptions and to define a (long-term) course of action.

On the one hand, it is evident that in order to reach a high-quality purposive robot behavior it is necessary to define novel representation structures able to capture and integrate the richness of sensory data (i.e., tactile and visual), as well as their heterogeneous nature.

On the other hand, sequential or even hybrid paradigms like sense-plan-act and sense-act(+plan) are limited in that they factitiously separate these three aspects. On the contrary, approaches interleaving sensing, representation and action are

expected to be fundamental for robots operating in real-world environments, like homes, mines, space or in the sea.

The objective is two-fold:

1) Design and develop innovative techniques to represent heterogeneous and multi-modal sensory data encoding real-world (possibly flexible) objects and events the robot perceives and interact with, taking into account both spatial and temporal features.

2) Investigate novel (software) architectures and planning frameworks for robot action (incl. language) able to exhibit integrated (task-level) symbolic and continuous planning capabilities, as well as to modify and adapt their representation structures and planning schemes on the basis of their experience.

Requirements: Interests in knowledge representation, planning, software architectures for robots, basics of C/C++.

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