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.

1. 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.

Contacts: fulvio.mastrogiovanni@unige.it

2. Coordinated planning, estimation, and navigation for autonomous mobile robots

Tutors: Marco Baglietto

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

Description: Development of mobile robots able to operate complex tasks in an unstructured environment is one of the most challenging objectives in robotics, as can be shown by the recent challenges by EuRoC, and is revealing to be of great interest for the industry.

The objective of this research program is to study and develop techniques for planning, estimation, and navigation allowing a team of mobile robots to accomplish a common task with a high level of autonomy. The use of a team can be useful to overcome possible constraints related to operating range and payload of each single mobile robot and should ensure redundancy and robustness of the overall system.

The team should be able to face unpredicted situations, faults, or changing of the operating environments only resorting to "on board" computational resources and sensors. Each member of the team should be provided of suitable obstacle avoidance strategies taking into account the possible presence of moving agents other than the team components.

Requirements: background in Control Theory and mobile robotics is needed.

Contacts: marco.baglietto@unige.it

3. Joint control and estimation for nonlinear systems

Tutors: Marco Baglietto

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

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.

Contacts: marco.baglietto@unige.it

4. Manufacturing of 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 technology 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.

Contacts: giorgio.cannata@unige.it

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.

Reference: S. YOUSSEFI, S. DENEI, F. MASTROGIOVANNI, G. CANNATA "A Middleware for Whole Body Skin-like Tactile Systems", 2011 IEEE-RAS 11th International Conference on Humanoid Robots, October 26-28, 2011, Bled, Slovenia.

Contacts: giorgio.cannata@unige.it

6. 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. Many ground robotics project involving mobile manipulation have been funded (as for example the ongoing MAREA national project). Mobile manipulation and bimanual operations will be key research topics for the factory of the future. Recently, the EU FP7 project TRIDENT has successfully completed the first steps in underwater autonomous floating intervention and the MARIS national project aims at extending the TRIDENT results to cooperative underwater intervention. As instead regards aerial robotics, the ongoing FP7 project ARCAS aims at developing intervention techniques for assembly operations carried out by flying robots.

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 cooperation between multiple robots to achieve complex intervention tasks will represent an important goal of the program. 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.

The PhD program will exploit different hardware resources for its experimental results: a crawler mobile manipulator for outdoor environments, two youBot platforms, and two floating underwater manipulators currently developed for the MARIS national 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

Contacts: pino@dist.unige.it - simetti@dist.unige.it

7. 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: S. DENEI, F. MASTROGIOVANNI, G. CANNATA, "Parallel Force-Position Control Mediated by Tactile Maps for Robot Contact Tasks", 2012 IEEE/RSJ International Conference on Intelligent Robots and Systems October 7-12, 2012, Vilamoura (Portugal).

Contacts: giorgio.cannata@unige.it

8. 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++.

Contacts: fulvio.mastrogiovanni@unige.it