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. 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 aim at developing robots that on the one hand can learn and adapt from their mistakes, and on the other are robust to work in real-world practical scenarios: e.g. at home, as personal assistants, as well as in industry as co-workers or to intervene in case of natural or man-made disasters. On the hardware side, besides the realization of full-fledged platforms, we address the development of the technologies for the next generation of robots based on soft and adaptable materials for sensing, actuation and computation. 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".

The PhD themes in this curriculum are offered by the iCub Facility and by the Department of Advanced Robotics (ADVR) at the Istituto Italiano di Tecnologia (IIT).

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.

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

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1. Event-driven vision sensors for humanoid robots

Tutors: Dr Chiara Bartolozzi

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

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). High motivation to work on a robotic platform.

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

2. Building the neuromorphic iCub

Tutors: Chiara Bartolozzi

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

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 snapshots 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 **integration of event-driven sensors and computing platforms 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 and provide adequate computing platforms such as the SpiNNaker system.
The research will focus on the development of the infrastructure for optimally interfacing event-driven hardware modules based on the Address Event Representation protocol on the iCub.

Requirements: degree in Electronic Engineering, Physics (or equivalent) and background on FPGA programming (VHDL, Verilog). High motivation to work on a robotic platform.

Reference: C. Bartolozzi, F. Rea, C. Clercq, M. Hofstätter, D. B. Fasnacht, G. Indiveri, and G. Metta, "Embedded neuromorphic vision for humanoid robots," in IEEE Computer Society Conference on Computer Vision and Pattern Recognition Workshops (CVPRW), 2011, pp. 129–135.

Contacts: chiara.bartolozzi@iit.it

3. Event-driven vision for the iCub

Tutors: Dr Chiara Bartolozzi, Dr Lorenzo Natale

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

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 information from event-driven sensors for robust interaction of the humanoid robot iCub with moving objects. The goal is to develop new techniques for the recognition and prediction of trajectories of moving targets including humans and objects and plan for precise reaching movements, by exploiting the high temporal resolution and compressive signal encoding of event-driven vision sensors mounted on the iCub.
Research will focus on the development of the infrastructure for handling event-driven sensory data and of event-driven vision algorithms for motion estimation as well as algorithms for trajectory prediction. Real time behaviour will be achieved by using compressive event driven computation and on-board processing on FPGA.

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 computer and FPGA 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.

Contacts: chiara.bartolozzi@iit.it , lorenzo.natale@iit.it

4. New techniques for vision-assisted speech processing for the iCub

Tutors: Dr Chiara Bartolozzi, Dr Leonardo Badino

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

Description: Robust speech detection in realistic environments for human robot interaction is still a challenging task. Vision is occasionally used for improving speech recognition in noisy acoustic environments, however, the temporal content of the visual information is severely limited by the temporal discretization of the frame-based acquisition. 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 goal of the proposed theme is the **exploitation of highly dynamical information from event-driven vision sensors for robust speech processing for the humanoid robot iCub**. The goal is to extract visual features and cues from the stream of visual events that are related to speech production landmarks and exploit them for further improving speech recognition.

The research will focus on the development of the infrastructure for handling event-driven sensory data and of novel algorithms for extraction of visual features from event-driven cameras.

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

Reference: G. Potamianos, C. Neti, G. Gravier, A. Garg, and A.W.Senior in Proceedings of the IEEE Vol. 91 No. 9 September 2003 pp. 1306-1326.

Contacts: chiara.bartolozzi@iit.it , leonardo.badino@iit.it

5. Speech production for automatic speech recognition in human–robot verbal interaction

Tutors: Prof Giorgio Metta, Dr Leonardo Badino, Prof Luciano Fadiga

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 partially controlled scenarios but still lags behind human level performance in unconstrained real usage situations and perform poorly whenever the type of acoustic noise, the speaker's accent and speaking style are "unknown" to the system, i.e., they are not sufficiently covered in the data used to train the ASR system. The goal of this PhD theme is to tackle the problem of ASR in a human to robot conversation. To this aim, we will create a robust Key Phrases Recognition system where commands delivered by the user to the 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. Notably, knowledge about speech production will be included in the training phase of the ASR following the suggestion that a model of the human articulatory system may help in filtering out noise from the interesting signal. This articulatory information will be integrated into a Deep Neural Network – Hidden Markov Model system. This work will be carried out and tested on the iCub platform.

Requirements: background in computer science, bioengineering, computer engineering, physics or related disciplines. Solid programming skills in C++, Matlab, GPU (CUDA) are a plus. Attitude for problem solving. Interests in understanding/learning basic biology.

Reference: Barker, J., Vincent, E., Ma, N., Christensen, H., Green, P., (2013) "The PASCAL CHiME Speech Separation and Recognition Challenge". Computer Speech and Language 27, 3, 621-633.

Contacts: giorgio.metta@iit.it, leonardo.badino@iit.it, luciano.fadiga@iit.it

6. Tactile object exploration

Tutors: Prof Giorgio Metta, Dr Lorenzo Natale

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

Description: Recent advances in tactile sensing have renewed the interest in the development of control strategies that exploit tactile feedback to control the interaction between the robot and the environment (see reference). Indeed, it has been shown that tactile feedback can complement or even substitute for vision for grasping, especially in those situations in which a model of the environment is not available. In humans it is believed that haptic exploration is fundamental to generate structured information to extract object properties like size, volume and shape. In robots haptic representations of objects have been investigated; some authors implement an implicit encoding which allows clustering objects with similar shapes. In a simulated scenario others use features inspired by the literature in computer vision to implement an algorithm that extracts tactile features and uses them for recognition.
The goal of this PhD project is to implement on the iCub strategies for object exploration and grasping based primarily on haptic feedback. To this aim we will use the sensory system of the iCub which includes a system of tactile sensors (fingertips, hands and arms) and force sensors. We will also study algorithms for extracting haptic features during object exploration and apply them to the problem of object recognition.

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.

Reference: Dahiya, R. S., Metta, G., Cannata, G., Valle, M., Guest Editorial Special Issue on Robotic Sense of Touch, IEEE Transactions on Robotics, Special Issue on Robotic Sense of Touch, Vol 23(3), 2011.

Contacts: giorgio.metta@iit.it, lorenzo.natale@iit.it

7. Development of soft MEMS tactile sensing technologies for robotics

Tutors: Prof Massimo De Vittorio, Prof Giorgio Metta

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

Description: Tactile sensing technologies, that may enable safer and enhanced interaction of robots with the environment and humans, are still in their infancy and significant progress is necessary both at the sensor level and at the system level for a more widespread application in robotics. In particular, for humanoid robots, tasks such as reaching, grasping and dexterous manipulation would greatly benefit from the development of high sensitivity and reliable tactile/force sensing devices. The goal of this project is therefore the development of high-quality flexible sensors for

robotics based on a soft MEMS approach and, in particular, the development of sensors capable of detecting normal and shear forces and their implementation and validation on the iCub platform. Based on the multidisciplinary know-how on MEMS, robotics, and signal processing as well as past experience with other state-of-the-art technologies (e.g. capacitive, PVDF).
The activity will deal with the design, modeling and fabrication of new integrated sensors using flexible Kapton films as substrates and Aluminum Nitride (AlN) as active material by the virtue of its piezoelectric/flexoelectric properties. Micromachined transducers based on this technology will be fabricated to detect normal and shear stress. A special attention will be devoted to the appropriate design of the sensor top interfacial layer (e.g. parylene) that is crucial for the correct interfacing of the devices with the environment. Ad-hoc interface electronics embedded and connected to the iCub main infrastructure will be developed. The candidate's work will take place both at the CBN-MEMS (IIT@Unile) and at the iCub Facility (IIT Genova) that are strongly collaborating on this project.

Requirements: the ideal candidate would have a degree in Electronic or Materials Engineering or related disciplines. A background in microelectronics is preferable as well as a strong motivation to work on a complex robotic system and some programming skills.

Contacts: giorgio.metta@iit.it, massimo.devittorio@iit.it

8. Whole-body force and motion estimation

Tutors: Dr Francesco Nori

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

Description: one of the core components in a control system is the so-called state estimation. In complicated system such as a humanoid robot, the state estimation problem is complicated by the complexity of the system (state space dimensionality) and by the number of sensors and sensor modalities (i.e. whole-body distributed position sensors, gyroscopes, accelerometers, touch, and force-torque sensors). Being a core component in a control loop, estimation is always subject to strict requirements in terms of computational time and delays (to avoid undesirable control lags). This research topic addresses the problem of whole-body force and motion estimation on the iCub humanoid. Within this context, the iCub is a singleton in consideration of the number of available sensors: more than 4000 tactile sensors, three-axis accelerometers (more than 50), six-axis force-torque sensors (6) and three-axis gyroscopes (20). The research activity will also consider the use of vision (stereo cameras mounted in the iCub eyes) to estimate the robot position within the environment. The research will be conducted within the European project CoDyCo (www.codyco.eu). The project outcome will be integrated in the YARP and iCub open-source software framework to improve the iCub whole-body motion control capabilities (http://codyco.eu/videos-menu/forcecontrol).

Requirements: the candidate needs to have an engineering background with strong competences in control theory. Competences in robotics, computer science and software programming will be positively evaluated.

Reference: M Fumagalli, S Ivaldi, M Randazzo, L Natale, G Metta, G Sandini, F Nori. Force feedback exploiting tactile and proximal force/torque sensing. Autonomous Robots 33 (4), 381-398.

Contacts: francesco.nori@iit.it

9. Whole-body distributed dynamics computations

Tutors: Dr Francesco Nori, Dr Lorenzo Natale, Prof Giuseppe Casalino

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

Description: The next generation of industrial robots will be torque controlled. Therefore, computing the differential equations which describe the robot whole-body dynamics will become a fundamental requirement. The algorithmic complexity of whole-body dynamic computations has been already extensively optimized (see R. Featherstone). Nowadays, the bottleneck of performances is not represented by the computational complexity itself but by the communication delays in collecting all the information necessary for the computation. This research project aims at designing and implementing an efficient algorithm for embedded and distributed whole-body dynamics computations. Several sensors and sources of information will be used: gyroscopes, accelerometers, touch, and force-torque sensors to cite a few. Implementations are foreseen on the iCub platform (www.icub.org) and validation in whole-body posture control (https://www.youtube.com/watch?v=jaTEbCsFp_M). The iCub humanoid robot was recently re-designed to host a system of Cortex-M4 cores interconnected with an Ethernet backbone. CPUs directly control the motors and have access to a rich system of sensors distributed on the entire body of the robot (tactile sensors, accelerometers, gyros as well as force and torque sensors).. This research project aims at designing an efficient algorithm for distributed whole-body dynamics computations and communication strategies that allows compensating jitters and delays among boards that control joints and sensors on different parts of the body.

Requirements: the ideal candidate has an engineering background with strong competences in in either control theory or development of real-time software for embedded systems. Competences in robotics, computer science and software programming will be positively evaluated.

Reference: G. Casalino, A. Turetta and A. Sorbara. Distributed Kinematic Inversion Technique for Modular Robotic Systems. In International Conference on Intelligent Robots and Systems (IROS 2007), San Diego, California, US, October 2007.

Contacts: francesco.nori@iit.it, lorenzo.natale@iit.it, pino@dist.unige.it

10. Innovative solutions for (task/motion) planning and task scheduling in robotic settings

Tutors: Prof Marco Maratea, Dr Francesco Nori

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

Description: A longstanding goal of Artificial Intelligence and planning is to build robots that can move around and manipulate objects in the physical world to achieve their goals. In order to improve the autonomy and overall functionality of these robots, reliable sensors, safety mechanisms, and general integrated software tools and techniques are needed. Historically, discrete task planning has been considered in the AI community, while continuous motion planning has been the focus in robotics. Effective task-oriented mobile manipulation, indeed, requires approaches to integrating task and motion planning, as well as to task scheduling that are capable of operating in dynamic and complex environments. The aim of this project is to design, implement and experiment innovative off-line and/or on-line algorithms for (task/motion) planning and task scheduling. Envisioned applications include (but are not limited to) planning and scheduling of distributed communication and computational resources. A possible case state study will be torque control (see reference), which involves several whole-body distributed sensors (position, gyroscopes, accelerometers, force/torque, touch) and computational units (local DSPs and central PC104). Remarkably, torque control is becoming a core component for robots of the next generation and its hardware implementation can be significantly improved by optimally scheduling computations and communications among the involved components. The project will be conducted in the context of the CoDyCo EU project (see http://www.codyco.eu/).

Requirements: background in computer science, robotics, computer engineering, and/or related disciplines. Attitude to problem solving; good mathematical and implementation skills.

Reference: Fumagalli, M.; Ivaldi, S.; Randazzo, M.; Natale, L.; Metta, G.; Sandini, G.; Nori, F. (2012). *Force feedback exploiting tactile and proximal force/torque sensing. Theory and implementation on the humanoid robot iCub. (PDF)* Autonomous Robots. Vol 33 No 4 Pages 381-398.

Contacts: marco.maratea@unige.it, francesco.nori@iit.it

11. Building the Humanoids of the future: Exploring the Mechatronic Technological Limits and New Design Philosophies for the development of a high performance functional humanoid platform

Tutors: Dr Nikos Tsagarakis

Department of Advanced Robotics (ADVR -IIT)
http://www.iit.it/en/research/departments/advanced-robotics.html

Description: Although significant progress have been made during the last two decades in the mechatronic development of humanoid robots there are still significant barriers to be overcome before these robots (structure, actuation and sensing) approach the performance of the human body. When compared with human humanoid robots significantly lack in performance, efficiency and physical robustness. To generate motions is highly inefficient and high impact interactions which are required for example during the execution of highly dynamic tasks, e.g. running cannot be tolerated by any existing humanoid system. Their design principles impose significant limitations both in the velocities/torque profiles that can be achieved at the joint level and in the capability of these systems to absorb the impacts. In addition the lack of compliance does not allow these robots to make use of the natural dynamics and storage of energy during the motion cycle. As a result these robots have higher energy demands since more effort is required by both the control system and the actuator. The aim of this topic is to improve the performance of the existing humanoid on the aspects discussed above by exploring both the mechatronic technological limits (structural materials, actuation and transmission systems) and new control philosophies. The outcome of these efforts will be verified though the development of a highly dynamic humanoid machine targeting to achieve joint torque and power close to those achieved by humans while at the same time demonstrating efficiency and physical robustness. 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 Mechanical engineering or Robotics. This is a multidisciplinary project where the successful candidates should have strong competencies in CAD mechanism design and good knowledge of robot kinematics/dynamics. (Mechanical design 70%, Dynamics/Control %30).

Reference: 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.

Contacts: nikos.tsagarakis@iit.it

12. Design principles and control of high performance robotic actuation systems

Tutors: Dr Nikos Tsagarakis

Department of Advanced Robotics (ADVR -IIT)
http://www.iit.it/en/research/departments/advanced-robotics.html

Description: 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. 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 systems powered by compliance actuators. Recently a new actuation concept based on an asymmetric antagonistic scheme has been developed at the Department of Advanced Robotics. This research will investigate this novel joint actuation and elastic transmission system and their associate control schemes and eventually demonstrate energy efficient and high peak operation using large energy storage capacity elements, efficient actuation drivers and energy recycling techniques. The developed joint concepts and controllers will be eventually applied to walking, hopping and in general legged robots. The research in the utility and control of the actuator will be also applied in high power bursts such as throwing, kicking and jumping of anthropomorphic robots. The work activity of this theme will be in line with the workplan of the WALK-MAN EU project (http://www.walk-man.eu/)

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%, 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.

Contacts: nikos.tsagarakis@iit.it

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

Tutors: Dr Nikos Tsagarakis, Dr Gustavo Medrano Cerda

Department of Advanced Robotics (ADVR -IIT)
http://www.iit.it/en/research/departments/advanced-robotics.html

Description: 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.

Contacts: nikos.tsagarakis@iit.it

14. Human/Robot Cooperative Whole body Manipulation

Tutors: Dr Arash Ajoudani, Dr Jinoh Lee, Dr Nikos Tsagarakis

Department of Advanced Robotics (ADVR -IIT)
http://www.iit.it/en/research/departments/advanced-robotics.html

Description: In recent years, the fast growing interest in versatility and flexibility of robotic systems working closely and interacting with humans in co-operative tasks or acting as assisting or prosthesis systems had led to the development of a wide range of systems: from full body humanoid robot co-workers to anthropomorphic manipulator prosthesis and exoskeleton systems aiming to aid and improve the life of humans with special needs. To increase such systems acceptability and compatibility, they should be capable of generating robust and efficient interactions

with the humans. To achieve this, it is essential to realize a robust and efficient whole body interaction controller using impedance control techniques. In this direction, it is profitable to incorporate in the motion control architecture of these systems human principles of motor control. As a consequence, not only a desired interaction performance will be realized, generated whole body motions will look natural, similar to the ones generated by humans executing a similar task.
Developed controllers will be experimentally evaluated is target tasks using the torque controlled humanoid robot, COMAN. 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 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, N. G. Tsagarakis, J. Lee, M. Gabiccini and A. Bicchi, "Natural Redundancy Resolution in Dual Arm Manipulation using Configuration Dependent Stiffness (CDS) Control", IEEE International Conference on Robotics and Automation (ICRA), 2014.

Contacts: nikos.tsagarakis@iit.it

15. Dynamic Locomotion Control and Planning

Tutors: Dr Zhibin Li, Dr Xin Wang, Dr Nikos Tsagarakis

Department of Advanced Robotics (ADVR -IIT)
http://www.iit.it/en/research/departments/advanced-robotics.html

Description: Despite the significant progress in Humanoid locomotion during the last decade, most of the present-day humanoids still suffer from major problems related to dynamically equilibrated walking, stable walking and physical interaction with the environment. Looking on the Humanoid locomotion developments, it can also be observed that most of them perform on flat surfaces. This is a very ideal surface property compared to surfaces existing in human environments where stairs, inclined surfaces, small obstacles and even rough surfaces exist. To date, there are only a few effective demonstrations about walking and motion planning in this kind of environments.

This research theme targets at developing techniques which will permit planning the motion and regulating both the dynamic equilibrium and body/feet posture of the humanoid in order to achieve walking on uneven surfaces, avoiding or stepping on obstacles with variable inclinations, and on particular surfaces such as stones and sands. 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. In particular, we will exploit the utilization of detected rough terrain/obstacle properties such as inclination from the contact force sensors located at the feet sole. The determined the rough terrain characteristics will be used to evaluate how the balance stability is affected when the robot is on this specific rough terrain, and therefore different control and locomotion planning methodologies will be developed to allow the humanoid to traverse while maintaining stability and balance. The methods will be studied in simulation and eventually validated in real experiments using the compliant humanoid robot COMAN developed under the European FP7 project AMARSI (www.amarsi-project.eu) as well as the high performance humanoid which is under development within the EU project WALK-MAN (www.walk-man.eu).

Requirements: Ideal applicants should possess strong background in modeling and control of physical systems, MATLAB and C/C++ programming. Experience and knowledge on mechatronics hardware, fundamental robotics and rigid body dynamics is a plus.

Reference: Zhibin Li, N.G. Tsagarakis, Darwin G. Caldwell, "Walking Pattern Generation for a Humanoid Robot with Compliant Joints", Autonomous Robots, Volume 35, Issue 1, pp 1-14, 2013.

Contacts: zhibin.li@iit.it

16. Whole-body Sensor Fusion of Humanoid Robots

Tutors: Dr Zhibin Li, Dr Xin Wang, Dr Nikos Tsagarakis
Department of Advanced Robotics (ADVR -IIT)
http://www.iit.it/en/research/departments/advanced-robotics.html

Description: To date, the sensor feedback provided by the sensors equipped in humanoid robot is very much limited compared to the rich sensory information exists in humans. Moreover, there lacks of an effective sensor fusion framework in practice that fuses the different feedback signals, estimates the parameters and the state of the system.

This proposed research theme aims at the development of the whole-body sensory feedback system that provides a set of fused feedback to assist the locomotion control, and monitor the state of the system. The whole-body sensor framework will be composed by three layers: the first layer is the elementary signal filtering and automatic offset removal of all types of sensors; the second layer is the sensor fusion of the processed signals from the first layer, which extract the processed data from the first layer and compute high level integrated information (for example, the online estimation of the center of mass of the robot, the kinematics/dynamics state, the identified terrain properties); the last layer will make an effective use of the extracted information from the second layer to assist and suggest the locomotion control framework about what the status of the robot is, what kind of control should be activated or dismissed and so on, as well as managing the system status report/record for further diagnosis when necessary.

Particularly in the first layer of the whole-body sensor fusion, the candidate is expected to develop self-calibration algorithms that explore the redundancy of the sensor feedback and an explicit dynamic model of the robot to calibrate those sensors which have signal drifting issue or temperature varying property. These algorithms should be able to run offline (a self-calibration procedure as a part of initialization of the system), and online (while robot is running on the field).

Both the whole-body sensor fusion will serve as a foundation for the control and planning of the locomotion which endow the humanoids to traverse various types of terrains. 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 humanoid which is under development within the EU project WALK-MAN (www.walk-man.eu).

Requirements: Applicants should have strong background in signal processing, digital filter design (Kalman filter, etc.), and programming skills in MATLAB and C/C++. Knowledge on mechatronics hardware, fundamental robotics and rigid body dynamics is a plus.

Contacts: zhibin.li@iit.it

17. 3D Perception for Humanoid Robots: Rough terrain locomotion and Free-form object manipulation

Tutors: Dr Dimitris Kanoulas, Dr Nikos Tsagarakis

Department of Advanced Robotics (ADVR -IIT)
http://www.iit.it/en/research/departments/advanced-robotics.html

Description: 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. We need vision! 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 humanoid robot (COMAN). 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 and Marsette Vona, Bio-Inspired Rough Terrain Contact Patch Perception, In the IEEE International Conference on Robotics and Automation, ICRA 2014.

Contacts: nikos.tsagarakis@iit.it

18. Building the Next Generation of Highly Dynamic Legged Robots with Joint Torque Control

Tutors: Dr Claudio Semini, Dr Michele Focchi

Department of Advanced Robotics (ADVR -IIT)
http://www.iit.it/hyq

Description: The flagship platform of the Dynamic Legged Systems lab is the Hydraulic Quadruped robot HyQ. This fully torque-controlled hydraulically actuated quadruped robot can navigate over rough terrain and perform highly dynamic tasks such as jumping and running with a variety of gaits. More recently the robot demonstrated its capability to perceive the environment, plan footholds and navigate over challenging terrain where reactive gaits would fail. HyQ is a unique research platform that is designed for unstructured environments, e.g. outdoors, accident and disaster sites, etc.

This PhD position will investigate new ways of designing and constructing the next generation of versatile, highly dynamic legged robots with joint torque control. Most of today’s legged robots lack the versatility, robustness and reliability that are required to successfully perform useful tasks in a real-world environment. Therefore this theme will start with a careful investigation and definition of the required specifications based on the target capabilities. Pushing the limits for all components does not always make sense and the trade-offs need to be correctly balanced to find a compromise between conflicting requirements (e.g. joint power vs. weight/volume). Materials, actuation, hydraulics, sensing, compact design, mechanisms, fast controllers, redundancy are key-elements for a successful robot design. Industry collaboration will be part of this position.

Requirements: strong background in robotics, mechanical or electrical engineering. Hands-on experience in CAD software required, please include images of personal mechanical designs into your CV. Understanding of robot kinematics and dynamics. Highly-motivated and passionate for robotics and legged locomotion, experienced in ROS and Matlab.

Reference: C. Semini, N. G. Tsagarakis, E. Guglielmino, M. Focchi, F. Cannella, and D. G. Caldwell, "Design of HyQ - a hydraulically and electrically actuated quadruped robot," JSCE, vol. 225, no. 6, pp. 831–849, 2011.

Contacts: claudio.semini@iit.it, michele.focchi@iit.it

19. Planning dynamic motions using reduced dimensionality models

Tutors: Dr Michele Focchi, Dr Ioannis Havoutis

Department of Advanced Robotics (ADVR -IIT)
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.
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: R.J. Full and D.E. Koditschek, Templates and anchors: neuromechanical hypotheses of legged locomotion on land *1999 202:3325-3332.*

Contacts: michele.focchi@iit.it, ioannis.havoutis@iit.it

20. Development of a Reconfigurable Robot Manipulator for Industrial Applications

Tutors: Dr Ferdinando Cannella

Department of Advanced Robotics (ADVR -IIT)
http://www.iit.it/en/research/departments/advanced-robotics.html

Description: Nowadays the manufacturing is facing an urgent demand on automation upgrade to meet the requirements from various types of manufacturing industry. One of the key features is replacing robots with human beings. Robotic manipulator, widely used in industry, plays an important role to accomplish this task. As a consequence, it is very important to design novel End-effectors or robotic grippers/hands with variety of functionality so that the robot can grasp and manipulate different assembly objects. Goal of this PhD is to design and build novel industry-level robotic end-effector based on the new concept developed by customers and researchers. That means a virtual prototype of this device will be done in order to simulate the manipulation, so the best solution will be found quicker, because few physical prototyping will be necessary.
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, virtual prototyping development (co-simulation that involves multi-body and finite element and control) is required as a basic skill.
As examples, two industrial applications are already accomplished: dexterous and flexible grippers for automotive and consumer goods (AUTORECON) and origami carton folding manipulator (ARCHAPS). At same time two research tasks are carrying out: modelling of humanoid and quadruped robot legs and a multi-points force measurement test rig for haptic investigations. This work will be under supervision of **Dr. Carlo Canali, Dr. Fei Chen**

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: F. Cannella, F. Chen, C. Canali, A. Eytan, A. Bottero, D. G. Caldwell, ''Design of an Industrial Robotic Gripper for Precise Twisting and Positioning in High-Speed Assembly'', in IEEE/SICE International Symposium on System Integration (SII2013), Kobe, Japan, Dec., 2013, pp. 443-448.

Contacts: ferdinando.cannella@iit.it, carlo.canali@iit.it, fei.chen@iit.it

21. Robot learning of motor skills

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.

Contacts: petar.kormushev@iit.it

22. Robot Learning for Agile Locomotion

Tutors: Dr Petar Kormushev, Dr 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.

Contacts: petar.kormushev@iit.it; nikos.tsagarakis@iit.it

23. Computer Vision and Machine Learning for Tumor Detection and Classification in Real-Time Endoscopic Video

Tutors: Dr Leonardo Mattos, Prof Vittorio Murino

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 in collaboration with the Department of Pattern Analysis and Computer Vision (PAVIS). 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.

Contacts: leonardo.mattos@iit.it; vittorio.murino@iit.it

24. Robot-Assisted Laser 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

25. 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.

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

26. Novel Interfaces and Assistive Systems for the Disabled

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

27. Miniaturized Tools for Microsurgery

Tutors: Dr Nikhil Deshpande, Dr Leonardo Mattos

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

Description: The creation and utilization of tools that are small enough to pass through the various conduits in the human body is an emerging area of medical innovation in the microsurgery domain. It involves the fabrication of miniaturized devices having physical, chemical, mechanical, and electronic functionalities that can be controlled or autonomously triggered based on the application. The challenges lie in providing the dexterity, access, control, and manipulation capability for the surgeons using these devices, as well as giving force/tactile and visual feedbacks during surgery. The tele-operation and control of the devices in the surgical site require new methods of training and skill acquisition for the surgeons. New user interfaces, surgical procedures, and test-beds need to be devised to simulate surgical conditions which can allow the microsurgical devices to be tested. This research shall investigate the development of miniaturized, robot-assisted, microsurgical tools with actuation and sensing capabilities. The program shall investigate intuitive, minimally obtrusive surgeon-machine interfaces utilizing novel head-mounted displays and haptic feedback technologies. The research shall advance the state-of-the-art in miniaturization of robot-assisted microsurgical tools and systems.

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

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

28. Development of high power and efficient assistive systems for the limbs

Tutor: Dr Nikos Tsagarakis, Dr Ioannis Sarakoglou

Department of Advanced Robotics (ADVR -IIT)
http://www.iit.it/en/research/departments/advanced-robotics.html

Description: This project targets on the development of power autonomous, intelligent single joint exoskeleton devices to act as power/force augmentation device 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 device 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 the fixation to the human limb interface. In contrast to the multidof highly complex force reflecting robotic exoskeletal structures, this unit can form the primitive block for building wearable force feedback systems with more degrees of freedom. We envisage the development of 1 or 2 DOF systems e.g. an elbow device, a shoulder/elbow an 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. One of the system requirements is long power autonomy. The system efficiency requirement will be tackled in all levels of the system development including the mechanical optimization of lightweight structures, the efficiency of actuators and transmission systems including energy storage concepts and the efficiency of power driving electronics.

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. (50% mechanical design, 30% control, 20% software).

Reference: Nikolaos Karavas, Arash Ajoudani, N.G. Tsagarakis, Jody Alessandro Saglia, Antonio Bicchi, Darwin G. Caldwell, "Tele-Impedance Based Stiffness and Motion Augmentation for a Knee Exoskeleton Device", IEEE International Conference on Robotics and Automation, ICRA 2013, pp 2194-2220.

Contacts: nikos.tsagarakis@iit.it

29. Wearable haptic systems for dexterous teleoperation and virtual Immersion

Tutor: Dr Ioannis Sarakoglou, Dr Nikos Tsagarakis

Department of Advanced Robotics (ADVR -IIT)
http://www.iit.it/en/research/departments/advanced-robotics.html

Description: The sense of touch is crucial in any kind of Virtual Reality simulation or teleoperation procedure where the task requires a user to engage his hand and fingers for controlling the virtual avatar or the teleoperated robot. In recent years rapid improvements in hardware and software have lead to effective force feedback devices that have been applied in various training simulators and teleoperation systems (e.g. Phantom, Omni, Omega, Virtuose, falcon, etc). However, in most of these instances the devices were desktop systems with reduced dexterity and general utility for unencumbered use. These joystick-like systems generally provide only point contacts and preclude use of individual fingers for more complex haptic scenarios where hands are used to feel forces of varying levels while manipulating objects in a large workspace (e.g. groping with fingers or manipulation). To address the teleoperation of robotic hands and object manipulation with force feedback, wearable force feedback devices have been developed in the form of hand exoskeletons. However hand exoskeletons are still lacking dexterity and more importantly high fidelity tactile feedback at the fingertips. This means that currently teleoperation or VR simulation of tasks where a robot or an avatar is required to perform a precision task such as lifting a nail from a table or picking a wire from a bundle, is extremely difficult or impossible due to the absence of tactile feedback. This PhD will concentrate on the development and integration of tactile feedback (pin-array and vibrotactile type) into a multi degree of freedom haptic system consisting of a hand exoskeleton and a grounded haptic device with large working volume. Existing design directions in tactile feedback [], hand exoskeletons [] and novel actuation systems, already developed in the department, will form the foundation where this PhD theme will build upon. The successful candidate will tackle the development integration and control of the subsystems toward a highly integrated wearable system for precision dexterous tele-manipulation.

Requirements: We are seeking candidates with a background in Electronic/Mechanical engineering Physical Sciences or Robotics. Experience and competencies in CAD mechanical design and knowledge of robot kinematics analysis would be a benefit. (Mechanical design 50%, Kinematics 30%, Control 20%)..

Reference: I. Sarakoglou, N. Garcia-Hernandez, N. G. Tsagarakis, and D. G. Caldwell, "A High Performance Tactile Feedback Display and Its Integration in Teleoperation," IEEE Transactions on Haptics, vol. 5, no. 3, pp. 252-263, 2012.

Contacts: ioannis.sarakoglou@iit.it

30. Development and Control of robot manipulators for Safer Physical Human Robot Interaction

Tutor: Dr Matteo Laffranchi, Prof Darwin Caldwell

Department of Advanced Robotics (ADVR -IIT)
http://www.iit.it/en/research/departments/advanced-robotics.html

Description: The focus of this research is the design optimization, development and control of a novel compliant manipulator and related actuation systems with variable physical damping actuators (VPDA, http://www.iit.it/en/advr-labs/humanoids-a-human-centred-mechatronics/advr-humanoids-projects/variable-physical-damping-actuators.html) for robust, fast, adaptable and damage-safe motions and interactions. The target is to improve the capabilities of the existing CompAct™ arm (http://www.iit.it/en/robots/compact-arm.html) by exploring both the mechatronic technological limits (structural materials, actuation and sensing) and new design and control philosophies towards the development of high performance manipulation systems. The Department of Advanced Robotics at IIT possesses a strong industrial know how in this field with 5+ patents.
In detail, the main goals of the project are to:

- improve VIA technology and develop actuators that are more robust, more stable, have reduced oscillatory behaviour, lower cost, have less friction and wear, etc.
- focus on the introduction of, and improvements in, other physical impedance parameters, e.g. damping or effective inertia through techniques originally developed for the VPDA,
- build a prototype of the upper body of a robot for physically interactive manipulation testing and to compare mature technologies for lightweight robots (KUKA LWR) with VIA and VPDA technologies.

The resulting developed systems will be capable of:

- more safely co-existing and co-operating with people (co-workers) and other robots;
- attain performance levels more commonly associated with humans.

Contacts: Matteo.Laffranchi@iit.it

31. Development of a High Performance Haptic Tele-manipulation System

Tutor: Dr Ioannis Sarakoglou. Prof Darwin Caldwell

Department of Advanced Robotics (ADVR -IIT)
http://www.iit.it/en/research/departments/advanced-robotics.html

Description: Interaction between humans and machines, particularly safe interaction, is a critical aspect of robotics. The focus of this research is the development of high fidelity user interfaces for telepresence and teleoperation that can rival the human hand in terms of manipulating dexterity, see http://www.iit.it/en/advr-labs/haptic-and-interaction-technologies.html. Within this research new haptic technologies and techniques will be applied to the control and operation of the COMAN humanoid (http://www.iit.it/en/advr-labs/humanoids-a-human-centred-mechatronics/advr-humanoids-projects/compliant-humanoid-platform-coman.html) and particular to the development of a high performance, teleoperation system that will use enhanced levels of haptic feedback to ensure accurate, high precision and dexterous control and manipulation of remote objects using a COMAN as the remote system.

The main goals of the project are to:

- enhance the nature of the operator interface at the remote and the user site
  - at the remote site to use a compliant torque controlled robot arm to improve control accuracy,
  - at the user site to develop high accuracy hand exoskeletons, finger tip tactile displays and tele-impedance control to augment the user experience and improve transparency.

Within the framework of a teleoperation platform the ESR will work on:

- development of algorithms for visual, haptic and tactile feedback,
- spatial mapping between the human hand and the robot hand and
- addressing the time delay of the teleoperation system.

Contacts: Ioannis.Sarakoglou@iit.it

32. Dexterous Human-Robot Collaborative Manipulation through Learning using Compliant robots within Unstructures Spaces

Tutor: Dr Sylvain Calinon. Prof Darwin Caldwell

Department of Advanced Robotics (ADVR -IIT)
http://www.iit.it/en/research/departments/advanced-robotics.html

Description: The recent development of compliant robots such as COMAN (http://www.iit.it/en/advr-labs/humanoids-a-human-centred-mechatronics/advr-humanoids-projects/compliant-humanoid-platform-coman.html) has opened up a host of new research possibilities in human-robot interaction and robot learning. Now, robots need not be behind fences (as in large manufacturing plants), and are increasingly capable of executing tasks in collaboration with human users. Such human-robot collaboration requires drastic changes in the way robots move, learn, react, and physically interact with the users and environment and this flexibility should be in the software as much as the hardware, i.e. flexibility through learning.

This work will address research themes related to the problem of transferring bimanual collaborative manipulation skills to robots in a user-friendly manner. Such skills involve rich and diverse research questions such as passive/active roles switching, leader/follower behaviours, specialization, turn-taking, compliance, inter-agent synchronization, action anticipation, intention recognition in joint action and the use of non-verbal cues to communicate intent. These issues will be studied in two contexts: 1) with bidirectional social teaching interaction with the compliant humanoid robot COMAN; 2) within a manufacturing scenario with an innovative setup based on two 7 DOFs compliant manipulators with sensorized hands.

The goals of the project are to:

- Develop a dexterous semi-autonomous teleoperation schemes for compliant Robot operating in not well defined spaces with uncertain physical interactions.
- Cope and learn to adapt to collisions and physical interactions .
- Exploration of haptics in teleoperation of compliant robots for improving performance as well for providing guidance to the operator in the context of bidirectional coupling.
- Development of data and knowledge fusion technique for the dexterous manipulation to learn how to detect collisions and react to physical interactions
- Development of a refined control model for flexible regulation of stiffness and damping behaviours of the compliant robot

Contacts: Darwin.Caldwell@iit.it