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, design of 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 backed 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. Sensor based control of bi-manual robots for human-robot cooperative operations

Tutor(s): Giorgio Cannata

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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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2. 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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3. A study about how human perceive robots in interaction processes

Tutor(s): Fulvio Mastrogiovanni
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Description: Human-robot interaction is expected to play a significant role in the near future. As soon as robots will be employed in environments and for tasks requiring them to be in close contact with humans, the implications of their behaviours on human's attitudes, emotions and feelings (eventually, behaviour) cannot be underestimated.
We are interested in assessing and measuring the effects of *controlled* robot behaviours on humans, specifically in all those aspects constituting what in cognitive psychology is termed non-verbal behaviour (e.g., gestures and their parameters, head motions, gaze), while humans and robots are engaged in a collaborative activity.
In fact, literature suggests that humans can be greatly influenced (at the subconscious level) by environmental and human factors, and their actions be dependent on perceptions they do not even conceptualise.
The PhD proposal has two main objectives: on the one hand, design, investigate and assess methods to adapt experimental protocols borrowed from behavioural and cognitive psychology to understand how human behaviour can be influenced by robot behaviour, and how humans interpret it; on the other hand, synthetize robot behaviours which takes human expectations into account, and convey a specific (non-verbal) message as humans would do.
To this aim, the student will have also to encode specific sensorimotor skills, which will be mediated by insights in cognitive and behavioural psychology. Such skills will have to be part of a robot behavioural architecture able to allow for advanced forms of cognitive human-robot interaction.
The experimental assessment will be conducted using a Baxter dual-arm manipulator in the context of human-robot interaction processes, e.g., object handovers. The project will be conducted in cooperation with University College London (UK), the National Institute of Informatics and Keio University (both in Japan).

Requirements:
- Ontology-based and probabilistic knowledge representation techniques.
- Software development in C/C++.
- Problem-solving and experimental attitude

References:
- N. Braisby and A. Gellatly. Cognitive Psychology. Oxford University Press, Oxford, U.K., 2012.
- J. A. Zlotowski, H. Sumioka, S. Nishio, D. F. Glas, C. Bartnek, H. Ishiguro. Persistence of the uncanny valley: the influence of repeated interactions and a robot's attitude on its perception. Frontiers of Psychology 6 (883), 2015.

- M. Bono, P. Maiolino, A. Lefebvre, F. Mastrogiovanni, H. Ishiguro. Robots acting on a stage: are they perceived as humans in interactions? In R. Nakatsu, P. Ciancarini and M. Rautenberg (Eds.) Handbook of digital games and entertainment technologies. Springer-Verlag Berlin Heidelberg, 2016.

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4. The use of language to bootstrap robot's knowledge and reasoning in human-robot interaction tasks

Tutor(s): Fulvio Mastrogiovanni

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Description: According to the cognitive perspective on language development and evolution in humans, the *language faculty* plays a decisive role in the development of both rational thought and reasoning. Such an approach criticises the classical paradigm which views language as a communication capability derived from thought and its basic rules as a by product, i.e., the Chomsky's notion of Universal Grammar.
If the cognitive perspective has some degree of plausibility, then the implications in human-robot interaction scenarios can be particularly important.
The main objective of this PhD proposal is to investigate methods to bootstrap robot's knowledge and reasoning capabilities by means of a dialogue-based human-robot interaction process. We aim at a scenario where a human teaches a robot about objects, their properties and mutual configurations, using both demonstration and dialogue. The robot must be able to ground sensory perceptions (e.g., visual or haptic) with the syntax and semantic clues uttered by the human during the dialogue. Using the acquired knowledge, the robot will be therefore able to manipulate objects on the basis of human-provided instructions.
The knowledge acquired by the robot through the human-robot interaction process and the reasoning schema are going to be represented using models whose structures are borrowed from recent studies in behavioural psychology: the student will evaluate and use such conceptual tools as probabilistic ontologies to ground knowledge expressed using the Bayesian theory of subjective probability, the Dempster-Shafer theory and its extensions, e.g., the Transferable Belief model, which are typically used to manage inconsistences.
The student will test and assess the developed models in a human-robot interaction scenario where a Baxter dual-arm manipulator will reason upon subjective spatial knowledge. The study will involve also joint work with the Japan Advanced Institute of Science and Technology (JAIST), as well as interdisciplinary work with experts in computational linguistics.

Requirements:
- Basic knowledge in statistics and probability theory.
- Knowledge representation and reasoning.
- Software development in C/C++.

References:

- G. Fauconnier. Mappings in thought and language. Cambridge University Press, Cambridge, MA, 1997.
- R. Hausser. Computational Linguistics and talking robots. Springer-Verlag Berlin Heidelberg, 2011.

- F. Pratama, F. Mastrogiovanni, S. G. Lee, N. Y. Chong. Long-term knowledge acquisition using contextual information in a memory-inspired robot architecture. Journal of Experimental and Theoretical Artificial Intelligence, *accepted for publication*. DOI: 10.1080/0952813X.2015.1134679.

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5. 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 on-line 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, machin 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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6. Cooperative Robotics for the Smart Factory

Tutor(s): Giuseppe Casalino

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Description: The application of robots within manufacturing industries dates back form the seventies and now represents a well-consolidated field of application.
Most of its successes could however be achieved by exploiting the possibility of generally having the robot working within well structured environments, even if rigid and therefore very much lacking of flexibility, where very many, if not all, of the robot operations could be planned in advance in their very details; and then executed with the required precision levels.
Accordingly with the Horizon 2020 Strategic Research Agenda (SRA) and related Multi Annual Roadmap (MRA) (but see also the recently launched European Challenge EUROC) all a set of challenges for the future factories have been therefore foreseen, also including the following important topics, by the way also addressing the specific needs of SME manufacturers:

- cost effectiveness at low lot sizes,
- intuitive to be used,
- easily adaptable to a wide variety of application tasks,
- easily reconfigurable modular kinematic structures,
- modular kinematic structures intrinsically exhibiting self-organizing properties (in terms of their reconfiguration and relevant motion control),
- exhibiting cooperation capabilities (with other robotic agents, as well as with humans during manipulation, assembly, transportation, etc.).

The proposed PhD program will address the last four of the above listed topics, by basing the activities concerning real time control and adaptation of the involved structures (mainly the self organization of modular robotic structures and cooperation capabilities) on some recent research results; clearly indicating the possibility of managing the mentioned topics within the same uniform, distributed and even decentralized, real time functional and algorithmic architectures.
Progresses in this direction are therefore expected as outputs of the PhD program; to be then experimented, for some typical manufacturing problems, within a strict integration with the higher levels of planning, decision and command, whose shift toward more abstract and simplified symbolic representation should actually be allowed, in the light of the expected real time control and adaptation results. To the above aims the PhD program will exploit different hardware resources for its experimental results; namely a crawler mobile manipulator for outdoor environments, two YouBot platforms and a Baxter bi-manual robotic system.

Requirements:
Applicants are expected to have strong background and experience in at least one of the following topics: mechatronics, multi-body kinematic and dynamic, control

theory, robotics. The candidates must also 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.

References:

- G. Casalino, G. Cannata, G. Panin, A. Caffaz. On a two-level hierarchical structure for the dynamic control of multifingered manipulation. Proceedings of the 2001 IEEE International Conference on Robotics & Automation (ICRA 2001), Seoul, Korea, May 2001.
- G. Casalino, A. Turetta, A. Sorbara. Distributed kinematic inversion technique for modular robotic systems. Proceedings of the 2007 International Conference on Intelligent Robots and Systems (IROS 2007), San Diego, CA, October 2007.
- E. Simetti, G. Casalino, S. Torelli, A. Sperindè , A. Turetta. Floating underwater manipulation: developed control methodology and experimental validation within the TRIDENT project. Journal of Field Robotics 31(3):364-385, May 2014.

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