PhD Program in Bioengineering and Robotics

Curriculum Humanoids and Advanced 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 and legged 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 address the development of the technologies for the next generation of robots 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".

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. Moreover the last years, there is a particular attention to the Transfer Technology with a special lab that aims to make the ADVR robots suitable for industrial applications.

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

1. Nonlinear Control of Humanoid Robots for Bipedal Locomotion

Tutor: Daniele Pucci, Ugo Pattacini, Giorgio Metta

Department: iCub Facility, Istituto Italiano di Tecnologia
https://www.iit.it/research/lines/icub

Description: The general purpose of providing humanoid robots with some degree of locomotion has driven most of research in the humanoid robotics community of the last decade. Legged and wheeled locomotion, for instance, have proven to be feasible on various humanoid robot platforms, which can now be envisioned as interfaces for user assistance in several domains. The intrinsic humanoid robot underactuation, however, combined with the (usually large) number of the robot degrees of freedom partially account for the continued attention the robotics community is paying to the locomotion problem. Although the performances of the state-of-the-art humanoid robots are promising, we are still a far cry from providing humanoid robots with robust locomotion capabilities.

The research project aims at designing control strategies for providing humanoid robots with bipedal locomotion capabilities. Walking on soft terrains, partial footholds, and rough terrains are among the envisioned scenarios. The main challenges for these cases are: i) the modelling of the pair robot-environment and the identification of the governing system dynamics; ii) the design of controllers with proven stability and robustness proprieties; iii) the development of robust, efficient implementations of the control algorithms. Envisioned control solutions make use of Lyapunov and feedback linearisation techniques [1,2].

The control algorithms will be implemented and tested on the state of the art iCub humanoid robot, one of the few humanoid robots fully torque controlled (http://y2u.be/VrPBSSQEr3A).

Requirements: the candidate needs to have an engineering or mathematical background with strong competences in control theory and computer science.

References:

Khalil K. Hassan, Nonlinear Systems, third edition, 2001.
Isidori A., Nonlinear Control Systems, 1995

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2. Deep learning for learning object affordances

Tutors: Vadim Tikhanoff, Giorgio Metta

Department: iCub Facility, Istituto Italiano di Tecnologia
https://www.iit.it/research/lines/icub

Description: In recent years, deep learning methods allowed progress in the deployment of machine learning to many difficult problems, which in turn dramatically increased the performance of applications such as computer vision, speech recognition, product recommendation, and a large amount of problems where large amounts of labeled data can be easily obtained. However, this revolution has had a relatively small impact in robotics, as a result of the specificity of low-level sensory data and the non-negligible amount of time it requires to collect them from a robot. Some studies have applied deep learning methods trained with robot data, showing promising results on a number of tasks, such as reaching, grasping or manipulation, but the ongoing applications are still quite narrow and few in number.

The concept of affordances can provide a promising framework to study the interaction of a robot with its environment, and thus to predict the consequences of its own actions on certain objects or with certain tools.

We are seeking for a highly motivated candidate interested in studying learning of affordances from large quantities of visuo-motor data. The aim of the project is to enable the iCub to learn autonomously the effects of its own actions, by gathering the data required to train the network with minimal human supervision. This knowledge will be applied for action and or/object selection to achieve specific tasks.

Requirements: the candidate is required to have a computer science background with strong competences in mathematics and machine learning. Proficiency in a programming language is required.

References:
Zhang F, Leitner J, Upcroft B and Corke P (2016a) Vision based reaching using modular deep networks: from simulation to the real world.
Levine, S., Pastor, P., Krizhevsky, A., Quillen, D. Learning Hand-Eye Coordination for Robotic Grasping with Deep Learning and Large-Scale Data Collection. ISER 2016
Mar, T., Tikhanoff, V., Metta, G., Natale, L. "Self-supervised learning of grasp dependent tool affordances on the iCub Humanoid robot." Robotics and Automation (ICRA), 2015 IEEE International Conference on. IEEE, 2015.

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3. Robot design for dexterous manipulation

Tutors: Alberto Parmiggiani, Giorgio Metta

Department: iCub Facility: https://www.iit.it/research/lines/icub

Description: The unique capabilities of the human hand and arm enable us to perform extremely fine and dexterous movements, such as those needed to write or to juggle. The emergence of these capabilities was undoubtedly essential in human evolution: our physical characteristics yield a dexterity that is unparalleled in the animal kingdom. Moreover, our manual skills are an important part of our interaction with the environment and of our capacities for feeling, exploring, acting, planning, and learning.
Researchers have been trying to replicate the capabilities of natural systems in artificial ones, by designing and building robotic hands and arms. Numerous progresses have been made in the past 30 years, but the dexterity of robotic hands is still far from their biological counterparts. Indeed, further developments in this area are necessary and can suggest insights regarding the processes underlying dexterous manipulation. For instance, creating better tactile sensing allows us to observe the touch patterns accompanying human hand actions. Designing different anthropomorphic hand and wrist shapes provides us with insights into the role of geometry for hand dexterity. Enabling robots to cope with a multitude of objects and actions challenges our understanding of how such skills need to be represented and coordinated.
This project will be carried out on the hand-forearm assembly of the iCub robot. In the initial part of the project, we will explore cutting edge technologies and experiment methods to enhance the hand and wrist capabilities. We will then work to integrate and implement the most promising approaches on the robot platform, and ensure they are sufficiently dependable to serve as a basis for advanced and dexterous manipulation tasks.

Requirements: Successful candidates should be highly self-motivated to pursue independent and interdisciplinary research. A background in Mechanical Engineering or related disciplines is required. Hands-on experience with analysis, design and implementation of robotic systems, as well as sensors and actuators, is strongly preferred.

References:
Johannes Lemburg and Frank Kirchner, “Conceptual and embodiment design of robotic prototypes” Int. J. Human. Robot. 08, 419, 2011 (DOI: http://dx.doi.org/10.1142/S0219843611002526)

Ashish D. Deshpande, Zhe Xu, Michael J. Vande Weghe, Jonathan Ko, Lillian Y. Chang, Benjamin H. Brown, David D. Wilkinson, Sean M. Bidic, and Yoky Matsuoka, “Mechanisms of the Anatomically Correct Testbed (ACT) Hand”. IEEE/ASME Trans. on Mechatronics, 2013.
Perla Maiolino, Marco Maggiali, Giorgio Cannata, Giorgio Metta and Lorenzo Natale, “A flexible and robust large scale capacitive tactile system for robots”. IEEE Sensors Journal, 2013.
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4. Autonomous learning of objects using multimodal, event driven cues

Tutors: Chiara Bartolozzi, Lorenzo Natale

Department: iCub Facility, Istituto Italiano di Tecnologia
https://www.iit.it/research/lines/icub
https://www.iit.it/research/lines/humanoid-sensing-and-perception

Description: To effectively interact with the environment and adapt to different contexts and goals, robots need to be able to autonomously explore and learn about objects. To this aim, we need machine learning strategies that allow to plan exploratory actions and take advantage of information from multiple sensory modalities. In particular, we will consider learning from haptic (touch, force and proprioception), auditory and visual cues (extracted from event based as well as conventional frame based cameras), obtained during exploratory actions, to investigate how different features contribute to object discrimination.
In the first part of the project we will implement behaviours that allow the robot to interact with objects through manipulation using predefined explorative procedures (like touching, power grasp, squeezing and contour following). Events in any sensory channel will trigger acquisition of features from all the available sensors. In the second part of the project, these features will be used to train machine learning algorithms for object recognition. The objective of this project is also to investigate to what extent features from different sensory channels contribute to object discrimination.

The outcome of this project will be a set of explorative procedures allowing a humanoid robot to interact with objects and extract features from multiple sensory channels and signal processing algorithms for detecting relevant events during object exploration that trigger feature extraction and identifying a set of features that allow to discriminate objects using multiple sensory modalities.

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.

References:
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
Ciliberto, C., Smeraldi, F., Natale, L., Metta, G., Online Multiple Instance Learning Applied to Hand Detection in a Humanoid Robot, IEEE/RSJ International Conference on Intelligent Robots and Systems, San Francisco, California, September 25-30, 2011.
Ciliberto, C., Fanello, S.R., Santoro, M., Natale, L., Metta, G. and Rosasco, L. "On the impact of learning hierarchical representations for visual recognition in robotics." In Intelligent Robots and Systems (IROS), 2013 IEEE/RSJ International Conference on, pp. 3759-3764.

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

5. Improved grasping through ED vision and affordances

Tutor: Chiara Bartolozzi, Vadim Tikhanoff, Ugo Pattacini

Department: iCub Facility, Istituto Italiano di Tecnologia
https://www.iit.it/research/lines/icub
https://www.iit.it/research/lines/humanoid-sensing-and-perception

Description: The interaction of robots with the environment and the successful completion of service tasks strongly depend on its capability of grasping and manipulating objects in a robust and reliable way. 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 exploit machine learning to devise the dynamics/behaviours of objects during clumsy or imprecise manipulation and grasping, and using such learned behaviours 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.
The fine temporal resolution of ED vision will be used to track objects and end effectors of the robot, for implementing fast closed-loop control of grasping and manipulation. Proprioceptive, tactile and visual feedback before, during and after grasping will be used to learn the effect of different types of grasping and actions of the robot on the objects. This method will improve the smoothness of the action, by the observation of the result of clumsy manipulation, correcting unsuccessful movements, and will allow to perform online corrective actions to stabilise and re- grasp unstable objects.
This research line will deliver a method for robust, smooth and flawless object grasping by means of fast sensory feedback and reaction, and improved movement planning

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.

References:
Glover, A., Bartolozzi, C. (2016, October). Event-driven ball detection and gaze fixation in clutter.
In Intelligent Robots and Systems (IROS), 2016 IEEE/RSJ International Conference on (pp. 2203-2208). IEEE.
Pattacini, U. et al., 2010. An Experimental Evaluation of a Novel Minimum-Jerk Cartesian Controller for Humanoid Robots. Taipei, Taiwan, s.n., pp. 1668-1674.
Mar, T., Tikhanoff, V., Metta, G., and Natale, L., Self-supervised learning of grasp dependent tool affordances on the iCub Humanoid robot, in Proc. IEEE International Conference on Robotics and Automation, Seattle, Washington, 2015

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6. Compressive Sensing and Low-Latency Embedded Processing for the iCub

Tutor: Chiara Bartolozzi

Department: iCub Facility, Istituto Italiano di Tecnologia
https://www.iit.it/research/lines/icub

Description: Full (and long lasting) energetic autonomy is crucial for the deployment of robots in daily life. Efficient sensory encoding is a way to reduce data acquisition, transmission, storage and processing, leading to power optimisation. Traditional sensing is based on the clocked-driven sampling of data from sensors (e.g. images from cameras, pressure values from matrices of taxels in the skin, etc…), leading to the acquisition of an enormous quantity of redundant data when the sensory input is unchanged over time (e.g. images from a camera in front of a static scene), and to large latency due to the acquisition of a full array of sensing elements. The biologically inspired "event-driven" sensory encoding samples the stimulus when the stimulus itself changes of a given amount. Only sensing elements that detect a change trigger communication and processing, with extremely short latency and high temporal resolution (1us).
The iCub robot features event-driven vision sensors, as well as FPGA-based electronics to compress clocked readout of tactile sensors exploiting event-driven encoding. The sensors are continuously sampled, but communication wakes-up at stimulation, with a mean reduction of the data-transfer up to 20% of the clocked-based encoding, sensibly improving transmission latency, bandwidth and power. The same infrastructure will be used to efficiently compress other sensors of the robot (e.g. encoders, accelerometers, etc..). At the same time, the processing power of FPGAs will be used to further compress the signal by real-time embedded pre-processing (e.g. for filtering, feature extraction, optical flow, saliency, etc.) and to generate fast reactive control.
This research line will hence deliver efficient sensory encoding and embedded processing for the development of autonomous robots, encompassing event-driven encoding of multiple sensory modalities and embedded computation for low latency real-time perception and control that will integrate with higher level (and slower) processing on the robot.

Requirements: degree in Computer Science, Electronic Engineering (or equivalent) and background in Computer Vision or Signal Processing. High motivation to work on a robotic platform and good programming skills also on FPGA.

References:
Bartolozzi, C., Natale, L., Nori, F. and Metta, G., "Robots with a sense of touch", Nat Mater, vol. 15(9), pp.921–925, 2016, doi:10.1038/nmat4731
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
Glover, A., Bartolozzi, C. (2016, October). Event-driven ball detection and gaze fixation in clutter. In Intelligent Robots and Systems (IROS), 2016 IEEE/RSJ International Conference on (pp. 2203-2208). IEEE.

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7. Multimodal perception of objects

Tutor: Lorenzo Natale, Lorenzo Rosasco

Department: Humanoid Sensing and Perception Laboratory, iCub Facility, Istituto Italiano di Tecnologia
https://www.iit.it/lines/humanoid-sensing-and-perception

Description:
Conventionally, robots rely on vision to perceive and identify objects. Although computer vision has recently made remarkable progress, touch and, in general, haptic information can still provide complementary information. This is because some material and object properties are simply not accessible, difficult to be estimated from vision (like the object weight, roughness), or even hidden by occlusions. During active object manipulation multi-modal information is available to the robot and can be used for learning. Yet, during recognition only partial information may be available (typically vision). This project will investigate how to integrate visual and haptic information for object discrimination. We will initial consider the case in which multi-modal information is available during training and recognition. In a second stage of the project we will investigate how learning with multi-modal cues can help object discrimination when only partial information is available (vision or touch).
This project will be carried out on the iCub robot. The robot sensory system includes cameras for vision, tactile sensors, position sensors and force/torque sensors. In the initial part of the project we will build a dataset for the experiments, by acquiring multi-modal data while the robot grasps a set of objects in various ways. We will then investigate methods for feature extraction (in particular, for vision, we will consider features from Deep Convolutional Neural Networks) and machine learning methods (e.g. multi-view learning, learning with privileged information) for object discrimination using individual and combined features.

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:
Higy, B., Ciliberto, C., Rosasco, L., and Natale, L., Combining Sensory Modalities and Exploratory Procedures to Improve Haptic Object Recognition in Robotics, in IEEE-RAS International Conference on Humanoid Robots, Cancun, Mexico, 2016
Pasquale, G., Ciliberto, C., Rosasco, L., and Natale, L., Object Identification from Few Examples by Improving the Invariance of a Deep Convolutional Neural Network, in Proc. IEEE/RSJ International Conference on Intelligent Robots and Systems, Daejeon, Korea, 2016, pp. 4904-4911

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8. Multimodal object exploration and grasping

Tutor: Lorenzo Natale, Ugo Pattacini

Department: Humanoid Sensing and Perception Laboratory, iCub Facility, Istituto Italiano di Tecnologia
https://www.iit.it/lines/humanoid-sensing-and-perception

Description:
Object shape is fundamental for planning grasping. Precise models of objects may not be available due to lack of object models, noise in the sensory system or simply occlusions. Object models can be however inferred by actively explore objects and extracting information from the sensory system. In this project we will investigate techniques for object modelling and object exploration using multi-modal cues. The main idea is that vision can provide initial guesses to guide the exploration and that this guess can be consequently refined using tactile information.
This project will develop novel techniques for automatic object modelling using multi-modal sensory information. The goal of this project is to advance the state-of-the-art in the field of automatic object modelling and, consequently, grasping and manipulation of unknown objects. This project will be carried out on the iCub robot using the stereo system on the robot and the tactile sensors in the hand. We will use depth information about the objects to build an initial estimation of the shape of the object (e.g. using superquadrics), we will then implement an active strategy that based on this initial guess will provide the robot with a sequence of points to be explored with the tactile system. This information will be then used to improve the model of the object and provide an accurate shape. Validation will be carried out on grasping tasks.

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:
Jamali, N., Ciliberto, C., Rosasco, L., and Natale, L., Active Perception: Building Objects' Models Using Tactile Exploration, in IEEE-RAS International Conference on Humanoid Robots, Cancun, Mexico, 2016
Vezzani, G., Pattacini, G., Natale, L. A Grasping Approach Based on Superquadric Models, in IEEE International Conference on Robotics and Automation, 2017
Björkman, M., Bekiroglu, Y., Högman, V., and Kragic, D., Enhancing visual perception of shape through tactile glances, in 2013 IEEE/RSJ International Conference on Intelligent Robots and Systems, 2013, pp. 3180–3186.

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

Tutor: Lorenzo Natale, Alessio Del Bue

Department: Humanoid Sensing and Perception lab (iCub Facility) and Visual Geometry and Modelling lab (PAVIS department)

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. The aim of this project is to endow the iCub with a fundamental layer of capabilities for detecting humans, their posture and social behaviour. Examples could be the ability to detect if a person is attempting to interact with the robot and to react accordingly. This requires a new set of computational tools based on Computer Vision and Machine Learning to detect people at close distance. This "face-to-face" scenario 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 Humanoid Sensing and Perception lab (iCub Facility) and Visual Geometry and Modelling Lab (PAVIS department). 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 strong computer programming skills.

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10. Scene analysis using deep-learning

Tutors: Lorenzo Natale, Lorenzo Rosasco

Description: machine learning, and in particular deep learning methods, have been applied with remarkable success to solve visual problems like pedestrian detection, object retrieval, recognition and segmentation. One of the difficulties with these techniques is that training requires a large amount of data and it is not straightforward to adopt them when training samples are acquired online and autonomously by a robot. One solution is to adopt pre-trained convolutional neural networks (DCNN) for image representation and use simpler classifiers, either in batch or incrementally. Following this approach DCNNs have been integrated in the iCub visual system leading to a remarkable increase of object recognition performance. However, scene analysis in realistic settings is still challenging due to scale, light variability and clutter. The goal of this project is to further investigate and improve the iCub recognition and visual segmentation capabilities. To this aim we will investigate techniques for pixel-base semantic segmentation using DCNNs and object detection mixing top-down and bottom-up cues for image segmentation.

Requirements: This PhD project will be carried out within the Humanoid Sensing and Perception lab (iCub Facility) and Laboratory for Computational and Statistical Learning. The ideal candidate should have a degree in Computer Science or Engineering (or equivalent) and background in Machine Learning, Robotics and possibly in Computer Vision. He should also be highly motivated to work on a robotic platform and have strong computer programming skills.

References:
Olga Russakovsky, Jia Deng, Hao Su, Jonathan Krause, Sanjeev Satheesh, Sean Ma, Zhiheng Huang, Andrej Karpathy, Aditya Khosla, Michael Bernstein, Alexander C. Berg and Li Fei-Fei, ImageNet Large Scale Visual Recognition Challenge, arXiv:1409.0575, 2014

Jon Long, Evan Shelhamer, Trevor Darrell, Fully Convolutional Networks for Semantic Segmentation, CVPR 2015

Pasquale, G., Ciliberto, C., Odone, F., Rosasco, L., and Natale, L., Teaching iCub to recognize objects using deep Convolutional Neural Networks, in Proc. 4th Workshop on Machine Learning for Interactive Systems, 2015

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11. Towards Flying Humanoid Robots

Tutor: Daniele Pucci, Francesco Nori, Giorgio Metta

iCub Facility: https://www.iit.it/research/lines/icub
Dynamic Interaction: https://www.iit.it/research/lines/dynamic-interaction-control

Description: Nonlinear control techniques for humanoid and flying robots have developed along different directions, and suffer from specific limitations. Besides the morphological differences between aerial and humanoid robots, one of the reasons accounting for this divergence is that humanoid robot control is often addressed assuming the robot attached to ground. In this case, the robot is referred to as *fixed-base*. The limitations of this approach arise when attempting to tackle the general locomotion control problem, which also requires the robot to make and break contacts to achieve locomotion. At the modelling level, the Euler-Poincare` formalism provides one with singularity free equations of motion for the humanoid robot. In this case, the robot is referred to as *floating base*: this formalism may allow the development of control techniques for the general locomotion problem, thus unifying flying and humanoid robot control techniques.

As a matter of fact, we believe that there is a strong technological benefit in conceiving robotic platforms capable of *contact locomotion*, *flight*, and *manipulation*. In this respect, *flight* and *manipulation* have already been implemented on many platforms, thus contributing to the so-called *aerial manipulation* [1], but robots combining the three aforementioned capacities are still missing.

This research project aims at developing control methods for flying humanoid robots, thus contributing towards the development of a unified control approach for flying and humanoid robots. The main challenges for this project are:

i) dealing with the robot under actuation;
ii) dealing with estimation of robot states;
iii) implementation of efficient control algorithms.

The research project will be also focusing on the choice of the humanoid robot propulsion and on preliminary tests on a real robotic platforms.

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

Reference:
[1] K. Kondak, et al., “Unmanned aerial systems physically interacting with the environment: Load transportation, deployment, and aerial manipulation,” in *Handbook of Unmanned Aerial Vehicles*. Springer, 2015, pp. 2755–2785.
[2] **Pucci, D.**; Traversaro, S.; Nori, F. "Momentum Control of an Underactuated Flying Humanoid Robot". Available online at: https://arxiv.org/pdf/1702.06075.pdf

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12. Simultaneous multimodal force and motion estimation

Tutor: Francesco Nori, Daniele Pucci

Department: Robotics, Brain and Cognitive Sciences (Istituto Italiano di Tecnologia)
http://www.iit.it/rbcs

Description: human motion capture (MoCap) finds applications ranging from entertainment (movies and games) to rehabilitation and sport activity monitoring. Standard marker-based technologies (e.g. the Vicon http://www.vicon.com) have been recently replaced in several applications with innovative marker-less systems such as the Xsens MVN (http://www.xsens.com/products/xsens-mvn) and the Microsoft Kinect (http://www.xbox.com/kinect). The main limitation of these systems is that they provide only kinematic measurements, typically position, velocities and accelerations. Starting from a technology previously developed and tested on the iCub [1], this research proposal aims at developing an innovative wearable technology for human force and motion capturing [2]. This information will be used for reactive and/or predictive control of movements during physical human-robot interaction. Applications are foreseen in the field of exoskeletons (with Matteo Laffranchi [3] and Jesus Ortiz [4]) and collaborative manipulation (with Arash Ajoudani [5]). This research activity is conducted within the European project An.Dy (http://www.andy-project.eu).

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

Reference:

[1] 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

[2] Latella, C.; Kuppuswamy, N.; Romano, F.; Traversaro, S.; Nori, F. Whole-Body Human Inverse Dynamics with Distributed Micro-Accelerometers, Gyros and Force Sensing. *Sensors* **2016**, *16*, 727.

[3] https://www.iit.it/research/lines/rehab-technologies-inail-iit-lab

[4] Toxiri, S., Ortiz, J., Masood, J., Fernández, J., Mateos, L. A., & Caldwell, D. G. (2015, December). A wearable device for reducing spinal loads during lifting tasks: Biomechanics and design concepts. In *Robotics and Biomimetics (ROBIO 2015).*

[5] L. Peternel, N. Tsagarakis, and A. Ajoudani, "Towards Multi-Modal Intention Interfaces for Human-Robot Co-Manipulation", IEEE International Conference on Intelligent Robots and Systems (IROS), 2016.

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13. Control of Hybrid Floating Base Systems for Humanoid Robot Locomotion

Tutor: Francesco Romano, Daniele Pucci, Francesco Nori

iCub Facility: https://www.iit.it/research/lines/icub
Dynamic Interaction: https://www.iit.it/research/lines/dynamic-interaction-control

Description: current state of the art walking algorithms for humanoid robots are based on simplified representations of the robot dynamics, which seldom consider the interactions between the robot and its surrounding environment. Usually, the robot trajectories are generated by exploiting stability criteria such as ZMP or Capture Point, and these trajectories are then stabilized by inverse kinematics based controllers. However, to fully exploit the dynamic capabilities of state of the art humanoid robots, taking into account both the full system dynamics and the robot-environment interaction is of paramount importance.

This research project aims at developing control methods for floating base systems subject to jumps in their configuration space, namely, hybrid floating base systems. The control framework is then particularly useful for humanoid robots since they can be modeled as hybrid floating base systems during locomotion on rigid contacts. Simulation and control of hybrid systems poses various difficulties. For example, switching events must be properly detected, thus impacting the underlying governing system dynamics. Event-based ODEs are the most diffuse tool to accomplish this task, but they are sensitive to Zeno conditions. The challenge of this project is to advance current state-of-the-art nonlinear control methods for their application on: (1) hybrid systems, (2) whole-body formulation and (3) real-time systems.

The developed control algorithm will be implemented and tested on the state of the art iCub humanoid robot, one of the few humanoid robots fully torque controlled (http://y2u.be/VrPBSSQEr3A). It will render the robot capable of moving in a real-world environment, e.g. walking at a sustained pace, with the possibility to traverse uneven and/or inclined terrains or climb stairs.

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

Reference:
[1] Khalil K. Hassan, *Nonlinear Systems, third edition,* 2001.
[2] Lygeros et al., Hybrid Systems: Modeling, Analysis and Control.
http://inst.cs.berkeley.edu/~ee291e/sp09/handouts/book.pdf

Contact: francesco.romano@iit.it, daniele.pucci@iit.it, francesco.nori@iit.it

14. Robust State Estimation for Humanoid Robots operating on Non-Rigid Contacts

Tutor: Silvio Traversaro, Daniele Pucci, Francesco Nori

Department: Dynamic Interaction Control Laboratory - iCub Facility (Istituto Italiano di Tecnologia)
https://www.iit.it/research/lines/dynamic-interaction-control

Description: humanoid robots need reliable estimates of their state (position, velocity, acceleration, internal joint torques and external forces) for locomotion and manipulation. Current estimation techniques either ignore the contacts made by the robot, or assume that this contacts are rigid and bilateral. For achieving operational autonomy in unstructured environments , humanoids of the future will need to estimate their state exploiting (rather then neglecting) the presence of non-rigid contacts.

This research project aims to identify models of non-rigid contacts suitable to use in realtime state estimation. The resulting models will be then be fused with the information coming from the rich set of sensors available on the iCub robot (6-Axis Force/Torque sensors, Robotic Skin, Distributed Inertial Sensors, RGB-D sensors) to provide a reliable state estimation to be used by the high level control algorithms. The main challenge is to extend existing estimation techniques to work on: (1) soft contacts (such as soft soil, sand or carpets) and (2) contact involving articulated structures (like a door or a seesaw).

Emphasis will be placed on the robustness of the resulting estimation techniques, for enabling use of the iCub on real world scenarios, e.g. walking on carpets and manipulating pillows in an actual apartment.

Requirements: the candidate needs to have an engineering, computer science or mathematical background. Prior experiences in robotics, probability theory, tribology and/or C++ programming will be positively evaluated.

Reference:

[1] C Ciliberto, L Fiorio, M Maggiali, L Natale, L Rosasco, G Metta, F Nori. **Exploiting global force torque measurements for local compliance estimation in tactile arrays.** IEEE/RSJ International Conference on Robots and Systems, 2014.

[2] F Nori, N Kuppuswamy, S Traversaro. **Simultaneous state and dynamics estimation in articulated structures.** IEEE/RSJ International Conference on Robots and Systems, 2015

Contact: silvio.traversaro@iit.it, francesco.nori@iit.it, daniele.pucci@iit.it

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

Tutors: Darwin Caldwell

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

Description: Legged robots present unique capabilities for traversing a multitude of rough terrains, where they have the potential to outperform wheeled or tracked systems. The control of such complex robotic platforms is a challenging task, especially in designs with high levels of kinematic redundancy. A wide range of approaches to legged locomotion exist; however, most are far from demonstrating a solution which performs with a level of flexibility, reliability and careful foot placement that would enable practical locomotion on the variety of rough and intermittent terrain humans negotiate with ease on a regular basis. The position advertised will focus on bridging this gap in the context of multi-directional navigation of unstructured environments. The work will be conducted on the IIT quadrupeds HyQ, HyQ2Max and the new centaur inspired robot HalfMan.

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.

Contacts: Darwin.Caldwell@iit.it

16. 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

17. 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

18. Legged Robots (Humanoids) for Hazardous Environment Interventions

Tutors: 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 humanoid robots such as **COMAN** and **WalkMan and WalkMan Jr** in these complex hazardous environments.

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

Contacts: Darwin.Caldwell@iit.it

19. Legged Robots (Quadrupeds) for Hazardous Environment Interventions

Tutors: Darwin G. Caldwell

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

Description: After Fukushima Daiichi nuclear disaster in 2011 the need for robots to deal with unstructured environments and replace humans in hazardous tasks became one of the main unsolved problems in robotics. 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**, **HyQ2Max** and the centaur inspired **HalfMan** to explore robot actions within complex hazardous environments.

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

Contacts: Darwin.Caldwell@iit.it

20. Advanced Teleoperation: Tele-locomotion, tele-manipulation, and human-machine interaction for extreme environments.

Tutor: Darwin Caldwell, Nikhil Deshpande

Positions: 2

Department of Advanced Robotics (Istituto Italiano di Tecnologia)

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

In some work environments, eg nuclear power plants (explosions, contamination, fire, etc.), Chemical, petrochemical, steel, and process industries (biological risks , fire, inhalation of smoke or toxic gas, etc.), construction and demolition waste (work at height/confined spaces or compromised air quality, etc.), submarine and extractive operations (drowning, lack of oxygen, fumes or toxic gases, etc.), even during routine activities such as general operation, inspection and maintenance, there can be a significant or extreme risk to the health and welfare of workers.

Robots and robotics can be an obvious solution to the human risk but although the robot may be able to physically perform some, most or all of the tasks they lack the cognitive ability to problem solve in complex environments. However, an advanced, intelligent user interface(s) linked to dexterous, multi-limbed, walking and wheeled mobile platforms could form a solution to substitute or assist workers in these stages, reducing or eliminating exposure to hazards.

This project will develop new hardware and master-slave teleoperation software, to operate in high risk industries with the goal of reducing these risks. The project will use, develop and integrate advanced technologies on tele-locomotion, tele-manipulation, and human-machine interaction. The project will build on the strong existing technological capabilities in the Department of Advanced Robotics (ADVR) Italian Institute of Technology, acquired through the successful implementation of various high-tech projects in this field. The technical know-how of these previous projects, including HyQ, WearHap, µRALP, Robo-Mate, and Walk-Man, will contribute to the development of an intuitive master-slave teleoperation interface forming an advanced user interface.

Requirements: The successful candidates will have a Master degree in Mechatronics, Robotics, Engineering or equivalent and will be able to work both in a team and independently. Experience in mechanical design, programming with C/C++ and knowledge of robot kinematics and dynamics is preferable. *Note: It is compulsory to prepare a research proposal on this topic.

Contact: Nikhil.Deshpande@iit.it, Darwin.Caldwell@iit.it

21. Intuitive control of industrial exoskeletons

Tutor: Darwin Caldwell, Jesus Ortiz

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

Description: An industrial exoskeleton is a complex wearable robotic device that provides an assistive force/torque to the operator to help him during a specific task. The assistance requirements might vary between tasks, operators and/or time. Current industrial exoskeletons use basic control strategies based on sensory input, pre-set configuration parameters and a few on-line adjustments. However, this is not enough for a flexible and user-friendly system, also considering the variability between tasks and users. For this reason, a human-robot collaboration interface including an intuitive command interface and an adaptive control system is desirable. The research would focus on the study of different intuitive command interfaces and adaptive control systems, design and development of an intuitive control system, which combines a novel user interface with a high-level adaptive controller, and testing and evaluation of the developed systems.

Main contribution: Advanced intuitive control for industrial exoskeletons

Main tasks:

- Research on different modalities of intuitive control interfaces
- Research on high-level controllers for user intention identification
- Research on human motion segmentation
- Design and development of a combined command interface and an adaptive high-level controller for industrial exoskeletons
- Testing and evaluation of command interface and controller

Requirements: The successful candidates will have a Master degree in Mechatronics, Robotics, Engineering or equivalent and will be able to work both in a team and independently. Experience in mechanical design, programming with C/C++ and knowledge of robot kinematics and dynamics is preferable. *Note: It is compulsory to prepare a research proposal on this topic.

Contact: **Jesus.Ortiz@iit.it, Darwin.Caldwell@iit.it**

22. Advanced Physical Human-Robot Interfaces for Exoskeletons

Tutor: Darwin Caldwell, Jesus Ortiz

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

Description: The interaction between the human body and a wearable robot is a critical aspect. The assistive forces produced by the robot have to be transmitted through the surface of the human body. The ways the forces are distributed on the human surface determine the effectiveness and comfort of the exoskeleton. However, the design of the physical interfaces is a challenging task, since the surface of the human body is not uniform and can vary in time. Furthermore, it is important to consider other aspects related with the comfort such as temperature, humidity, breathability, biological compatibility, etc. The research would focus on characterization of the human body surface and modelling of the interaction of between a wearable robot and the human body, as well as the development and testing of advanced physical human-robot interfaces for an industrial exoskeleton.

Main contribution: Characterization of the human body for the interaction with a wearable robot

Main tasks:

- Research on physical human body interaction
- Modelling of the physical interaction between a wearable robot and the human body
- Developing a "capacity" map of the human body
- Developing of physical human-robot interfaces for an industrial exoskeleton
- Testing and validation of different physical human-robot interfaces

Requirements: The successful candidates will have a Master degree in Mechatronics, Robotics, Engineering or equivalent and will be able to work both in a team and independently. Experience in mechanical design, programming with C/C++ and knowledge of robot kinematics and dynamics is preferable. *Note: It is compulsory to prepare a research proposal on this topic.

Contact: **Jesus.Ortiz@iit.it, Darwin.Caldwell@iit.it**

23. LEGGED LOCOMOTION-CONTROL: Locomotion Control of a Mobile Manipulation platform with Hybrid leg and wheel functionality

Tutor: Nikos Tsagarakis, Navvab Kashiri

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

Description:
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 focus on the development of locomotion pattern generators and mobility control of a CENTAURO form mobile manipulation platform that uses legs and small wheels to combine the advantages of wheeled and legged locomotion (https://www.centauro-project.eu/). 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 combinations of leg gaits and wheel mobility mechanisms will be developed and evaluated in simulation and finally implemented and validated on the CENTAURO prototype.
Requirements: We are seeking for highly motivated candidates with a background in Electrical, Control engineering, Physical Sciences or Robotics. Candidates should have strong competencies in robot dynamics, control and excellent programming skills in Matlab and C++. (Programing and Simulation 30%, Dynamics 30%, Control %40). The experience on dynamic simulators (e.g. Gazebo, Webot, RoboTran, etc.) and ROS would be plus. *Note: It is compulsory to prepare a research proposal on this topic.
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

24. LEGGED LOCOMOTION-CONTROL: Whole-body Sensor Fusion and Motion Adaptation of a Legged Manipulation Robot

Tutor: Nikos Tsagarakis, Navvab Kashir,I, Chengxu Zhou.

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

Description:
To date, the sensor feedback provided by the sensors equipped in legged robot is very much limited compared to the rich sensory information exists in humans. Moreover, there is a lack of an effective sensor fusion frameworks in practice that fuses the different feedback signals, estimates the parameters and the state of the system which can be subsequently used for the motion control of the machine.
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 and manipulation 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 and manipulation control framework about what the status of the robot is, what kind of control/adaptation mechanisms 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 and manipulation which endow the legged mobile manipulation platform to traverse various types of terrains. These methods will be experimentally validated using the high performance humanoid WALK-MAN (www.walk-man.eu) and the quadruped manipulation robot CENTAURO (https://www.centauro-project.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 as well experience with different simulation tools (e.g. Gazebo, Webot, RoboTran, etc.) is a plus. (Programing and Simulation 30%, Dynamics 30%, Control %40).
*Note: It is compulsory to prepare a research proposal on this topic.
Contact: nikos.tsagarakis@iit.it

25. LEGGED LOCOMOTION-CONTROL: Robust Locomotion of Humanoids in an Unstructured Environment Under External Forces

Tutor: Chengxu Zou, Nikos Tsagarakis

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

Description:
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. *Note: It is compulsory to prepare a research proposal on this topic.
Reference: Przemyslaw Kryczka, Petar Kormushev, Nikos G Tsagarakis, Darwin G Caldwell, “Online regeneration of bipedal walking gait pattern optimizing footstep placement and timing”, Intelligent Robots and Systems (IROS), 2015 IEEE/RSJ International Conference on, pp3352-3357, 2015.
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26. LEGGED LOCOMOTION-CONTROL: Dexterous Humanoid Walking on Restricted and Unstable Footholds

Tutor: Nikos Tsagarakis, Chengxu Zou

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

Description:
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. *Note: It is compulsory to prepare a research proposal on this topic.

Reference: Chengxu Zhou, Xin Wang, Zhibin Li, Darwin Caldwell, Nikos Tsagarakis, “Exploiting the redundancy for humanoid robots to dynamically step over a large obstacle”, Intelligent Robots and Systems (IROS), 2015 IEEE/RSJ International Conference, pp 1599-1604, 2015

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27. CONTROL: Human-Robot Collaborative Control of a Mobile Manipulation platform with Hybrid leg and wheel functionality

Tutors: Nikos Tsagarakis, Arash Ajoudani,

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

Description:
The robots are coming out of the cage, and getting closely involved into human life and physically interacting with them to execute tasks in a collaborative manner.
This research theme will focus on the development of a collaboration control framework that will permit a human operator to perform heavy manipulation tasks in collaboration and direct interaction with a CENTAURO form mobile manipulation platform that uses legs and small wheels to combine the advantages of wheeled and legged locomotion (https://www.centauro-project.eu/). The project will look on the development of human motion/impedance intention estimation modules and collaboration controllers that take into account the human motion and impedance estimations to command and drive the execution of the manipulation task. Autonomous motion and impedance regulation principles will also be applied at the robot side to assist the human partner in commanding the collaborative behaviours of the robot assistan.t.
Requirements: We are seeking for highly motivated candidates with a background in Electrical, Control engineering, Physical Sciences or Robotics. Candidates should have strong competencies in robot dynamics, control and excellent programming skills in Matlab and C++. (Programing and Simulation 30%, Dynamics 30%, Control %40). The experience on dynamic simulators (e.g. Gazebo, Webot, etc.) and ROS would be plus. *Note: It is compulsory to prepare a research proposal on this topic.
Reference: L. Peternel, N.G. Tsagarakis, D.G. Caldwell, Darwin and A. Ajoudani", Adaptation of robot physical behaviour to human fatigue in human-robot co-manipulation", IEEE-RAS 16th International Conference on Humanoids, pp489-494, 2017
Contact: nikos.tsagarakis@iit.it

28. CONTROL: Whole-body Control of Hybrid Humanoid-Quadruped Robotic Platform

Tutor: Jinoh Lee, Nikos Tsagarakis

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

Description:
Recent advances in humanoid research aim at bringing robots into the real world which is complex, unstructured, cluttered and dynamically changing and encourage to operate in various scenarios where only human-like levels of agility, dexterity, robustness, reliability and manipulation/locomotion will be sufficient. This research will cover these issues in hybrid robotic system with legged loco-manipulation using a high performance and high efficiency electric platform, that will combine a quadruped legged base with high dexterity upper body with dual arms – inspired by the Greek mythology, Centaurs. This combination will amalgamate the talents and capabilities of highly dynamic quadrupedal locomotion over rough and unstructured terrain with a humanoid inspired upper body and arms to provide a high dexterity bimanual manipulative structure.
This research therefore will focus on exploiting an advanced whole-body control strategy of hybrid robotic platform to guarantee agile responses and high dexterity to cope with multi contacts of dual arm and four legs and the high kinematic redundancy. It also will include the high-level motion planning to provide excellent manipulation skills in certain tasks with multiple sensors. The methods will be verified in dynamic simulation environment such as Gazebo, Robotran, and V-REP; and will be demonstrated on physical robots such as Centaur robot which is being developed under the European H2020 project CENTAUR (http://www.centaur-project.eu/) and PHOLUS project. This project topic is multidisciplinary, thus the collaboration with other members will be encouraged, e.g. locomotion and 3D perception.

Requirements:
We are preferably seeking for highly motivated candidates with a background in robotics and control engineering. Especially, knowledge on robust control theory and operational-space control with redundant robots will accelerate the progress on this phD theme. 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++ in Linux and MATLAB). The experience on dynamic simulators (e.g. Gazebo, RoboTran, V-REP) is mandatory and ROS would be plus. *Note: It is compulsory to prepare a research proposal on this topic. *Note: It is compulsory to prepare a research proposal on this topic.
Reference: Jinoh Lee, Houman Dallali, Maolin Jin, Darwin G. Caldwell, Nikos Tsagarakis' "Robust and Adaptive Whole-body Controller for Humanoids with Multiple Tasks under Uncertain Disturbances," 2016 IEEE International Conference on Robotics and Automation (ICRA 2016), Stockholm, Sweden, May, 2016, Jinoh Lee, Pyung Hun Chang, Rodrigo S. Jamisola Jr., "Relative Impedance Control for Dual-Arm Robots Performing Asymmetric Bimanual Tasks," IEEE Trans. on Industrial Electronics, Vol. 61, No. 7, July 2014
Contact: Jinoh.lee@iit.it, nikos.tsagarakis@iit.it

29. ROBOTIC ACTUATION: New Efficient actuation systems based on the blending of Forced and Natural dynamics

Tutor: Nikos Tsagarakis, Jorn Mazhan

Department of Advanced Robotics (Istituto Italiano di Tecnologia)
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). *Note: It is compulsory to prepare a research proposal on this topic.

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

30. ROBOTIC ACTUATION: Design principles and control of high performance robotic actuation systems

Tutor: Nikos Tsagarakis, Navvab Kashiri

Department of Advanced Robotics (Istituto Italiano di Tecnologia)
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). *Note: It is compulsory to prepare a research proposal on this topic.

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

31. ROBOTIC ACTUATION: 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

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. 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 %). *Note: It is compulsory to prepare a research proposal on this topic.

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.
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.

Contact: jorn.malzahn@iit.it, nikos.tsagarakis@iit.it

32. MULTIMODAL PERCEPTION: 3D Perception for 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

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. 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.
*Note: It is compulsory to prepare a research proposal on this topic.

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

Contact: dimitrios.kanoulas@iit.it, nikos.tsagarakis@iit.it

33. MULTIMODAL PERCEPTION: 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

Description:
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++). *Note: It is compulsory to prepare a research proposal on this topic.

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.

Contact: ioannis.sarakoglou@iit.it, nikos.tsagarakis@iit.it

34. WEARABLE ROBOTICS: Development of Under-actuated upper limp wearable systems for Teleoperation 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

Description:
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. The activity of this project is strongly linked to the recently started EU H2020 project SOFTPRO (http://www.softpro.eu/)
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). *Note: It is compulsory to prepare a research proposal on this topic.
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
Contact: ioannis.sarakoglou@iit.it, nikos.tsagarakis@iit.it

35. WEARABLE ROBOTICS: Development of EXO-Muscles: Wearable Add-On Elastic power 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

Description:
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. The activity of this project is strongly linked to the recently started EU H2020 project SOFTPRO (http://www.softpro.eu/)
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). *Note: It is compulsory to prepare a research proposal on this topic.
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.
Contact: nikos.tsagarakis@iit.it, ioannis.sarakoglou@iit.it

36. Locomotion Planning and Adaptation Strategies for Multi-Legged Robotic Platforms on Soft Terrains

Tutors: Andreea Rădulescu, Victor Barasuol, Claudio Semini

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

Description:
The Hydraulic Quadruped robot - HyQ - is a fully torque-controlled hydraulically actuated quadruped robot [link], capable of locomotion over rough terrain and performing highly dynamic tasks such as jumping and running with a variety of gaits. It is a unique research platform, designed for unstructured environments, e.g. outdoors and disaster sites.
Legged robots present unique capabilities for traversing challenging terrains, where they offer a clear advantage over wheeled platforms. A wide range of approaches to legged locomotion exist; however, most are far from demonstrating a solution which performs with a level of flexibility, reliability and careful foot placement that would enable practical locomotion on the variety of rough, soft or intermittent terrains. The success of these behaviours often relies on tuning a large number of parameters, which can be a lengthy empirical procedure, requiring an expert user.
This position will focus on bridging this gap in the context of locomotion adaptation. The study will focus on reshaping an initial whole body trajectory (optimal for stiff terrain surfaces). By applying machine learning methods we can allow the adaptation of this trajectory to perform locomotion on softer surfaces, e.g., sand, pebbles and mud. This will allow the robot to robustly navigate a much wider range of natural terrain scenarios. The work will be conducted on the HyQ and HyQ2Max robotic platforms.
Ideal requirements: Background in robotics, computer science, electrical or mechanical engineering. Understanding of robot kinematics and dynamics, strong C++ skills. Highly-motivated and passionate for robotics and legged locomotion, experienced in Matlab and/or ROS. Previous knowledge of machine learning techniques is a plus.
Contacts: andreea.radulescu@iit.it**,** victor.barasuol@iit.it, claudio.semini@iit.it

37. Force Harvesting with Short-Term Contacts for Multi-Legged Robot Locomotion on Movable and Slippery Terrain

Tutors: Michele Focchi, Victor Barasuol, Claudio Semini

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

Description:
In real life scenarios a legged robot is facing an environment which is continuously changing. From the locomotion point of view this means that the foot-to-ground contact stability is not ensured along the leg support period. Indeed, the interaction with the terrain can have its own dynamics (e.g. moving rocks and slippery surfaces).
A possible strategy to perform locomotion on such challenging surfaces is to understand this dynamics, exploiting it to generate (up to some extent) proper ground reaction forces to drive the robot. To tackle this problem we will investigate the concept of "force harvesting" where we design suboptimal contact forces considering that the interaction will be limited in time (e.g. when stepping on rolling rocks or slippery surfaces). The research will be conducted and experimentally evaluated on our quadruped robotic platforms HyQ and HyQ2Max.
Ideal 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.
Contacts: michele.focchi@iit.it, victor.barasuol@iit.it, claudio.semini@iit.it

38. Flexible Systems Development for Industrial Applications

Tutors: Ferdinando Cannella, Carlo Canali, Francesco Nori, Arash Ajoudani and Darwin Caldwell

ADVANCED INDUSTRIAL AUTOMATION LAB
http://www.iit.it/en/advr-labs/advanced-industrial-automation.html
ADVANCED ROBOTICS (Italian Institute of Technology)
https://www.iit.it/en/research/departments/advanced-robotics.html

Description:
In these years, we are in the midst of a fourth wave of technological advancement: the rise of new digital industrial technology known as Industry 4.0, a transformation that makes possible to gather and analyse data across machines, enabling faster, more flexible and more efficient processes to produce higher-quality goods at reduced costs. This new era of digital enterprise is based on nine technology advances [1], in particular on data collecting from humans and machines for robotic numerical modelling and simulation (for machine design, for product development, for manufacturing process, for value chain management, etc.) and on autonomous robots (to improve both the flexibility and the machine-human collaboration). It's matter of fact that two of the ultimate basic ideas of the Industrial 4.0 are:

1) the Digital Twin, that is an exact copy (numerical model) of the physical mock-up and that permits to the machine designers to exploit the power of digitalization to achieve improved efficiency and quality;
2) the collaborative robot that should interact with worker in the process lines, both from safety point of you and, at same time, dealing with more complex and heavy task (i.e. sawing, hammering, drilling, milling, etc.) that requires high compliance and impact energy dumping.

Nevertheless, the current industrial robots are still not flexible (i.e. to high mix low volume manufacturing) nor adaptive (to the machine-human collaboration) yet.
In this scenario a new robotic design approach should be developed in order to quickly deploy both the robotic flexibility and adaptivity into robotic manufacturing systems (which may include also multiple arm or robots, multiple sensors and related machines).

Then the goals of this PhD will be:

- study, design and build a novel flexible and adaptive manipulator based on the experience obtained from previous projects (Autorecon, AvioAero, EuroC, etc.) inspired from the nature of human beings hands, arms and/or other similar bio-mechanisms.
- develop a Digital Twin improving the current virtual prototyping development (co-simulation with control and flexible multi-body)
- include software level based on ROS (or ROS-industrial) which is modular, reconfigurable, adaptive, easy to use to integrate and control various robotic systems will be developed. The study include the use of such a software to integrate data coming from sensors, other devices, robots and to integrate the system in a network (IOT).

The research is carried out within the **Advanced Industrial Automation Lab** (AIAL is the lab within Advanced Robotics Department where the innovative, multidisciplinary approach to humanoid design and control, and the development of novel robotic components and technologies are addressed to the industrial needs) and in strictly collaboration with the **Dynamic Interaction Control** (the **DIC** activities aim at endowing humanoids with advanced action and physical interaction capabilities), the **Human-Robot Interfaces and Physical Interaction** (H2I2 aims to….), the **Center for Micro-BioRobotics** (CMBR) and the **MSC software** (undisputed worldwide leader for multibody simulations). 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 bio-inspired robots suitable for the industrial plants.

[1]https://www.bcgperspectives.com/content/articles/engineered_products_project_business_industry_4_0_future_productivity_growth_manufacturing_industries/

This multidisciplinary work will be under supervision of **Dr. Ferdinando Cannella (AIAL), Dr. Mariapaola D'Imperio (AIAL), Dr. Carlo Canali (AIAL), Dr. Francesco Nori (DIC), Dr. Arash Ajoudani (HRI2), Dr. Barbara Mazzolai (CMBR) and Dr. Luca Castignani (MSC.Software)**

Requirements:

this position is open to a PhD candidate should be enthusiastic, with strong interesting in bio-inspired mechanism and skill in computer science; moreover the robotic modelling will be valuable. The ideal competencies should be in control with strong programing skill, especially program using C++ under Linux. The background must have also robotics with skill in using of flexible multi-body simulators (i.e. MSC.ADAMS, NASTRAN, MARC, etc.).

Required technical skills: **70% control, 30% Mechanism.**

Reference:

Mariapaola D'Imperio, Luca Carbonari, Alsayegh, M., Bertram, T., Matteo Palpacelli, Darwin G. Caldwell,, Ferdinando Cannella, "Flexible robotic arm dynamics through deflection screw approach" (2016) MESA 2016 - 12th IEEE/ASME International Conference on Mechatronic and Embedded Systems and Applications - Conference Proceedings, art. no. 7587169, DOI: 10.1109/MESA.2016.7587169

L. Fiorio, F. Romano, A. Parmiggiani, G. Sandini, and Francesco Nori. Stiction compensation in agonist-antagonist variable stiffness actuators. In Proceedings of Robotics: Science and Systems, Berkeley, USA, July 2014.

A. Ajoudani, N. Tsagarakis, and A. Bicchi, "Choosing Poses for Force and Stiffness Control", 2016, submitted.
B Mazzolai, V Mattoli, Robotics: Generation soft, Nature 536 (7617), 400-401, 2016.

http://www.maxwellsci.com/print/rjaset/v6-3778-3783.pdf

Contacts: ferdinando.cannella@iit.it, carlo.canali@iit.it, francesco.nori@iit.it, arash.ajoudani@iit.it

39. Industrial Robotics for Inspection and Maintenance

Tutors: Carlo Canali, Ferdinando Cannella, Darwin Caldwell

ADVANCED INDUSTRIAL AUTOMATION LAB
http://www.iit.it/en/advr-labs/advanced-industrial-automation.html
ADVANCED ROBOTICS (Italian Institute of Technology)
https://www.iit.it/en/research/departments/advanced-robotics.html

Description:
The successful PhD candidate will be involved into the design and study of inspection robots to be used in industrial applications. The goal of the study is to develop one or more mechatronics systems to be used as a versatile and flexible device for inspection porpoise. The study of the state of the art in robotics referred to the current status of manufacturing industry is part of the thesis. The analysis of most demanding needing in industrial applications will drive the development of the device. The robot to be designed integrates several sub-systems and can be deployed in several tasks ranging from inspection, maintenance and quality control. The system must be able to access small spaces, navigate in harsh environments and carry on a number of sensors and actuators depending from the application.
As a general rule the system need to be Industry 4.0 complaints including the following features:

- Inter-operability: The ability of machines, devices, sensors, and people to connect and communicate with each other, aggregation of raw sensor data to higher-value context information.
- Physically support humans by conducting a range of tasks that are unpleasant, too exhausting, or unsafe for their human co-workers. This could include telepresence, remote operation, and augmented reality.
- The ability of the systems to make decisions on their own and to perform their tasks as autonomously as possible.

This work will be under supervision of **Dr. Carlo Canali and Dr. Ferdinando Cannella**

Requirements:
Background in mechatronics, mechanical engineering, electronic engineering, or equivalent
Desired qualifications:
The successful applicant is expected to have a strong background in electronics, mechanics or mechatronics Experience with real hardware, and excellent hands-on practical skills are essentials, the ideal candidate has a strong proactive attitude and problem solving capabilities.
Team working and competence in one or more of the following topics are required:
Mechatronics
Mechanical or Electronic design
Control and software engineering

Reference:
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

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.

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.

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