PhD Program in Bioengineering and Robotics

Curriculum Advanced and Humanoid Robotics
Research themes

In the spirit of the doctoral School on Bioengineering and Robotics, the goal of the "advanced and humanoid robotics" curriculum is to study the design, realization, programming and control of anthropomorphic robots as well as robotic systems inspired from living organisms like plants and soft animals. Students will work at the forefront of mechatronics and computer science research jointly covering the full development cycle from software to mechanical design and from machine learning to realization of sensors, actuators and electronics. We address the development of the technologies for the next generation of robots based on soft and adaptable materials for sensing, actuation and computation. The goal is to develop robots that can adaptively interact with their environment, learn from their mistakes, and succeed in performing safely and reliably in real-world environments. Foreseen applications for anthropomorphic robots range from real-world practical scenarios - e.g., at home, as personal assistants- to industry as co-workers, to natural or man-made disaster scenarios. Humanoid robot software deals with vision, audition and tactile perception as well as the ability to look, reach and manipulate the world while walking freely to reach their targets, interacting naturally with the environment and their human "teachers". Soft robots inspired from plants and soft animals address several applicative scenarios, ranging from environmental monitoring, to soil exploration in emergency situations, search and rescue, and medical applications (i.e. surgical robotics).

The PhD themes in this curriculum are offered by the iCub Facility, by the Department of Advanced Robotics (ADVR) at the Genova Headquarters of the Istituto Italiano di Tecnologia (IIT) and by the Center for Micro-BioRobotics (CMBR), in Pontedera (Pisa), part of the IIT multidisciplinary research network.

The iCub Facility is the main integrator of IIT's research and technology on the iCub humanoid robotic platform. The iCub is the humanoid robot child designed to support researchers interested in the themes of learning, control, cognition, and interaction, both at IIT and worldwide. The goal of the iCub Facility is to lead the development of the iCub, arrange and time the construction of new versions, supervise the incorporation of new technologies and possibly foster their commercial exploitation. We create opportunities for collaboration at IIT and worldwide in a large network of iCub owners via European funded projects or commercial contracts. The iCub Facility ideal candidates are students with a master's degree in engineering, computer science, physics or related disciplines, open to learning, to novelty but keeping always an eye on the possibility of implementing research on the state of the art iCub humanoid robot.

Research within the ADVR concentrates on an innovative, multidisciplinary approach to humanoid design and control, and the development of novel robotic components and technologies. This encompasses activities from both the hard and soft systems areas of robotics. In particular, research on humanoid robotics at ADVR mostly focuses on the COMAN humanoid robot. The development of the COMAN body exploits the use of actuation systems with passive compliance, with two main goals: i) to reduce the distinction between plant and controller that is typical in traditional control engineering to fully exploit complex body properties, and ii) to simplify perception, control and learning and to explore how compliance can be exploited for safer human robot interaction, reduced energy consumption, simplified control, and faster and more aggressive learning.

The Center for Micro-BioRobotics (CMBR) began its scientific activity at the end of 2009 with the aim to perform advanced research and to develop innovative methodologies, robotic technologies, new materials, and advanced components at the micro/mesoscale. The micro/mesoscale domain shows dramatic potential for giving rise to new science and new technology, and for offering innovative engineering solutions to many practical application issues. Artefacts can be developed by observing, analyzing and modeling phenomena and strategies used by living creatures in order to achieve motion and propulsion, and to efficiently and adaptively interact with the environment. Bio-inspired approaches can help to develop robots that are more suitable for unstructured environments than today's robots. These robots, implementing solutions inspired by Nature, show better performance in terms of reactivity, adaptability, flexibility, and more compliant mechanisms. "Bio" means also technological solutions oriented to biomedical applications, such as functionalized nanofilms and robotic devices for drug delivery, therapy, and diagnosis, as well as to environmental monitoring, e.g. plant-inspired robots for soil exploration.

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

1. Articulatory information for automatic speech recognition in human–robot verbal interaction

Tutors: Giorgio Metta, Leonardo Badino

Department: iCub Facility (Istituto Italiano di Tecnologia)
http://www.iit.it/iCub

Description: State-of-the art Automatic Speech Recognition (ASR) systems produce remarkable results in some scenarios but still lags behind human level performance in several real usage scenarios and perform poorly whenever the type of acoustic noise, the speaker's accent and speaking style are "unknown" to the system, i.e., are not sufficiently covered in the data used to train the ASR system. The goal of the present theme is to create a robust speaker-independent *Key Phrases Recognition* system where commands delivered by a user to a robot (i.e., the key phrases) have to be recognized in unconstrained utterances (i.e., utterances with hesitations, disfluencies, additional out-of-task words, etc.), in the challenging conditions of human-robot verbal interaction where speech is typically distant (to the robot) and noisy. To improve the robustness of the recognition system to intrinsically challenging and/or unknown conditions we will create recognition systems that combine acoustic features with predicted vocal tract articulatory movements (Canevari et al. 2013) thus exploiting the articulatory representation of speech where phonetic targets (i.e., the articulatory targets necessary to produce a given sound) are largely invariant and complex phenomena observed in speech are can be compactly modeled.

Requirements: The successful candidate will have a degree in computer science, bioengineering, physics or related disciplines. A background in speech and language processing is a plus.

Reference: Canevari, C., Badino, L., Fadiga, L., Metta, G., "Cross-corpus and cross-linguistic evaluation of a speaker-dependent DNN-HMM ASR system using EMA data", Interspeech Workshop on Speech Production for Automatic Speech Recognition, Lyon, France, 2013.

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2. Whole-body real-time motion planning and control in compliant humanoids: theory and implementation on the iCub

Tutors: Francesco Nori, Giorgio Metta, Daniele Pucci

Istituto Italiano di Tecnologia, Department: RBCS http://www.iit.it/rbcs and **iCub Facility** http://www.iit.it/iCub

Description: the iCub is among the few humanoids capable of whole-body motion control while being compliant to perturbations (https://www.youtube.com/watch?v=VrPBSSQEr3A). These capabilities are possible thanks to the iCub peculiar sensors such as whole-body distributed tactile and force sensing. These sensors allow the iCub to simultaneously control joint movements, joint torques and interaction forces. Within this context, motion control is still an open research activity since previous approaches mainly dealt with kinematic movement planning. The iCub instead needs a dynamic planner to simultaneously plan movements, torques and interaction forces. The goal of the proposed theme is to develop a kinematic and dynamic motion control software. Given a control task, the foreseen controller will compute not only the kinematics (i.e. joint trajectories) but also the dynamics (i.e. joint torques and interaction forces) to perform the task. Among the various solutions to the problem, optimal control will represent a primary focus of attention. Specific tasks will include multi-contact motion planning [2], whole-body motion planning [3] and non-rigid contact motion planning. The project will be conducted within the context of a European project and the candidate will be asked to spend a six months experience in a foreigner country as a visiting Ph.D. student.

Requirements: candidate is requested to have a background in control theory, computer science and/or robotics. Specific background in optimal control will be positively evaluated.

Special requirements: this theme is supported by an ITN-H2020 research grant (SECURE). Candidates should satisfy the eligibility criteria of the Marie Skłodowska-Curie Actions. The position is suitable for candidates who have not have resided or carried out their main activity in Italy for more than 12 months in the last 3 years preceding their recruitment.

Note: the position is associated with a considerably higher salary than a regular studentship and offers many opportunities to travel to the other European partners in the network.

Reference:

[1] F Nori, S Traversaro, E Jorhabib, F Romano and D Del Prete A.; Pucci. iCub Whole body Control through Force Regulation on Rigid Noncoplanar Contacts. *Frontiers in Robotics and AI*.

[2] A Escande, A Kheddar, S Miossec. Planning support contact-points for humanoid robots and experiments on HRP-2. 2006 IEEE/RSJ International Conference on Intelligent Robots and Systems.

[3] Moritz Diehl, Hans Joachim Ferreau, and Niels Haverbeke. Efficient Numerical Methods for Nonlinear MPC and Moving Horizon Estimation. Nonlinear Model Predictive Control. Lecture Notes in Control and Information Sciences Volume

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3. Body representations learning for whole body control

Tutors: Giorgio Metta, Francesco Nori

Department: iCub Facility (Istituto Italiano di Tecnologia)
http://www.iit.it/en/research/departments/icub-facility.html

Description: The goal of this PhD theme is to develop complex body representations for the iCub robot utilizing visual, tactile, force, and motor signals. This representation enables control of the robot in the presence of multiple potential or actual contacts. It will e.g. determine that certain configurations are convenient to support the robot during task execution and actively seek contact with the environment rather than avoiding it. This model will be also compared with an existing neuroscience model of the so-called peripersonal space representation. The main result will be a set of software libraries that contain learning methods (e.g. probability density estimation, regression, etc.) and sensory processing (e.g. optical flow estimation, stereo vision, etc.). These algorithms will jointly contribute to the acquisition of the body and peripersonal space representation. Specifically for this theme, we will seek to build controllers for the whole body of the robot (legs, arms, etc.) which use the acquired sensorimotor representations.

Requirements: candidate is requested to have a background in control theory, computer science and/or robotics. Specific background in optimal control will be positively evaluated.

Special requirements: this theme is supported by an ITN-H2020 research grant (SECURE). Candidates should satisfy the eligibility criteria of the Marie Skłodowska-Curie Actions. The position is suitable for candidates who have not have resided or carried out their main activity in Italy for more than 12 months in the last 3 years preceding their recruitment. **Note:** the position is associated with a considerably higher salary than a regular studentship and offers many opportunities to travel to the other European partners in the network.

Reference:

[1] Roncone, A.; Hoffmann, M.; Pattacini, U.; Metta, G. Automatic kinematic chain calibration using artificial skin: self-touch in the iCub humanoid robot. IEEE International Conference on Robotics and Automation (ICRA2014) pp.2305-2312 Hong Kong, China, May 31-June 7, 2014

Contacts: giorgio.metta@iit.it, francesco.nori@iit.it

4. Tactile object manipulation and perception

Tutors: Dr Lorenzo Natale

Department: iCub Facility (Istituto Italiano di Tecnologia)
http://www.iit.it/iCub

Description: recent progress in tactile technology allows studying algorithms for advanced manipulation and exploration of objects. Tactile and, more in general haptic feedback, allows extracting local features like surface texture, curvature and hardness. These are fundamental features to guide object manipulation and perform for example object re-grasping, bimanual manipulation and controlled slip. Controlled object interaction in turn produces information about the physical and geometrical properties of objects that can complement or even substitute vision for object recognition. The goal of this PhD is to study signal processing algorithms and control strategies for extracting object features from vision and tactile feedback during object manipulation. We will investigate how the features collected during manipulation can be integrated and used for object recognition. This project will be carried out on the iCub humanoid robot using the tactile system on the hand [1][2]).

Requirements: the ideal candidate would have a degree in Computer Science, Engineering or related disciplines; a background in control theory and machine learning. He would also be highly motivated to work on robotic platform and have computer programming skills.

References:

[1] Maiolino, P., Maggiali, M., Cannata, G., Metta, G., Natale, L., *A Flexible and Robust Large Scale Capacitive Tactile System for Robots*, IEEE Sensors Journal, vol. 13, no. 10, pp. 3910-3917, 2013.

[2] Schmitz A., Maiolino P., Maggiali M., Natale L., Cannata G., Metta G., *Methods and Technologies for the Implementation of Large Scale Robot Tactile Sensors*, IEEE Transactions on Robotics, Volume 27, Issue 3, pp. 389-400, 2011.

Contacts: lorenzo.natale@iit.it

5. Real-time software architectures for humanoid robots

Tutors: Dr Lorenzo Natale

Department: iCub Facility (Istituto Italiano di Tecnologia)
http://www.iit.it/iCub

Description: In the past few years humanoid robots have evolved at a rapid pace. Research has made impressive advancements on both mechatronics and cognitive capabilities, including learning, perception and control. At the same time the explosion of the market of mobile devices has led to a remarkable increase in the computational capabilities of embedded CPUs and has made available higher resolution sensors and inertial units.

Research on humanoid robotics is attacking problems such as human-robot interaction, whole body control, object manipulation and tool use. These research efforts must be supported by an adequate software infrastructure which allows experimenting with new hardware and algorithms while at the same time reducing debugging time and maximizing code-reuse. The complexity of humanoid robots and their peculiar application domain require that further software engineering efforts are devoted to support the proper integration of diverse capabilities. The goal of this PhD project is to develop novel solutions to these problems. Topics include:

- Domain Specific Languages and their application to software development in humanoid robotics
- Interoperability between heterogeneous systems
- Strategies for coordination and arbitration of software components
- Programming of behaviors for natural HRI
- Real-time architectures and communication protocols
- Increasing robustness of robot software through testing, self-monitoring, fault tolerance, and autonomous system health inspection

Requirements: the ideal candidate would have a degree in Computer Science, Engineering or related disciplines with background in robotics and software engineering. He would also be highly motivated to work on a real robotic platform.

References:

[1] Paikan, A., Fitzpatrick, P., Metta, G., and Natale, L., Data Flow Port's Monitoring and Arbitration, Journal of Software Engineering for Robotics, vol. 5, no. 1, pp. 80-88, 2014.

[2] Fitzpatrick, P., Ceseracciu, E., Domenichelli, D., Paikan, A., Metta, G., and Natale, L., A middle way for robotics middleware, Journal of Software Engineering for Robotics, vol. 5, no. 2, pp. 42-49, 2014.

[3] R. Simmons, D. Kortencamp, D. Brugali. Robotics Systems Architectures and programming, Handbook of Robotics II ed., Springer 2013.

[4] D. Brugali and A. Shakhimardanov. Component-based Robotic Engineering. Part II: Models and systems. In IEEE Robotics and Automation Magazine, March 2010.

[5] D. Brugali and P. Scandurra. Component-based Robotic Engineering. Part I: Reusable building blocks. In IEEE Robotics and Automation Magazine, December 2009.

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6. Sensing humans: enhancing social abilities of the iCub platform

Tutors: Dr Lorenzo Natale and Dr. Alessio Del Bue

Department: iCub Facility (Istituto Italiano di Tecnologia)
http://www.iit.it/iCub

Description: there is general consensus that robots in the future will work in close interaction with humans. This requires that robots are endowed with the ability to detect humans and interact with them. However, treating humans as simple animated entities is not enough: meaningful human-robot interaction entails the ability to interpret social cues and human intentions. Such capabilities are fundamental prerequisites to program the robot to react appropriately to humans and to bias the interpretation of the scene using nonverbal cues (gaze or body gestures).

The aim of this project is to endow the iCub with a fundamental layer of capabilities for detecting humans, their posture and social intentions. Examples could be the ability to detect if a person is attempting to interact with the robot or his posture and intentions. Conventional research in Computer Vision and Machine Learning focuses on applications in which the image patch of a whole person (or group of people) is visible without strong occlusions in. On the other hand, face-to-face interaction requires developing novel algorithms for coping with situations in which large areas of the body are occluded or only partially visible.

Requirements: This PhD project will be carried out within the iCub Facility in collaboration with the Department of Pattern Analysis and Computer Vision (PAVIS). The ideal candidate should have a degree in Computer Science or Engineering (or equivalent) and background in Computer Vision and/or Machine Learning. He should also be highly motivated to work on a robotic platform and have computer programming skills.

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7. Spatial modeling of three-dimensional maps from stereo and RGBD sensors

Tutors: Dr Lorenzo Natale and Dr. Tariq Abuhashim

Department: iCub Facility (Istituto Italiano di Tecnologia)
http://www.iit.it/iCub

Description: the ability to acquire high-resolution depth information allows for using three-dimensional geometries to build detailed shapes. The latter is fundamental for tasks that require complex interaction between the robot and the environment like balancing, walking or object grasping/manipulation. Local shape information can in fact used to segment the scene and plan foot or hands placement to stabilize the robot or the fingers to achieve a stable grip of objects. This is a challenging task because it requires observations on both the geometry and the visual appearance of the surrounding surfaces, in relation to the body of the robot. To perform such tasks, features need to be extracted from the data allowing different regions to be compared and matched. Depending on the complexity of the viewed scene, these features can be extracted from the depth data alone or need to be augmented with those extracted from images. The aim of this PhD is to study the general problem of scene understanding by combining three-dimensional depth observations with visual appearance from images. The goal is to investigate novel features for local shape description and machine learning techniques for classification. We consider tasks like locomotion and object manipulation in scenarios that involve whole-body control.

Requirements: the ideal candidate would have a degree in Computer Science, Engineering or related disciplines, with a background in Computer Vision and Machine Learning. He would also be highly motivated to work on robotic platform and have computer programming skills.

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8. Event-driven human and action detection for the iCub

Tutors: Chiara Bartolozzi, Lorenzo Natale

Department: iCub Facility (Istituto Italiano di Tecnologia)
http://www.iit.it/en/research/departments/icub-facility.html

Description: Interacting with a dynamical environment is one of the major challenges of robotics. Biology clearly outperforms robotic systems when acting in real scenarios in terms of appropriateness of the behavioural response, robustness to interference and noise, adaptation to ever changing environmental conditions, and energy efficiency. All these properties arise from the characteristics of the radically different style of sensing and computation used by the biological brain.

In conventional robots, sensory information is available in a sequence of static snapshots and high dynamics can be sensed only by increasing the sampling rate. However the available bandwidth limits the amount of information that can be transmitted forcing a compromise between resolution and speed. Event-driven vision sensors transmit information as soon as a change occurs in their visual field, achieving incredibly high

temporal resolution, coupled with extremely low data rate and automatic segmentation of significant events.
The proposed theme aims at the exploitation of highly dynamical and sparse information from event-driven sensors for fast detection of humans and action recognition. The automatic motion based segmentation performed by the event-driven cameras allows for fast detection of regions of interest. The research focus will be the exploitation of this segmentation for the detection and recognition of moving body parts to implement fast real-time human detection and action recognition. The ultimate goal is to improve awareness and interaction skills of the iCub robot.

Requirements: degree in Computer Science or Engineering (or equivalent) and background in Computer Vision and/or Machine Learning. High motivation to work on a robotic platform and good programming skills.

Reference: Benosman, R.; Clercq, C.; Lagorce, X.; Sio-Hoi Ieng; Bartolozzi, C., "Event-Based Visual Flow," Neural Networks and Learning Systems, IEEE Transactions on , vol.25, no.2, pp.407,417, Feb. 2014, doi: 10.1109/TNNLS.2013.2273537

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9. Event-driven affordances for the iCub

Tutors: Chiara Bartolozzi, Vadim Tikhanoff, Ugo Pattacini

Department: iCub Facility (Istituto Italiano di Tecnologia)
http://www.iit.it/en/research/departments/icub-facility.html

Description:
Grasping and manipulation are two necessary skills of a robot that needs to reliably work and cooperate with humans. The performance of a robot when interacting with objects heavily relies on robot calibration, 3D scene reconstruction and accurate action execution. In realistic environments all of the above is prone to errors that can result in failure of the planned action. In humans, such errors are counterbalanced by adaptive behaviours that build on the knowledge of the results of actions and on the early detection of failures that allows for the execution of corrective actions.

The goal of this project is to learn the behaviour of objects during clumsy or imprecise manipulation and grasping, and using this knowledge to plan and perform corrective actions. A bad grasping will cause the object to fall in specific ways, the robot can then learn the association between a specific action parameter (for example hand pre-shaping, direction of grasping, object 3D configuration, etc.) and the trajectory of the falling object, effectively learning its “falling affordances”. The robot can then use this information to better plan the next grasping action on the same object and to perform corrective actions. This task will rely on the integration of traditional color-based high spatial resolution vision with accurate and fast observation of the object motion by event-driven cameras, characterised by extremely high temporal resolution.

Requirements: degree in Computer Science or Engineering (or equivalent) and background in Computer Vision and/or Machine Learning. High motivation to work on a robotic platform and good programming skills.

Reference:

[1] Benosman, R.; Clercq, C.; Lagorce, X.; Sio-Hoi Ieng; Bartolozzi, C., "Event-Based Visual Flow," Neural Networks and Learning Systems, IEEE Transactions on , vol.25, no.2, pp.407,417, Feb. 2014, doi: 10.1109/TNNLS.2013.2273537

[2] Tikhanoff, V.; Pattacini, U.; Natale, L.; Metta, G., "Exploring affordances and tool use on the iCub", 2013, IEEE/RAS International Conference of Humanoids Robotics

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10. Event-driven vision sensors for humanoid robots

Tutors: Chiara Bartolozzi

Department: iCub Facility (Istituto Italiano di Tecnologia)

http://www.iit.it/en/research/departments/icub-facility.html

Description: Carrying out real-world tasks robustly and efficiently is one of the major challenges of robotics. Biology clearly outperforms artificial computing and robotic systems in terms of appropriateness of the behavioural response, robustness to interference and noise, adaptation to ever changing environmental conditions, or energy efficiency. All these properties arise from the characteristics of the radically different style of sensing and computation used by the biological brain.

In conventional robots, sensory information is available in a sequence of static frames and high dynamics can be sensed only by increasing the sampling rate. Unfortunately the available bandwidth limits the amount of information that can be transmitted forcing a compromise between resolution and speed.

The goal of the proposed theme is the development of bio-inspired event-driven artificial vision sensors that will be mounted and validated on the humanoid robot iCub. The goal is to convey to the robot the most informative signal that it can use to robustly interact with the world.

The research will focus on the design of mixed-mode analog/digital circuits for photo-transduction and focal-plane processing. Different architectures and circuits will be considered for the pixel design, evaluating the trade-off between complexity (and fill-in factor) and sensor pre-processing capabilities. Additionally, ad hoc digital asynchronous logic circuits and interfaces based on the "Address Event Representation" protocol will be developed for optimally interfacing the sensor with the robot.

Requirements: degree in Electronic Engineering, Physics (or equivalent) and background in Analog and/or Digital Circuit Design, possibly on FPGA programming (VHDL, Verilog).

Reference: C. Posch, D. Matolin, and R. Wohlgenannt, "A QVGA 143 dB Dynamic Range Frame-Free PWM Image Sensor With Lossless Pixel-Level Video Compression and Time-Domain CDS," IEEE J Solid-State Circuits, vol. 46, no. 1, pp. 259–275, Jan. 2011

Contacts: chiara.bartolozzi@iit.it

11. Development of a Hybrid Mobile Manipulation platform with mixed leg and wheel functionality

Tutor: Nikos Tsagarakis

Department of Advanced Robotics (Istituto Italiano di Tecnologia)
http://www.iit.it/en/research/departments/advanced-robotics.html

Emerging robots operating within man-made real-word workspaces will have to walk, reach, physically interact, pick up, retrieve and manipulate a variety of objects, tools and interfaces designed for human use. Such mobile manipulation is an activity that humans naturally perform by combining two motion capabilities: locomotion and manipulation. This need of mobile manipulation has been tackled in the past with the development of a variety of mobile manipulation systems made by robotic arms installed on mobile bases with the mobility provided by wheels and legs mechanisms. On one hand wheeled rovers provide optimal solutions for well-structured, and relatively flat terrains environments, however, outside of these types of workspaces and terrains their mobility decreases significantly and usually they can only overcome obstacles smaller than the size of their wheels. Compared to wheeled robots, legged robots are more sophisticated to design, build and control but they have obvious mobility advantages when operating in unstructured terrains and environments.

This research theme will explore the development of a new robotic platform for mobile manipulation that uses legs and small wheels to combine the advantages of wheeled and legged locomotion. On flat terrains directly driven wheels will move the robot quickly and efficiently in an omnidirectional way by independently adjusting their speed and orientation. When driving over uneven ground, the legs will adapt to the surface, such that the posture of the main body is stabilized. Different principles and implementations of the leg-wheel mechanisms will be evaluated in simulation and finally implemented and validated on prototypes. The mechanical design developments will accompanied by activities on the regulation strategies of this new leg-wheel locomotion system.

Requirements: We are seeking for highly motivated candidates with a background in Electronic/Mechanical engineering, Physical Sciences or Robotics. Candidates should have competencies in CAD mechanical design and/or robot dynamics and control. (Mechanical design 60%, Simulation/Dynamics/Control %40).

Reference: N.G.Tsagarakis, S. Morfey, G.Medrano-Cerda, H. Dallali, D.G.Caldwell, "An Asymmetric Compliant Antagonistic Joint Design for High Performance Mobility", IEEE International Conference on Intelligent Robots and Systems (IROS), 2013, pp 5512-5517.

Contact: nikos.tsagarakis@iit.it

12. Design and Control of Novel Lightweight Robotic Joint-Link Modules with distributed variable stiffness

Tutor: Jörn Malzahn, Nikos Tsagarakis

Department of Advanced Robotics (Istituto Italiano di Tecnologia)
http://www.iit.it/en/research/departments/advanced-robotics.html

The department of Advances Robotics is currently one of the world leading research institutes in the development and new actuation systems ranging from series compliant actuators to actuators with variable compliance and damping characteristics. The intrinsic compliance absorbs shocks during accidental impact on the joint level. This equally contributes to the protection of gears, sensors as well as objects and humans in the vicinity of the robot and enables the sensing of interactive contacts. In addition, elastic components in the actuation may improve the motion efficiency of the robotic system through energy storage and release during locomotion or permit to generate high power motions during throwing, kicking and jumping actions.
Despite the recent advances in this field, robotic actuation still does not match the efficiency and power capacity observed animals and humans. This severely limits the capabilities and operation times of today's robotic systems e. g. in robotic assistance or disaster response scenarios.

The objective behind this topic is to devise novel robotic joint-link modules, which maximize the amount of storable energy in relation to the overall mechanism weight in comparison. Therefore, this work will integrate the principle of variable compliance on both, the actuator as well as the link level along with suitable control techniques. This holistic and integrated approach to variable elastic actuation is envisioned to increase the design degrees of freedom of future high performance robot mechanisms.

Requirements: We are seeking for highly motivated candidates with a background in Mechanical engineering, Control Theory or Robotics. This is a multidisciplinary topic where the successful candidates should have experiences in CAD mechanism design and strong competences in robot kinematics, dynamics and control. (Mechanical design 30 %, Kinematics/Dynamics/Control 70 %).

References:

N.G. Tsagarakis, Stephen Morfey, Gustavo Medrano-Cerda, Zhibin Li, Darwin G. Caldwell, “Compliant Humanoid COMAN: Optimal Joint Stiffness Tuning for Modal Frequency Control”, IEEE International Conference on Robotics and Automation, ICRA 2013, pp 673-678.

J. Malzahn, R. F. Reinhart, T. Bertram “Dynamics Identification of a Damped Multi Elastic Link Robot Arm under Gravity”, IEEE International Conference on Robotics and Automation, ICRA 2014, pp 2170-2175.

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13. New Efficient actuation systems based on the blending of Forced and Natural dynamics

Tutor: Nikos Tsagarakis, Gustavo Medrano Cerda

Department of Advanced Robotics (Istituto Italiano di Tecnologia)
http://www.iit.it/en/research/departments/advanced-robotics.html

The department of Advances Robotics is currently one of the world leading research institutes on the development and new robotic actuation systems ranging from series compliant actuators to actuators with variable compliance and damping characteristics. Elastic components in the actuation may improve the motion efficiency of the robotic system through energy storage and release during locomotion or permit to generate high power motions during throwing, kicking and jumping actions. However, this energy efficiency improvement has not yet demonstrated in real robotic systems. This research theme will explore the development of a new actuator idea that permits a joint to switch from natural to forced dynamics through novel transmission systems. Different principles and implementations of this actuation will be evaluated in simulation and finally implemented and validated on single joint proof of concept prototypes. The mechanical design developments will accompanied by activities on the regulation strategies of these new actuation systems to maximize their efficient operation. This is a high risk research theme on innovative actuation systems which can potentially generate high pay off in terms of novel outcome and dissemination of results.

Requirements: We are seeking for highly motivated candidates with a background in Electronic/Mechanical engineering, Physical Sciences or Robotics. Candidates should have competencies in CAD mechanical design and/or robot dynamics and control. (Mechanical design 50%, Simulation/Dynamics/Control %50).

Reference: N.G.Tsagarakis, S. Morfey, G.Medrano-Cerda, H. Dallali, D.G.Caldwell, "An Asymmetric Compliant Antagonistic Joint Design for High Performance Mobility", IEEE International Conference on Intelligent Robots and Systems (IROS), 2013, pp 5512-5517.

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14. Humanoid whole body proprioception, exteroception and ego motion sensing

Tutor: Zhibin Li, Jörn Malzahn, Xin Wang, Nikos Tsagarakis

Department of Advanced Robotics (Istituto Italiano di Tecnologia)
http://www.iit.it/en/research/departments/advanced-robotics.html

Proprioception gives humans a sense of their relative posture and motion of their individual body parts along with the efforts that are taken to realize them. In humans the proprioceptive "sensors" can be found in the tendons, muscle spindles and joints. The proprioception is complemented by the vestibular system, which equips humans with information about the body position, velocity and acceleration. In addition exteroception describes the ability of humans to sense their surrounding environment through e. g. visual and audio information.

This topic aims to transfer human inspired capabilities to humanoid robots, by mutually calibrating the sensors of humanoid robots and fusing their data. This way the successful candidate will contribute to the state-of-the-art and escalate the variety of information that can be extracted from available sensor data.

The successful candidate will develop an effective hierarchal sensor fusion framework that combines the different measurement signals, estimates the parameters as well as the state of the system. The framework will include self-calibration algorithms that explore the redundancy of the sensor feedback and an explicit dynamic model of the robot.

The whole-body sensor fusion framework is envisioned to assist the motion planning and control, manipulation and monitor the state of the whole robotic system, e.g. temperature, data log, fault record. The goal is to endow humanoid robots to traverse various types of terrains, remove heavy obstacles, operate human oriented tools and devices.

These methods will be experimentally validated using the compliant humanoid robot COMAN developed under the European FP7 project AMARSI (www.amarsi-project.eu) as well as the high performance WALKMAN humanoid developed by the EU project WALK-MAN (www.walk-man.eu).

Requirements: Applicants should have strong background in signal processing, digital filter design (Kalman filter, etc.), robot kinematics and dynamics. The successful candidate has good programming experience in MATLAB and C++. Knowledge on mechatronics hardware is a plus.

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15. Control Principles for Enhanced and Autonomous Humanoid Physical Interaction

Tutors: Arash Ajoudani, Jinoh Lee, Nikos Tsagarakis

Department of Advanced Robotics (Istituto Italiano di Tecnologia)
http://www.iit.it/en/research/departments/advanced-robotics.html

Effective and stable execution of a manipulation task in an uncertain environment requires that the task force and position trajectories of the robot are appropriately commanded. One way to achieve this goal is to understand the versatility and the stability of the human interaction behavior and potentially integrate similar concepts into the robot control frameworks for effective planning and realization of the reference trajectories. For instance, utilization of similar concepts such as human motor synergies for coordinated control of large number of degrees of freedom can potentially result in less control burden and a desired interaction performance. While the exploitation of this concept in kinematic coordinates has led to the development of several successful robotic designs and control strategies, its extension to dynamic coordinates, such as coordinated regulations of the joint stiffness or torque in robot hands, arms or legs, remains to be investigated. Therefore, in this program we will introduce novel thinking and techniques to the control of highly redundant humanoid robots to achieve a stable and versatile physical interaction. Proposed controllers will be experimentally validated in humanoid robots developed in the advanced robotics department such as WALK-MAN (**http://www.walk-man.eu/**) and COMAN while executing target manipulation tasks in an autonomous or tele-operated fashion.

Requirements: We are preferably seeking for highly motivated candidates with a background in control engineering or robotics. This is a multidisciplinary project where the successful candidates should have strong competencies in software coding (e.g. C++ and MATLAB) and good knowledge of robot kinematics/dynamics and control.

Reference: A. Ajoudani, C. Fang, N. G. Tsagarakis, and A. Bicchi, "Dimensionality Reduction in Arm Endpoint Stiffness Representation: Application to Teleimpedance Control", IEEE International Conference on Intelligent Robots and Systems (IROS), 2015.

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16. Human/Robot Interfaces for Cooperative Whole body Manipulation

Tutors: Arash Ajoudani, Jinoh Lee, Nikos Tsagarakis

Department of Advanced Robotics (Istituto Italiano di Tecnologia)
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A key factor in the realization of intuitive human-robot cooperation is an appropriate consideration of the human intention in the robot control framework. This will result in transparent interactions between the human and the robot while avoiding the generation of undesired conflicting movements or interaction forces. Therefore, in this program, we seek for effective and real-time modelling of the human intention which will be included in the design of the novel robot controller to achieve intuitive and transparent human/robot cooperation. This program will consider a potential use of bio-signals such as electromyography or electroencephalography as model inputs to extract human motor control parameters. On the other hand, the design of robust and adaptive robot controllers will be investigated for effective integration of the coworker/assistant follower's intension.

Target collaborative tasks will be defined and experimentally evaluated using torque controlled humanoid robots such as COMAN developed under the European FP7 project AMARSI (www.amarsi-project.eu) and WALK-MAN. The work activity of this theme will be in line with the developments of the WALK-MAN (http://www.walk-man.eu/) and CogiMon (http://cogimon.eu/) EU Projects.

Requirements: We are preferably seeking for highly motivated candidates with a background in control engineering or robotics. This is a multidisciplinary project where the successful candidates should have strong competencies in software coding (e.g. C++ and MATLAB) and good knowledge of robot kinematics/dynamics and control.

Reference: N. Karavas, A. Ajoudani, N. Tsagarakis, J. Saglia, A. Bicchi and D. Caldwell, "Tele-Impedance based Assistive Control for a Compliant Knee Exoskeleton: Stiffness Augmentation and Motion Assistance", Robotics and Autonomous Systems, 2014.

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17. Reactive Whole-body Manipulation for Humanoid Falling and Recovery

Tutors: Jinoh Lee, Arash Ajoudani, Nikos Tsagarakis

Department of Advanced Robotics (Istituto Italiano di Tecnologia)
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The robots are coming out of the cage, and getting closely involved into human life. Particularly, after Fukushima nuclear disaster in 2011, the need of robots to deal with unstructured environments and replace humans in hazardous tasks became an important virtue Humanoids are naturally highlighted for their potential capability to access to unstructured and uncertain environments. However, one of the significant barriers to practically operate the humanoid robot is that it is difficult to avoid falling over and being damaged.

The target of this search project is to develop novel methodology which enables the humanoid to reactively control whole-body motion after falling over. The key aspects will cover 1) efficient real-time falling detection; 2) optimal falling motion planning; and 3) robust whole-body control. Multi-sensors such as proprioception, visual perception and IMU can be used for the falling detection, where novel multi-sensor fusion approach is one of interesting directions. The falling-motion planning is aiming to minimize damages in an optimum way for both on-line and off-line. Robust dynamic control algorithms are needed to guarantee agile whole-body responses to cope with the planned motion with hierarchical order of multiple tasks. The methods will be verified in dynamic simulation environment and on physical humanoid robots such as COMAN developed under the European FP7 project AMARSI (www.amarsi-project.eu) and WALK-MAN a new high performance humanoid recently developed at IIT. This project topic is multidisciplinary, thus the collaboration with other members will be encouraged, e.g. 3D perception. The work activity of this theme will be in line with the developments of the WALK-MAN EU project (http://www.walk-man.eu/).

Requirements: We are preferably seeking for highly motivated candidates with a background in robotics and control engineering. This is a multidisciplinary project where the successful candidates should have strong competencies in robot kinematics/dynamics/control and in software coding (e.g. C++ and MATLAB) The experience on dynamic simulators (e.g. Gazebo, Webot, RoboTran, etc.) and ROS would be plus.

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18. 3D Perception for Humanoid Robots: Rough terrain locomotion and Free-form object manipulation

Tutor: Dimitris Kanoulas, Nikos Tsagarakis

Department of Advanced Robotics (Istituto Italiano di Tecnologia)

http://www.iit.it/en/research/departments/advanced-robotics.html

After Fukushima Daiichi nuclear disaster in 2011 the need of robots to deal with unstructured environments and replace humans in hazardous tasks became one of the main open problems in robotics. Rapid advancements in actuation and control over the last few years enabled articulated humanoid robots to both walk in uneven terrain and perform dexterous manipulation using their hands. These capabilities are usually gained without using 3D perception at all, by assuming that either the environment is mostly known and well-structured, or the uncertainty can be tolerated by low-level feedback control. In real world scenarios these assumptions may not hold. 3D perception is required! The problem of foot placement in rough terrain (for example in a rocky trail) for walking or the problem of grasping free-formed objects (for example a rock) using 3D perception remains one of the central challenges in robotics and is the key aspect for completing locomotion or manipulation tasks in unknown environments. The aim of this topic is to develop new environment reconstruction techniques that enable humanoid robots to perform both legged locomotion and manipulation tasks in unstructured environments using **3D perception for foot or hand placement**. The state-of-the-art 3D perception sensors will be used (stereo/time-of-flight cameras, laser sensors, or structured light systems) along with other perception sensors like tactile, force control, or IMU ones. The dense 3D point cloud that is acquired from a range sensor will require some geometric simplifications for reasoning the contact between the robot's foot/hand and an area in the environment. Modeling these contact areas around and on a robot while using **Simultaneous Localization and Mapping (SLAM)** techniques for creating and keeping a map of these with respect to the robot is a key aspect for completing these tasks. The developed methods will be tested both in simulation and on a real full-size humanoid robot (**WALK-MAN**). The project is interdisciplinary since perception needs to be combined with path planning and control techniques for making the actual robot complete a task. Thus the collaboration with other members of the project will be required into that direction. The work activity of this theme will be in line with the developments of the WALK-MAN EU project (http://www.walk-man.eu/).

Requirements: This topic lies in the intersection of Computer Vision and Robotics. Ideal applicants should have strong analytical and programming skills (C/C++ and MATLAB). A relevant degree is required, for instance in Computer Science or Engineering. A background in Robotics/Computer Vision is desirable, while knowledge of the Robot Operating System

(ROS), the Point Cloud Library (PCL), or the Open Source Computer Vision Library (OpenCV) is a big plus. The applicants should be fluent in English and team players.

Reference: Dimitrios Kanoulas, "Curved Surface Patches for Rough Terrain Perception", Ph.D Thesis, 2014.

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19. Robust Locomotion of Humanoids in an Unstructured Environment Under External Forces

Tutor: Nikos Tsagarakis

Department of Advanced Robotics (Istituto Italiano di Tecnologia)
http://www.iit.it/en/research/departments/advanced-robotics.html

Recent developments, especially in relation to DARPA challenge, brought numerous improvements to the capabilities of humanoid robots. There are however still problems that need to be solved before we can apply humanoids to practical tasks. One of them is a robust locomotion of humanoids in an unknown environment under external forces and disturbances. Whatever practical task we will want a humanoid robot to perform, it will involve physical interaction with an environment and/or objects. Also we cannot assume that the robots will have a comfort of walking on a flat and structured ground. This brings us to the topic of this research. Robust locomotion of a humanoid robot on an uneven terrain subject to forces coming either from objects being manipulated by humanoid or from obstacles.

The successful candidate will work on real-time locomotion control. This will involve gait and whole-body motion planning, given the perceived map of environment; whole body state estimation based on proprioceptive and exteroceptive sensory data; stabilization control and gait re-planning based on the perceived information. All algorithms developed in this work should be implemented and tested on our new humanoid robot WALK-MAN. It has been developed under the European FP7 project WALK-MAN (http://www.walk-man.eu/). WALK-MAN is an adult size humanoid robot designed with an objective of application in search and rescue scenarios. The robot has compliant joint structures, 6 axis Force/Torque sensors at the ankles and the feet soles are equipped with pressure sensing arrays . These, together with MultiSense head allow for proprioceptive and exteroceptive sensing.

Requirements: Applicant should possess strong background in: physical system, modeling and rigid body dynamics, robust control theory, MATLAB and C/C++ programing languages. Previous experience with biped locomotion is a plus.The following qualities will be advantageous: knowledge of optimization techniques (QP, SQP etc.), knowledge of signal processing (KF, EKF etc.), hands-on experience with robotic platforms.

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20. Dexterous Humanoid Walking on Restricted and Unstable Footholds

Tutor: Nikos Tsagarakis, Przemyslaw Kryczka

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Despite the significant progress made in Humanoid locomotion during the last decade most of the present-day humanoids still suffer from major problems related to stable walking in terrains other than even. Flat terrains are though very ideal surfaces compared to terrains existing in human environments where stairs, inclined surfaces, small obstacles and even rough surfaces may exist. Up to now, there are only few effective demonstrations about walking and motion planning on this kind of environments.

A new humanoid robot WALK-MAN has been developed under the European FP7 project WALK-MAN (http://www.walk-man.eu/).). This newly developed robot has compliant joint structures, 6 axis Force/Torque sensors at the ankles and the feet soles are equipped with pressure sensing arrays which permit to explore walking on:

a) Uneven terrains and stepping on obstacles of limited surface that may result in limited area footholds.

b) Particulate solid surfaces consisting of particles of different size and density which may not provide fully stable footholds.

In this project techniques will be developed to plan the execution of dexterous foot probing and regulate the gait motions accordingly ensuring both the dynamic equilibrium and body/feet posture of the humanoid to achieve walking on uneven surfaces of limited support area avoiding or stepping on obstacles with variable inclinations, on unstable particulate surfaces such as terrains composed of small stones. These methods will take into account kinematics/dynamics and self-collision constraints while detection of the terrain properties will be assisted by rich sensory feedback from the feet of the humanoid. We will explore how to detect rough terrain/obstacle properties such as size, inclination and stability using the sensorized ankle and feet of the humanoid. Having determined the rough terrain characteristics, how the balance stability will be maintained when the robot will be on this specific rough terrain will be evaluated and different control and trajectory planning methodologies will be developed to allow the humanoid to pass through while maintaining stability and balance.

Requirements: Applicant should ideally possess strong background in physical system modeling and control, MATLAB and C/C++ programming. Knowledge on mechatronics hardware, fundamental robotics and rigid body dynamics is a plus.

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21. Development of Under-actuated upper limp wearable systems for assistive manipulation, and rehabilitation

Tutor: Ioannis Sarakoglou, Nikos Tsagarakis

Department of Advanced Robotics (Istituto Italiano di Tecnologia)
http://www.iit.it/en/research/departments/advanced-robotics.html

This theme focuses on the development of wearable kinesthetic devices for the upper limp including devices for the hand and arm. One of the main objectives of the design of these systems is to move away from the traditional design paradigms of upper limp exoskeleton devices that target to develop systems with many actuators following anthropomorphic exoskeleton structures attached to the upper limp segments using physical interfaces with multiple fixation points. With special attention on the systems ergonomics both a t the level of physical interface as well as at the level of the functionality this project will follow instead a different approach that will permit the development of devices which can execute closely functional rehabilitation as that provided by physiotherapist towards systems that combine the benefits of robotic aid automated rehabilitation with the natural execution of physiotherapy regimes as performed by the dedicated medical personnel. At the implementation and physical interface level the project will attempt to minimize the complexity yet keeping the functionality of the device through the use of under-actuation and the employment of minimalistic physical interface principles that can resemble the interaction between the physiotherapist and the patients' upper limp.

Requirements: The successful candidates will have a Master degree in Mechatronics, Robotics, Mechanical Engineering or equivalent and will be able to work both in a team and independently. Experience in CAD mechanical design, programming with C/C++ and Matlab is mandatory and knowledge of robot kinematics and dynamics is preferable. (60% mechanical design, 20% control, 20% software).

Reference: J Iqbal, H Khan, NG Tsagarakis, DG Caldwell, "A novel exoskeleton robotic system for hand rehabilitation–Conceptualization to prototyping", Biocybernetics and biomedical engineering 34 (2), 79-89

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22. Development of EXO-Muscles: Wearable Add-On High power modular force augmentation Units

Tutor: Nikos Tsagarakis, Ioannis Sarakoglou, Arash Ajoudani

Department of Advanced Robotics (Istituto Italiano di Tecnologia)

http://www.iit.it/en/research/departments/advanced-robotics.html

This project targets on the development of power autonomous, intelligent single muscle-type actuation units to act as power/force augmentation devices of individual joints of the human limbs (arms or legs). The term "wearable" implies for a portable, lightweight systems favouring comfort and ergonomics. The improvement of the wearability of the EXO-Muscles will be therefore considered during the development process and optimizations will be applied in all stages of the mechatronic developments related to the actuation system, the device structure and physical interface to the human limb. In contrast to the multidof highly complex force reflecting robotic exoskeletal structures, this unit can form the primitive force augmentation unit for building wearable force feedback systems with improved ergonomics and comfort. We envisage the development of 1 or 2 DOF systems e.g. an elbow device, or elbow/wrist or a knee/hip system. The regulation of the assistive forces will be performed considering control schemes built around rich sensing state feedback that will include traditional force/torque sensing technologies in conjunction with biofeedback modalities that will allow the estimation of human effort and joint fatigue. An additional rich sensory interface will allow the estimation of the human body posture, motion intention/measurement and human/environment contact state. Based on this the assistive operation will be "intelligently" tuned to ensure that the appropriate level of assistance is delivered.

Requirements: The successful candidates will have a Master degree in Mechatronics, Robotics, Mechanical Engineering or equivalent and will be able to work both in a team and independently. Experience in CAD mechanical design, programming with C/C++ and Matlab is mandatory and knowledge of robot kinematics and dynamics is preferable. (60% mechanical design, 20% control, 20% software).

Reference: Nikos Karavas, Arash Ajoudani, N. G. Tsagarakis, Jody Saglia, Antonio Bicchi, Darwin G. Caldwell, "Tele-impedance based Assistive Control for a Compliant Knee Exoskeleton", Robotics and Autonomous Systems 2014.

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23. Cutaneous and Kinesthetic sensing for robotic arms, dextrous hands and feet

Tutor: Ioannis Sarakoglou, Nikos Tsagarakis

Department of Advanced Robotics (Istituto Italiano di Tecnologia)
http://www.iit.it/en/research/departments/advanced-robotics.html

Tactile/force sensing is an important area in haptics, teleoperation and robotic dexterous manipulation. Manipulation of objects through robotic hands can only be efficiently performed if the interaction between the robotic hand and the object is effectively sensed. Similarly precise and careful locomotion requires the sense of interaction between the foot and the ground that goes beyond the standard F/T sensing modules usually integrated in the feet of legged robots. Currently research and development in tactile/force sensing is directed toward anthropomorphic sensors which attempt to match the sensing capabilities of the human skin and which resemble its mechanical properties. This proves to be a great and exiting challenge. This research will focus on new tactile/force sensing technologies suitable for application on robotic arms, hands and feet. It will involve research in the areas of distributed pressure tactile sensing in the form of highly anthropomorphic/bio-mimetic artificial skins and force sensing with semi-rigid skins in the form of high accuracy monolithic force/torque sensors. New sensor designs will be sought based on the current sensing technologies such as resistive, capacitive, piezoelectric, piezoresistive or new materials such as nano-particle filled polymers. Appropriate methods will be sought for developing and integrating large populations of sensing elements into structures suitable to operate as robotic skins. The candidate will also tackle the technological challenges in connectivity, power, and the signal processing of the distributed sensor. The candidate will work closely within a team of researchers and technicians toward developing working systems with a final goal to integrate tactile sensing in humanoid platforms such as COMAN (http://www.iit.it/en/advr-labs/humanoids-a-human-centred-mechatronics/advr-humanoids-projects/compliant-humanoid-platform-coman.html) and WALK-MAN (http://www.walk-man.eu/).

Requirements: The ideal candidate will be a talented individual with an Electronics or Mechatronics background and a strong performance in hardware design projects. The candidate should be willing to work in diverse areas, ranging from simulation (MATLAB, Maple Sim, etc), hardware design and software development (C++).

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24. Motion strategies for multi-legged robots in unstructured environments

Tutors: Michele Focchi, Roy Featherstone, Claudio Semini

Department: Dynamic Legged Systems lab, Department of Advanced Robotics (ADVR)
http://www.iit.it/hyq

Description: The Hydraulic Quadruped robot - HyQ - is a fully torque-controlled hydraulically actuated quadruped robot [link]. HyQ is designed to locomote over rough terrain and perform highly dynamic tasks such as jumping and running with a variety of gaits. It is a unique research platform that is designed for unstructured environments, e.g. outdoors, accident and disaster sites, etc.

Choosing the right action to undertake whenever a legged robot is about to lose its balance is paramount when addressing unstructured environments. In particular, different motion skills and recovery algorithms can be implemented accounting for the natural dynamics and the actual morphology of the robot without trying to enforce on the robot a high level template behavior. This position will investigate new approaches both in planning and control based on the real robot dynamics (e.g. balancing on two point feet while performing secondary tasks with the other limbs and the body). The robotic platform under study is IIT's new hydraulic Centaur robot, which is based on the torque-controlled quadruped robot HyQ enhanced with a pair of new torque-controlled hydraulic arms. The joints of the arms should be taken into consideration together with the leg joints in the planning/control strategy.

Requirements: background in robotics, computer science, electrical engineering or mechanical engineering. Understanding of robot kinematics and dynamics, strong C++ skills. Passionate for robotics and legged locomotion, experienced in ROS and Matlab.

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25. Planning dynamic motions using reduced dimensionality models.

Tutors: Michele Focchi, Ioannis Havoutis, Claudio Semini

Department: Dynamic Legged Systems lab, Department of Advanced Robotics (IIT)
http://www.iit.it/hyq

Description: The Hydraulic Quadruped robot - HyQ - is a fully torque-controlled hydraulically actuated quadruped robot [www.iit.it/HyQ]. HyQ is designed to locomote over rough terrain and perform highly dynamic tasks such as jumping and running with a variety of gaits. It is a unique research platform that is designed for unstructured environments, e.g. outdoors, accident and disaster sites, etc.

Models of reduced dimensionality can often capture the main dynamic characteristics of complex robotic structures. Examples include the rimless wheel, SLIP and table-cart models that have been used to describe the dynamic properties of running and walking robots. Planning with such models can lead to more manageable search-spaces that can naturally decompose to locally robust controllers. Following the "templates & anchors" paradigm proposed by Full and Koditschek [1] and using locally robust controllers much in the spirit of

Burridges' sequential juggling robot controllers [2], we aim to decompose dynamic locomotion to planning through a set of well-behaved locally robust controllers.

Requirements: strong background in robotics, computer science, electrical engineering or mechanical engineering. Understanding of robot kinematics and dynamics, strong C++ skills. Highly-motivated and passionate for robotics and legged locomotion, experienced in ROS and Matlab.

References:

[1] R.J. Full and D.E. Koditschek, Templates and anchors: neuromechanical hypotheses of legged locomotion on land *1999 202:3325-3332.*

[2] R. R. Burridge, A. A. Rizzi and D. E. Koditschek, Sequential Composition of Dynamically Dexterous Robot Behaviors *The International Journal of Robotics Research June 1999 18: 534-555, doi:10.1177/02783649922066385*

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26. Robotic Surgery with Improved Safety using Machine Learning for Intelligent Robot Tele-operation and Partial Autonomy

Tutors: Dr Petar Kormushev, Prof Darwin G. Caldwell

Department of Advanced Robotics (ADVR – IIT)
http://www.iit.it/advr

Flexible hyper-redundant systems are becoming of increasing interest in medical applications where the flexibility of the robot can be used to direct the surgery around delicate tissues, however, these system are highly non-linear with complex dynamic making them very difficult to control.

This project will develop and implement machine learning algorithms to improve the intelligence of control and perception in flexible devices and enhance safety.

The advantages of using machine learning will be investigated in multiple potential areas, as follows: in low-level robot control using model learning approaches; in feedback control considering multi-modal input from position, force and pressure sensors; in tele-operation using learning of context-dependent skills for assisting the human operators (surgeons).

The work will also investigate the possibility of using partial autonomy at a lower control level using reactive strategies for robot control. With respect to safety the project will consider how to use the development of learning algorithms to automatically detect abnormalities during robot teleoperation. These abnormalities may include excessive forces/pressure, excessive bending, unusual signals potentially indicating problems during the medical procedure.

Requirements: background in computer science, mathematics, engineering, physics or related disciplines.

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27. Novel Robot Control Paradigms enabled by Machine Learning for Intelligent Control of the Next Generation Compliant and Soft Robots

Tutors: Dr Petar Kormushev, Prof Darwin G. Caldwell

Department of Advanced Robotics (ADVR – IIT)
http://www.iit.it/advr

Description: Despite the significant mechatronic advances in robot design, the motor skill repertoire of current robots is mediocre compared to their biological counterparts. Motor skills of humans and animals are still utterly astonishing when compared to robots. This PhD theme will focus on machine learning methods to advance the state-of-the-art in robot learning of motor skills. The type of motor skills that will be investigated include object manipulation, compliant interaction with objects, humans and the environment, force control and vision as part of the robot learning architecture.

The creation of novel, high-performance, passively-compliant humanoid robots (such as the robot COMAN developed at IIT) offers a significant potential for achieving such advances in motor skills. However, as the bottleneck is not the hardware anymore, the main efforts should be directed towards the software that controls the robot. It is no longer reasonable to use over-simplified models of robot dynamics, because the novel compliant robots possess much richer and more complex dynamics than the previous generation of stiff robots. Therefore, new solutions should be sought to address the challenge of compliant robot control.

Ideas from developmental robotics will be considered, in search for a qualitatively better approach for controlling robots, different than the currently predominant approach based on manually-engineered controllers.

The work within this PhD theme will include developing novel robot learning algorithms and methods that allow humanoid robots to easily learn new skills. At the same time, the methods should allow for natural and safe interaction with people. To this end, the research will include learning by imitation and reinforcement learning, as well as human-robot interaction.

Requirements: background in computer science, mathematics, engineering, physics or related disciplines.

Reference:

P. Kormushev, S. Calinon, D.G. Caldwell. Reinforcement Learning in Robotics: Applications and Real-World Challenges. MDPI Journal of Robotics (ISSN 2218-6581), Special Issue on Intelligent Robots, vol.2, pp.122-148, 2013.

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28. Agile Robot Locomotion using Machine Learning for Intelligent Control of Advanced Humanoid Robots

Tutors: Dr Petar Kormushev, Prof Nikos Tsagarakis

Department of Advanced Robotics (ADVR – IIT)
http://www.iit.it/advr

Description: The state-of-the-art high-performance, passively-compliant humanoid robots (such as the robot COMAN developed by IIT) offer a significant potential for achieving more agile robot locomotion. At this stage, the bottleneck is not the hardware anymore, but the software that controls the robot. It is no longer reasonable to use over-simplified models of robot dynamics, because the novel compliant robots possess much richer and more complex dynamics than the previous generation of stiff robots. Therefore, a new solution should be sought to address the challenge of compliant humanoid robot control.

In this PhD theme, the use of machine learning and robot learning methods will be explored, in order to achieve novel ways for whole-body compliant humanoid robot control. In particular, the focus will be on achieving agile locomotion, based on robot self-learned dynamics, rather than on pre-engineered dynamics model. The PhD candidates will be expected to develop new algorithms for robot learning and to advance the state-of-the-art in humanoid robot locomotion.

The expected outcome of these efforts includes the realization of highly dynamic bipedal locomotion such as omni-directional walking on uneven surfaces, coping with multiple contacts with the environments, jumping and running robustly on uneven terrain and in presence of high uncertainties, demonstrating robustness and tolerance to external disturbances, etc. The ultimate goal will be achieving locomotion skills comparable to a 1.5 - 2 year-old child.

Requirements: background in computer science, mathematics, engineering, physics or related disciplines.

Reference:

P. Kormushev, S. Calinon, D.G. Caldwell. Reinforcement Learning in Robotics: Applications and Real-World Challenges. MDPI Journal of Robotics (ISSN 2218-6581), Special Issue on Intelligent Robots, vol.2, pp.122-148, 2013.

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29. Dexterous Robotic Manipulation using Machine Learning for Intelligent Robot Control and Perception

Tutors: Dr Petar Kormushev, Prof Darwin G. Caldwell

Department of Advanced Robotics (ADVR – IIT)
http://www.iit.it/advr

Description: This project will investigate collaborative human-robot task learning and execution that uses the available perception (particularly tactile). The work will develop algorithms for learning of collaborative skills by direct interaction between a non-expert user and a robot. The tasks will build the necessary control algorithms to allow effortless and safe physical human-robot interaction using the available tactile feedback.

The final objectives will include: acquiring the perceptual information needed for robot to co-manipulate an object with human, understanding human's state in an interaction task so as to react properly, building a framework for online compliant human-robot interaction based on real-time feedback of the state of the object and human.

The project will also consider semi-supervised and unsupervised skill learning approaches. It will develop tactile-guided autonomous learning algorithms based on state-of-the-art methods for reinforcement learning and deep learning. The tactile feedback will help to increase the performance of skill execution autonomously by the robot through trial-and-error interactions with the objects in the environment.

In addition this work will focus on supervised skill learning approaches. It will develop tactile-guided learning algorithms based on state-of-the-art methods for learning by imitation and visuospatial skill learning. The tactile perception information will be used both in the learning phase and the execution phase, to improve the robustness and the range of motor skill repertoire.

Requirements: background in computer science, mathematics, engineering, physics or related disciplines.

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30. Robot-Assisted Microsurgery

Tutors: Dr. Leonardo Mattos, Dr. Nikhil Deshpande

Department of Advanced Robotics (ADVR – IIT)
http://www.iit.it/en/advr-labs/biomedical-robotics.html

Description: Microsurgeries are demanding operations that required high precision and dexterity. They also represent a surgical area in which robotics can have a deep impact, helping surgeons perform more precise and safer operations, or even pioneer previously impossible procedures. This research will contribute to the area of minimally invasive robot-assisted laser microsurgery. It will build upon results from the European project µRALP (www.microralp.eu) to create the next generation tools for high precision / high quality laser microsurgeries. This will involve the mechatronic design and control of a new miniaturized laser micromanipulator, as well as the evaluation and testing of new systems in collaboration with our partner surgeons. During this process the student will develop expertise in surgical robotics, medical equipment design, control systems, user interfaces and usability analysis.

Requirements: background in engineering; interest in the design, fabrication and analysis of robots and mechanisms for microsurgical applications. Experience in CAD-based mechanical design or microfabrication are desired. The candidate must be fluent in both spoken and written English.

Contacts: leonardo.mattos@iit.it; nikhil.deshpande@iit.it

31. Smart Clinical Tools

Tutors: Dr. Leonardo Mattos, Prof. Brian Davies

Department of Advanced Robotics (ADVR – IIT)
http://www.iit.it/en/advr-labs/biomedical-robotics.html

Description: Robotics can significantly improve clinical practice by offering tools and systems able to augment the clinicians' sensing and actuation capabilities. This PhD program will be centered on this concept and will contribute to the evolution of clinical tools through the development of new assistive robotic and mechatronic devices for delicate clinical applications, such as microsurgeries or intravenous injections on infants and diabetic patients. The research will be carried out in collaboration with partner clinicians and will focus on improving delicate operations that currently rely completely on the experience and manual dexterity of healthcare professionals. During this process the student will develop expertise in medical robotics, force sensing and control, imaging, micromanipulation, microinjection and haptic feedback.

Requirements: background in engineering; interest in the design, fabrication and analysis of mechatronic devices for clinical applications. Experience in mechanical design or robotics would be advantageous. The candidate must be fluent in both spoken and written English.

Contact: leonardo.mattos@iit.it; b.davies@imperial.ac.uk

32. Novel Interfaces and Technologies for Assistive Robotic Systems

Tutor: Dr. Leonardo Mattos, Dr. Nikhil Deshpande

Department of Advanced Robotics (ADVR – IIT)
http://www.iit.it/en/advr-labs/biomedical-robotics.html

Description: Technology can go a long way toward improving the quality of life of people who happen to have disabilities, including the elderly and those with debilitating diseases such as amyotrophic lateral sclerosis (ALS), muscular dystrophy, etc. This PhD program will focus on the creation of novel interfaces and systems to assist people with disabilities realize fundamental activities such as communication, environment control, social interactions and the ability to move around independently. It may also involve the investigate technologies suitable for assisted living using body-area and ambient wireless computing networks. The research will involve close collaboration with partner clinicians and technology end-users, allowing the student to develop expertise both in biomedical engineering (biosensors, actuators, control systems) and ergonomics (human factors, usability, human-computer interaction).

Requirements: background in biomedical engineering, computer science or related disciplines; interest in the design, implementation and evaluation of assistive systems. Experience in brain-machine interfaces (BMI) or the acquisition and processing of biosignals would be advantageous. The candidate must be fluent in both spoken and written English.

Contacts: leonardo.mattos@iit.it; nikhil.deshpande@iit.it

33. Real Time Tumor Detection and Classification in Endoscopic Video

Tutors: Dr. Leonardo Mattos

Department of Advanced Robotics (ADVR – IIT)
http://www.iit.it/en/advr-labs/biomedical-robotics.html

Description: In this PhD program the student will become familiar with endoscopic imaging for minimally-invasive surgery and will develop expertise in computer vision and machine learning techniques with the goal of creating a new system for automatic tumor detection, segmentation and classification. This will include the use of data from real-time tumor imaging systems such as narrow-band imaging (NBI) and fluorescence imaging systems. This research will be carried out within the Department of Advanced Robotics. It will also involve close collaboration with partner surgeons. Results of this work will enable the creation of an optical biopsy system, which will help surgeons diagnose lesions in the office without the need for tissue excisions. It will also allow the creation of enhanced augmented reality systems for robot-assisted surgeries, helping surgeons visualize and establish safer surgical margins for cancer tissue removal.

Requirements: background in computer science or engineering; strong interest in medical image and image processing. Experience in computer vision and machine learning would be advantageous. The candidate must be fluent in both spoken and written English.

Contact: leonardo.mattos@iit.it

34. Cognitive Modeling and Control in Laser Microsurgery

Tutors: Dr. Leonardo Mattos, Loris Fichera

Department of Advanced Robotics (ADVR – IIT)
http://www.iit.it/en/advr-labs/biomedical-robotics.html

Description: Lasers are used in a number of surgical procedures as cutting tools, where their use has gained popularity due to the need for high quality incisions eg in surgery on the vocal folds. The quality of the incision is effects the accuracy of both the incision depth and width. For traditional surgery this incision quality depends mainly on the surgeon's ability to handle a scalpel and his/her sense of touch, but laser surgery requires a different type of dexterity. Improper use of the laser may result in harmful and undesired effects such as carbonization. To improve the quality of the incision and reduce the harmful effects the interaction between the laser and the tissue must be accurately modeled and controlled.

This project will build on previous work in the EU project µRALP (www.microralp.eu) to develop a cognitive model of the interaction and use this to control the laser power, on-time etc providing augmented senses of reality to the surgeon and improving his/her capacity to accurately perform incision, ablations etc.

Requirements: background in computer science, AI, or engineering; strong interest in medical image and image processing. Experience in computer vision and machine learning would be advantageous. The candidate must be fluent in both spoken and written English.

Reference:

D. Pardo, L.Fichera, D.G. Caldwell, L.Mattos, "Learning Tissue Temperature Dynamics on Agar-Based Phantom Tissue Surface During Single Point CO2 Laser Exposure", Neural Processing Letters, Oct.2014, ISSN: 1370-462, **DOI: 10.1007/s11063-014-9389-y.**

Contact: leonardo.mattos@iit.it

35. Development of Reconfigurable and Module Robotic Software for Novel Robotic Manipulator

Tutor: Dr. Ferdinando Cannella, Prof. Darwin Caldwell

Department of Advanced Robotics (ADVR – IIT)

https://www.iit.it/en/research/departments/advanced-robotics.html
Advanced Industrial Automation Lab
http://www.iit.it/en/advr-labs/advanced-industrial-automation.html

Description: Nowadays the manufacturing is facing an urgent demand on automation upgrade to meet the requirements from various types of manufacturing industry. However, the current robotic manufacturing system is still not flexible and adaptive to high mix low volume manufacturing. One of the challenges is to study and solve how to quickly deploy the robotic software and hardware suitable and adaptive to robotic manufacturing changes, which may include multiple robots, sensors (vision, force) and related machines. As a consequence, it is very important to design novel module and reconfigurable software framework to manage multiple types of robots and robotic systems. Goal of this PhD is to study, design and build novel industry-level software based on ROS or ROS-Industry which is modular, reconfigurable, adaptive, easy to use to integrate and control various robotic systems. It means the system should be able to detect, communicate and control almost every current existed robotic systems or communication styles. Meanwhile also build a reconfigurable robotic manipulator so as to test the developed software. The manipulator design will be based on the experience obtained from previous projects, but also is inspired from the nature of human beings hands or other similar bio-mechanisms. Since it is very complicated to design a bio-inspired robotic mechanism, the virtual prototyping development (co-simulation that involves multi-body and finite element and control) is required as a basic skill.

Moreover the research is carried out within the ADVR that concentrates on an innovative, multidisciplinary approach to humanoid design and control, and the development of novel robotic components and technologies. This encompasses activities from both the hard and soft systems areas of robotics. Thus the industrial developments exploit these advances that permit to design the humanoid-like robots suitable for the industrial plants.

Requirements: this position is open to a PhD candidate with strong interesting in reconfigurable mechanism and skill in computer science. The background must be in robotics. The ideal competencies should be in computer science with strong programing skill, especially program using C++ under Linux. Required technical skills: **80% computer science, 20% Mechanism**

References:

[1] Fei Chen, Ferdinando Cannella, Carlo Canali, Traveler Hauptman, Giuseppe Sofia, Darwin G. Caldwell, ''In-Hand Precise Twisting and Positioning by a Novel Dexterous Robotic Gripper for Industrial High-Speed Assembly'', IEEE International Conference on Robotics and Automation (ICRA 2014), Hong Kong, China, May 2014.

[2] Carlo Canali Cannella, Ferdinando; Fei Chen , Sofia, Giuseppe; Eytan, Amit; Caldwell, G. Darwin, "An automatic assembly parts detection and grasping system for industrial manufacturing," Automation Science and Engineering (CASE), 2014 IEEE International Conference on , vol., no., pp.215,220, 18-22 Aug. 2014. doi: 10.1109/CoASE.2014.6899329

[3] Fei Chen, Ferdinando Cannella, Horonobu Sasaki, Carlo Canali, Toshio Fukuda, ``Error Recovery Strategies for Electronic Connectors Mating in Robotic Fault-tolerant Assembly System'', IEEE/ASME 10th International Conference on Mechatronic and Embedded Systems and Applications (MESA 2014), Senigallia, Italy, pp. 1-6, September 2014.

[4] Chen, Fei; Sekiyama, K.; Cannella, Ferdinando; Fukuda, Toshio, "Optimal Subtask Allocation for Human and Robot Collaboration Within Hybrid Assembly System," Automation Science and Engineering, IEEE Transactions on , vol.PP, no.99, pp.1,11, 0, doi: 10.1109/TASE.2013.2274099

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36. Design and Development of Non-Rigid Lightweight Dexterous Robot Manipulator

Tutor: Dr. Ferdinando Cannella, Prof. Darwin Caldwell

Dept of Advanced Robotics (Italian Institute Of Technology)
https://www.iit.it/en/research/departments/advanced-robotics.html

Advanced Industrial Automation Lab
Http://Www.Iit.It/En/Advr-Labs/Advanced-Industrial-Automation.Html

Description: Currently the compliance of the robots is given by the flexible joint and the precision is guaranteed by the rigid link. The results is an heavy robot with high accuracy but low speed performances. The using of elastic link to reduce the weight and to extend the flexibility from the joints to whole robot is a non-new idea, but it is still an open challenge for many issues: the precise position control is affected by the deflection, long lasting oscillations prolong the settling time, and so on. Solving these problems means to improve the potentiality of the robots: e.g. reducing the weight and then the power for moving them (that means more autonomy and higher performances), the elastic deformation can be stored and realised to harvest energy, these results can be applied to similar design (fire-rescue turntable ladders as well as cherry pickers, etc.).

So the goal of this PhD is to design and build novel robot with elastic link, to go further the current state of art (e.g. TUDOR project) improving the design part which takes in account the structure behaviour. Then this behaviour will be implemented in the force control to exploit the link elasticity for the compliance interaction between robot and environment, i.e. impulsive interaction with environment.

Moreover the research is carried out within the ADVR that concentrates on an innovative, multidisciplinary approach to humanoid design and control, and the development of novel robotic components and technologies. This encompasses activities from both the hard and soft systems areas of robotics that are suitable also for industrial applications.

Requirements: this position is open to a PhD candidate with strong interesting in reconfigurable mechanism and skill in mechanics. The background must be in mechanical/mechatronic engineer or robotics. The ideal competencies should be in multibody simulation/finite element analysis and robot dynamics and control. Required technical skills: **70% mechanics, 30% control.**

Reference:

[1] Fei Chen, Ferdinando Cannella, Carlo Canali, Traveler Hauptman, Giuseppe Sofia, Darwin G. Caldwell, ''In-Hand Precise Twisting and Positioning by a Novel Dexterous Robotic Gripper for Industrial High-Speed Assembly'', IEEE International Conference on Robotics and Automation (ICRA 2014), Hong Kong, China, May 2014.

[2] Carlo Canali, Ferdinando Cannella, Fei Chen, Traveler Hauptman, Giuseppe Sofia, Amit A. Eytan, Darwin G. Caldwell "High Reconfigurable Self-Adaptive Robotic Gripper for Flexible Assembly" in Proceedings of the ASME 2014 International Design and Engineering Technical Conferences & Computers and Information in Engineering Conference, IDETC/CIE 2014, August 17-20, 2014, Buffalo, NY

[3]Mariapaola D'Imperio ,Ferdinando Cannella, Fei Chen, Daniele Catelani, Claudio Semini and Darwin G. Caldwell "Modelling Legged Robot Multi-Body Dynamics Using Hierarchical Virtual Prototype Design" -Proceedings of Living Machines'14 Proceedings of the Second international conference on Biomimetic and Biohybrid Systems.

[4] Ferdinando Cannella, Alberto Garinei, Mariapaola D'Imperio and Gianluca Rossi, "A Novel Method For The Design Of Prostheses Based On Thermoelastic Stress Analysis And Finite Element Analysis" Journal Of Mechanics In Medicine And Biology Vol. 14, No. 5 (2014) 1450064, World Scientific Publishing Company, Doi: 10.1142/S021951941450064.

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37. Legged Robots for Hazardous Environment Interventions I

Tutors: Prof Darwin G. Caldwell

Department of Advanced Robotics (ADVR – IIT)
http://www.iit.it/advr

Description (Humanoids): The world, both natural and man-made, is a **complex, unstructured, cluttered and dynamically changing environment,** in which humans and animals move with consummate ease, avoiding injury to themselves, damage to the environment and performing simple and complex tasks involving coordination of arms and legs. Wheeled and tracked robots are increasingly able to work in some of these terrains, particularly those that have naturally or artificially smoothed and flattened surfaces, but there are, and ultimately will continue to be, many scenarios where only human/animal-like levels of **agility, compliance, dexterity, robustness, reliability** and **movement/locomotion** will be sufficient.

To operate within infrastructures originally designed for humans, but which are, or have become, hostile or dangerous, a robot should possess a rich repertoire of human-like skills, and a human or animal inspired (but not necessarily copied) form. Any robot operating in such conditions should also exhibit physical power, agility and robustness, manipulation and locomotion capability, and ultimately have the capacity to reach and physically interact with dials, levers, valves, doors, control surfaces etc within the harsh environment.

These hazardous human engineered environments create challenges and opportunities which will demand increased functionality in the legged robots, moving from the current domain dominated by simple walking and balance maintenance, to address key whole body interaction issues (coordinated upper and lower body) during physical contact with humans, other robots, and the environment.

This project will explore the use of humanoid robots such as **COMAN** and **WalkMan** in these complex hazardous environments.

Requirements: background in computer science, mathematics, engineering, physics or related disciplines.

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38. Legged Robots for Hazardous Environment Interventions II

Tutors: Prof Darwin G. Caldwell

Department of Advanced Robotics (ADVR – IIT)
http://www.iit.it/advr

Description: The world, both natural and man-made, is a **complex, unstructured, cluttered and dynamically changing environment,** in which humans and animals move with consummate ease, avoiding injury to themselves, damage to the environment and performing simple and complex tasks involving coordination of arms and legs. Wheeled and tracked robots are increasingly able to work in some of these terrains, particularly those that have naturally or artificially smoothed and flattened surfaces, but there are, and ultimately will continue to be, many scenarios where only human/animal-like levels of **agility, compliance, dexterity, robustness, reliability** and **movement/locomotion** will be sufficient.

To operate within infrastructures originally designed for humans, but which are, or have become, hostile or dangerous, a robot should possess a rich repertoire of human-like skills, and a human or animal inspired (but not necessarily copied) form. Any robot operating in such conditions should also exhibit physical power, agility and robustness, manipulation and locomotion capability, and ultimately have the capacity to reach and physically interact with dials, levers, valves, doors, control surfaces etc within the harsh environment.

These hazardous human engineered environments create challenges and opportunities which will demand increased functionality in the legged robots, moving from the current domain dominated by simple walking and balance maintenance, to address key whole body interaction issues (coordinated upper and lower body) during physical contact with humans, other robots, and the environment.

This project will explore the use of quadruped robots such as **HyQ** and **HyQ2Max** in these complex hazardous environments.

Requirements: background in computer science, mathematics, engineering, physics or related disciplines.

Contacts: Darwin.Caldwell@iit.it

39. Development of soft bodied growing robots

Tutors: Dr Barbara Mazzolai, Dr. Lucia Beccai, Dr Alì Sadeghi

Department: Center for Micro-BioRobotics (Istituto Italiano di Tecnologia)
http://mbr.iit.it/

Description: Moving in an unstructured environment such as soil requires approaches that are constrained by the physics of this complex medium and can ensure energy efficiency and minimize friction while exploring and searching. Among living organisms, plants are the most efficient at soil exploration, and their roots show remarkable abilities that can be exploited in artificial systems. Energy efficiency and friction reduction are assured by a growth process wherein new cells are added at the root apex while mature cells of the root remain stationary and in contact with the soil. We will investigate how promising techniques, like 3D printing or similar, can be applied to develop a robot self-growing solution [1][2]. It has been demonstrated that the addition of material at the tip area of a robotic artefact facilitates soil penetration by omitting peripheral friction. As a consequence the overall energy consumption decreases down to 70% comparing with penetration obtained by pushing into the soil the robotic device from its base. Endowing the artefact with a tubular structure provides a path for delivering materials and energy to the tip of the system and for collecting information for exploratory tasks. The goal of this PhD is to study solutions coming from Nature (mainly, plants) in order to develop a new generation of soft-bodied robots able to grow and move in unstructured environments. In this context, we will also perform study and investigation on technical solutions for the development of a growing robot with the capability of reversibility and bio-compatibility for medical applications at centimeteric scale.

Requirements: the ideal candidate has a degree in Mechanical or Biomedical Engineering, or related disciplines; a background in mechanical design, fabrication, and/or control. He/she is also highly motivated to work on robotic platforms and has computer programming skills.

References:

[1] A. Sadeghi, A. Tonazzini, L. Popova and B. Mazzolai, A Novel Growing Device Inspired by Plant Root Soil Penetration Behaviors, PLoS ONE 9(2), 2014.

[2] A. Sadeghi, A. Tonazzini, L. Popova, B. Mazzolai, Robotic Mechanism for Soil Penetration Inspired by Plant Roots, 2013 IEEE International Conference on Robotics and Automation (ICRA), Karlsruhe, May 6 - 10, 2013

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40. Development of a new class of bioinspired high-efficiency and low power consumption actuators for soft robots

Tutors: Dr Barbara Mazzolai, Dr Edoardo Sinibaldi

Department: Center for Micro-BioRobotics (Istituto Italiano di Tecnologia)
http://mbr.iit.it/

Description: The goal of this PhD is to develop innovative actuators characterised by high-efficiency and low power consumption for soft robots. The design of these actuators will be also based on manufacturing principles inspired from Nature, specifically plants. Actually, the question of how plants move in the absence of muscles has attracted the interest of many scientists in both past and current times. An understanding of these nonmuscular movements holds potential for developments in applied sciences and engineering, especially for the creation of novel biomimetic actuation strategies. Many plant movements are based on osmosis, since osmotic actuation is a ubiquitous plant-inspired actuation strategy that has a very low power consumption but is capable of generating effective movements in a wide variety of environmental conditions. In light of these features, we have already developed a novel, low-power-consumption actuator that is capable of generating suitable forces during a characteristic actuation time on the order of a few minutes. Based on the analysis of plant movements and on osmotic actuation modeling, we have designed and fabricated a forward osmosis-based actuator with a typical size of 10 mm and a characteristic time of 2–5 minutes [1, 2, 3], which can exert forces above 20N and thus effectually usable in bioinspired devices. Starting from these results, this PhD aims to go beyond, developing cell-like actuation units also featuring compliant structures and possibly capable of morphological changes during actuation, suitable for integration with soft robotics effectors (such as grippers, manipulation tools, etc...).

Requirements: the ideal candidate would have a degree in Mechanical or Biomedical Engineering, or related disciplines; a background in mechanical design and fabrication. He/she would also be highly motivated to work on robotic platform and have computer programming skills.

References:

[1] E. Sinibaldi, A. Argiolas, G. L. Puleo, B. Mazzolai, Another lesson from plants: the forward osmosis-based actuator, PLoS ONE 9(7), 2014.

[2] E. Sinibaldi, G. Puleo, F. Mattioli, V. Mattoli, F. Di Michele, L. Beccai, F. Tramacere, S. Mancuso, B. Mazzolai, Osmotic actuation modelling for innovative biorobotic solutions inspired by the plant kingdom, Bioinspiration & Biomimetics, Vol 8, pp 025002, 2013

[3] B. Mazzolai, A. Mondini, P. Corradi, C. Laschi, V. Mattoli, E. Sinibaldi and P. Dario, A Miniaturized Mechatronic System Inspired by Plant Roots, IEEE Transaction on Mechatronics, vol 16(2), pp. 201-212, 2012

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41. Control of bioinspired distributed robotic systems

Tutors: Dr Barbara Mazzolai, Dr. Alessio Mondini, Dr. Lucia Beccai

Department: Center for Micro-BioRobotics (Istituto Italiano di Tecnologia)
http://mbr.iit.it/

Description: The properties biologists recognise as exemplifying intelligent behaviour are: information sensing, processing and integration; decision making and control of behaviour; learning; memory; choice; self-recognition; foresight by predictive modelling and computation to optimise resource acquisition with economy of effort. Many plants possess all of these capabilities. In animals, behaviour usually refers to movements generated by muscles; plant intelligence on that basis does not exist. Nonetheless, plants respond to internal and external signals showing individual and collective behaviours [1,2]. Thus, a simple definition of “plant intelligence” could be adaptively variable growth and development during the lifetime of the individual. Plants are able to perform preferential pathways by prioritizing touch, temperature, humidity, nutrients and salt gradients cues; as well as cooperative behaviours. Ideally in a plant-inspired robot the information on touch (as well as all sensory information) is not processed at high level (as in e.g. humanoids). However biologists still consider plant ‘perception’ to relate to all the internal and distributed (not centralized by a ‘brain’) processes that bring plants to move (or ‘take action’) as a response to the tactile stimulus. Even if this happens in different timescales than in animals/humans, it will be very important to shed light on how to use such a distributed intelligence to build smart sensors and control. Such a system will bring to significant improvements in terms of efficient movement, soft interaction, and control architecture. All these adaptive abilities of plants will lead to develop smart devices - not solely with the ability to sense - but with the capability to follow stimuli/gradients and to take decisions to accomplish the needed tasks. The goal of this PhD is study and develop bioinspired control and communication models, based on emergent cooperative and competitive behaviour in plants. The models developed will be simulated and then integrated and validated in soft plant-inspired robotic platforms.

Requirements: the ideal candidate has a degree in Computer Science, or related disciplines; a background in control. He/she is also highly motivated to work on robotic platforms and has computer programming skills.

References:

[1] M. Ciszak, D. Comparini, B. Mazzolai, F. Baluska, T.F. Arecchi, T. Vicsek, S. Mancuso, Swarming behavior in plant roots, PLoS ONE, 7(1), 2012

[2] B. Mazzolai, V. Mattoli, L. Beccai, E. Sinibaldi “Emerging Technologies Inspired by Plants”, in Springer Bioinspired Approaches for Human-Centric Technologies, 2014

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42. Development of bioinspired soft tactile systems capable of active touch in unstructured environment

Tutors: Lucia Beccai, Barbara Mazzolai, Massimo Totaro

Department: Center for Micro-BioRobotics, CMBR (Istituto Italiano di Tecnologia)

http://mbr.iit.it/

Description:

Natural tactile sense can inspire ideas for artificial sensing. Tactile processes are related to the mechanical properties of the hosting body and on how the body moves and interacts in the environment, and on the mechanical and physical aspects of this interaction. Therefore to bring truly innovative touch sensitive devices the body and tactile functionality must be investigated as one system. Artificial tactile sensors should be designed and built by keeping in one device both biomimetic mechanical features (like softness, flexibility and stretchability) and functionality (like force, strain, etc…), and in order to go beyond current approaches of tactile sensing and electronic skins, a special attention is needed on mimicking the compliance of the tactile system with objects/environment. As robotic systems we focus on soft robots to pursue a more natural interaction with the environment and we aim at building tactile systems fully embedded in soft robots that can accomplish active touch, i.e. they move in the environment in order to acquire the tactile information. The soft robots are inspired on plants and they will move by growth and due to sensory feedback from the environment, including touch. The goal of the proposed theme is to design and build a new generation of soft tactile systems capable to operate in a growing plant-inspired soft artifact that is continually mechanically stimulated by it's the non-structured environment (e.g., soil). The sensorized robots will be developed to encode multidirectional mechanical stimuli.

The research will focus on the development of bioinspired soft tactile systems able to distinguish and elaborate multiple mechanical stimulations in unstructured environments. To this aim, the candidate will be involved in the design, fabrication and characterization of soft bodied sensing robots. He/she will use novel materials (e.g. conductive polymers, composites of soft materials and conducting nanoparticles/fibers, etc..) and their related fabrication technologies (e.g. soft lithography, direct laser writing, electrospinning, thin film deposition, etc). Additionally, the design and test of simple electronic interfaces for signal conditioning and elaboration will be addressed.

Requirements: degree in Electronic or Material Engineering, Material Science, Physics, or equivalent. A background on micro-nanotechnologies is preferable. High motivation to work on bioinspired technologies and robotics.

Reference:

[1] C. Lucarotti, M. Totaro, A. Sadeghi, B. Mazzolai, and L. Beccai, "Revealing bending and force in a soft body through a plant root inspired approach," Scientific Reports vol. 5, n. 8788, 2015 doi:10.1038/srep08788

[2] L. Viry, A. Levi, M. Totaro, A. Mondini, V. Mattoli, B. Mazzolai, and L. Beccai, "Flexible three-axial force sensor for soft and highly sensitive artificial touch," Advanced Materials, vol. 26, pp. 2659-2664, 2014

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