Università degli Studi di Genova – Istituto Italiano di Tecnologia

Corso di Dottorato "Bioengineering and ¬Robotics"
Curriculum "Advanced and Humanoid Robotics"

Anno Accademico 2018-2019
Ciclo XXXIV

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. Multi-modal object exploration and grasping

Tutor: Lorenzo Natale and Ugo Pattacini

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

Description:
To plan successful grasping a robot it is important to have accurate estimation of the object pose and shape. Precise information on the object pose may be unavailable due to noise in the sensory system or occlusions. When dealing with novel objects, this problem becomes more complex because the robot cannot rely on precise 3D models of the objects. For these reasons, grasping of unknown objects or whose pose is uncertain is still an open problem in robotics.

This project aims at designing algorithms for object exploration, tracking and modelling by integrating visual and tactile information. The idea is to exploit vision to derive an initial estimation of the object pose and shape, and refine this estimation using the tactile information acquired while touching it. The main challenges are: i) implement control strategies to explore the object, ii) devise algorithms for fusing measures coming from the visual and tactile sensors and iii) develop techniques for modelling the object.

This project will be carried out on the iCub robot using the stereo system on the robot and the tactile sensors in the hand. 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, Bayesian filtering, and/or computer vision and machine learning. He would also be highly motivated to work on robotic platform and have computer programming skills.

References:
Vezzani, G., Pattacini, U., Pasquale, G., and Natale, L., Improving Superquadric Modeling and Grasping with Prior on Object Shapes, in IEEE-RAS International Confenrence on Robotics and Automation, 2018.

Vezzani, G., Pattacini, U., Battistelli, G., Chisci, L., and Natale, L., Memory Unscented Particle Filter for 6-DOF Tactile Localization, in IEEE Transactions on Robotics, vol. 33, no. 5, pp. 1139-3098, 2017.

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.

Contacts: lorenzo.natale@iit.it, ugo.pattacini@iit.it

2. Perception and Machine Learning for Manipulation

Tutor: Lorenzo Natale and Lorenzo Rosasco

Department: Humanoid Sensing and Perception Laboratory, and Laboratory for Computational and Statistical Learning
https://www.iit.it/lines/humanoid-sensing-and-perception
https://www.iit.it/it/centers/lcsl-mit

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. In the robotic community, there has been growing interest in the application of machine learning and data driven approaches, to solve object manipulation and grasping tasks. Adopting data driven approaches in robotics is challenging. Acquiring training examples is expensive and requires several hours or days of experiments, and appropriate explorative actions. Training deep-learning models is typical off-line, and it does not allow robot to quickly adapt when faced with a novel situation.

This project falls squarely at the intersection between machine learning and robotics. The goal is to exploit machine learning to advance the capabilities of robots to interact with the environment, grasping and manipulating objects. The focus is on the study of strategies that allow learning to be autonomous, and incremental machine learning techniques that allow the robot to dynamically adapt to novel situations (i.e. novel objects, changes in the scene). Possible topics include:

- Perception of affordances, from object detection to detection of object parts;
- Scene segmentation;
- Robot self-perception for visual control of manipulation;
- Data-driven approaches to object grasping.

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:
Maiettini, E., Pasquale, G., Rosasco, L., and Natale, L., Interactive Data Collection for Deep Learning Object Detectors on Humanoid Robots, in Proc. IEEE-RAS International Conference on Humanoid Robots, Birmingham, UK 2017.

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.

Camoriano, R., Pasquale, G., Ciliberto, C., Natale, L., Rosasco, L., and Metta, G., Incremental Robot Learning of New Objects with Fixed Update Time, in Proc. IEEE International Conference on Robotics and Automation, Singapore, 2017, pp. 3207-3214.

3. Vision for walking robots

Tutors: Lorenzo Natale, Daniele Pucci

Department: Humanoid Sensing and Perception Laboratory, and Dynamic Interaction Control Laboratory, Istituto Italiano di Tecnologia
https://www.iit.it/lines/humanoid-sensing-and-perception
https://www.iit.it/research/lines/dynamic-interaction-control

Description:
The ability to acquire high-resolution depth information allows for using three-dimensional geometries to build detailed shapes. The latter is fundamental for tasks that require complex interaction between the robot and the environment like balancing and walking, with and without hand support. Local shape information can in fact be used to segment the scene and to plan foot and hand placement to stabilize the robot. This is a challenging task because it requires observations on both the geometry and the visual appearance of the surrounding surfaces, in relation to the body of the robot. To perform such tasks, features need to be extracted from the data allowing different regions to be compared and matched. Depending on the complexity of the viewed scene, these features can be extracted from the depth data alone or need to be augmented with those extracted from images.

The aim of this PhD is to study the general problem of scene understanding by combining three-dimensional depth observations with visual appearance from images. The goal is to leverage on deep-models to extract visual descriptors and perform classification. We consider locomotion tasks in scenarios that involve whole-body control. Experiments will be carried out on the iCub humanoid robot.

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

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4. State Estimation for Humanoid Robots

Tutors: Daniele Pucci, Silvio Traversaro, Giorgio Metta

Department: Dynamic Interaction Control Laboratory
https://www.iit.it/research/lines/dynamic-interaction-control

Description: the importance of state estimation for humanoid robot locomotion goes without saying. Robot position, velocity, acceleration, internal joint torques and external forces are a few fundamental quantities that state estimation for humanoid robots is usually interested in. The main limitations of current estimation techniques reside in the assumptions made when modeling the surrounding robot environment. For instance, contacts between the robot and the environment are either ignored or assumed to be rigid and bilateral, which is not representative of the real-world scenario in many applications.

This research project aims at identifying contact models that enable real-time state estimation for humanoid robots. The studied models will be then fused with the information coming from the rich set of sensors available on the iCub humanoid robot (6-Axis Force/Torque sensors, Robotic Skin, Distributed Inertial Sensors, RGB-D sensors, etc.) to provide a reliable state estimation to be integrated in 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, which shall enable the iCub to operate in real world scenarios, e.g. walking on soft carpets.

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

Reference:

[1] G. Nava *et al*., "Modeling and control of humanoid robots in dynamic environments: ICub balancing on a seesaw," *2017 IEEE-RAS 17th International Conference on Humanoid Robotics (Humanoids)*, Birmingham, 2017,pp.263-270. doi: 10.1109/HUMANOIDS.2017.8246884

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

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5. Geometric Control for Humanoid Robot Locomotion

Tutors: Daniele Pucci and Giorgio Metta

Department: Dynamic Interaction Control Laboratory
https://www.iit.it/research/lines/dynamic-interaction-control

Description: despite decades of research in the subject, a unified control theory for humanoid robots interacting with the surrounding environment is still missing. More precisely, the contacts between the robot and the environment modify the topological properties of the space where the system representing the humanoid robot evolves. This topological variability depending on contacts complexifies the synthesis of controllers for humanoid robots achieving different kinds of tasks.

The research project aims at designing geometric control strategies for humanoid robots when balancing and walking in dynamic environments and with multiple contacts. Envisioned case studies are: balancing with multiple contacts and on soft terrains; walking on elastic floors are.

The main challenges for the research project are:

i) the system modelling of the pair robot-environment;

ii) the design of geometric controllers with proven stability and robustness proprieties;

iii) the development of robust, efficient implementations of the control algorithms.

Envisioned control solutions make use of geometric control techniques applied to floating base systems with rigid contacts. 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.

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

References:

[1] Khalil K. Hassan, Nonlinear Systems, third edition, 2001.

[2] Bullo, F., Lewis, A.D. , Geometric Control of Mechanical Systems, Lewis, A.D.2004.

Contact: daniele.pucci@iit.it, giorgio.metta@iit.it

6. Towards Aerial Humanoid Robotics

Tutors: Daniele Pucci and Giorgio Metta

iCub Facility: https://www.iit.it/research/lines/icub
Dynamic Interaction Control: 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 requires the robot to make and break contacts to achieve locomotion. The *fixed-base assumption* is then circumvented by modern modelling techniques, and the robot is referred to as *floating base*. In this case, one may attempt at developing control techniques for the general locomotion problem for floating base systems, thus unifying flying and humanoid robot control techniques.

In this direction, we do believe that there is a strong technological benefit in conceiving robotic platforms capable of *terrestrial locomotion*, *flight*, and *manipulation*. *Flight* and *manipulation* have already been implemented on many platforms, thus contributing to the so-called *aerial manipulation* [1], but robots combining *terrestrial locomotion*, *flight*, and *manipulation* 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 platform.

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] D. Pucci, S. Traversaro and F. Nori, "Momentum Control of an Underactuated Flying Humanoid Robot," in *IEEE Robotics and Automation Letters*, vol. 3, no. 1, pp. 195-202, Jan. 2018.
doi: 10.1109/LRA.2017.2734245

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7. Legged Robot Control: Locomotion Planning and Control of a Hybrid Legged/Wheeled Robot Platform

Tutor: Navvab Kashiri, Nikos Tsagarakis

Humanoid and Human Centred Mechatronics Research line
https://www.iit.it/research/lines/humanoids-human-centered-mechatronics
Department of Advanced Robotics, Istituto Italiano di Tecnologia

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 hybrid locomotion planning strategies for a CENTAURO robot, which is equipped with wheeled and legged mobility (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.

Reference:
Baccelliere, L., Kashiri, N., Muratore, L., Laurenzi, A., Kamedula, M., Margan, A., ... & Tsagarakis, N. G. (2017, September). Development of a human size and strength compliant bi-manual platform for realistic heavy manipulation tasks. In Intelligent Robots and Systems (IROS), 2017 IEEE/RSJ International Conference on, pp. 5594-5601.
Contact: navvab.kashiri@iit.it, nikos.tsagarakis@iit.it

8. Legged Robot Control: Whole-body Falling-over Recovery Control for Humanoids

Tutor: Jinoh Lee, Nikos Tsagarakis

Humanoid and Human Centred Mechatronics Research line
https://www.iit.it/research/lines/humanoids-human-centered-mechatronics
Department of Advanced Robotics, Istituto Italiano di Tecnologia

Description: The need of robots to deal with unstructured environments and replace humans in hazardous tasks became an important virtue. Humanoids are naturally highlighted for their potential capability to access to unstructured and uncertain environments. However, one of the significant barriers for a humanoid to operate is that its sensitivity to falls that will be eventually avoidable in realistic and relatively unstructured grounds. The target of this search project is to develop novel methodologies, which will enable a torque-controlled humanoid to sense the uncertain environment and to reactively control the entire body motion to recover after falling over. The key aspects will cover the following developments:

- whole-body sensing algorithm using proprioceptive sensors (e.g., joint torque sensors, encoders and IMU) and exteroception (e.g., force-torque sensors and stereo vision), and
- motion planning and control for recovering action of the entire body using robust dynamic control schemes.

The methods will be verified in dynamic simulation environment and on bipedal robots such as WALK-MAN (https://walk-man.eu), a new high performance humanoid recently developed at IIT, and CogIMon EU project (https://cogimon.eu/). The work activity of this theme will be in line with the developments of the CogIMon EU project (https://cogimon.eu/) so thus offers an opportunity to experience the European project.

Requirements:
We are preferably seeking for highly motivated candidates with a background in robotics and control engineering. Especially, knowledge on operational-space control with redundant robots and robust control theory (such as disturbance observer) 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.

Reference:
Chan Lee, Jinoh Lee, Jörn Malzahn, Nikos Tsagarakis, Sehoon Oh, "A Two-Staged Residual for Resilient External Torque Estimation with Series Elastic Actuators ," 2017 IEEE-RAS International Conference on Humanoid Robots, pp817-823, 2017
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 ICRA 2016.
Contact: Jinoh.lee@iit.it, nikos.tsagarakis@iit.it

9. Legged Robot Control: Dexterous Humanoid Walking on Restricted and Unstable Footholds

Tutor: Nikos Tsagarakis, Chengxu Zou

Humanoid and Human Centred Mechatronics Research line
https://www.iit.it/research/lines/humanoids-human-centered-mechatronics
Department of Advanced Robotics, Istituto Italiano di Tecnologia

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. The WALK-MAN has been developed under the European FP7 project WALK-MAN (http://www.walk-man.eu/). WALK-MAN 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 uneven terrains and particulate solid surfaces consisting of particles of different size and density, which may not provide fully stable footholds.
In this topic, 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. 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 modelling and control, MATLAB and C/C++ programming. Knowledge on mechatronics hardware, fundamental robotics and rigid body dynamics is a plus.

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
Contact: nikos.tsagarakis@iit.it

10. Robot Interaction Control: Impedance regulation principles for Harsh and Agile Physical interaction

Tutors: Nikos Tsagarakis, Enrico Mingo Hoffman

Humanoid and Human Centred Mechatronics Research line
https://www.iit.it/research/lines/humanoids-human-centered-mechatronics
Department of Advanced Robotics, Istituto Italiano di Tecnologia

Description: This research theme will focus on the development of motion/impedance control principles for robots required to execute aggressive and powerful physical interactions with the environment. This will require generating high-speed motions while at the same time ensuring the maximum robot protection against the task impacts.
A physical interaction control framework that will permit the above will be developed and validated on a CENTAURO form mobile manipulation platform (https://www.centauro-project.eu/) that is equipped with torque/impedance controlled, intrinsically robust compliant actuators realized with high power and strength density motor drives. To reach this target, the project will look on the development of motion/impedance regulation strategies, momentum control techniques and kinematic redundancy exploitation to robustly execute powerful physical interactions.
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 and 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.

Reference:
Baccelliere, L., Kashiri, N., Muratore, L., Laurenzi, A., Kamedula, M., Margan, A., ... & Tsagarakis, N. G. (2017, September). Development of a human size and strength compliant bi-manual platform for realistic heavy manipulation tasks. In Intelligent Robots and Systems (IROS), 2017 IEEE/RSJ International Conference on, pp. 5594-5601.
Hoffman E. M., Laurenzi A., Muratore L., Tsagarakis N. G. and Caldwell D. G., 2018. Multi-Priority Cartesian Impedance Control based on Quadratic Programming Optimization. In Robotics and Automation (ICRA), 2018 IEEE International Conference on. IEEE.
Contact: nikos.tsagarakis@iit.it, enrico.mingo@iit.it

11. Robot Interaction Control: Whole-body Multiple Contact Physical Interaction Control of a Hybrid Legged/Wheeled Robot Platform

Tutor: Jinoh Lee, Nikos Tsagarakis

Humanoid and Human Centred Mechatronics Research line
https://www.iit.it/research/lines/humanoids-human-centered-mechatronics
Department of Advanced Robotics, Istituto Italiano di Tecnologia

Description: Recent advances in humanoid research aim at bringing robots into the real world which is complex, unstructured, cluttered and dynamically changing and encourage operating 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 a hybrid robotic platform – inspired by the Greek mythology (Centaurs) that has a quadruped legged base and a high dexterity upper body with two arms. 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 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. The methods will be verified in dynamic simulation environment such as Gazebo, Robotran, 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/).

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, or RoboTran) and ROS would be plus.

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," IEEE ICRA 2016.
Contact: Jinoh.lee@iit.it, nikos.tsagarakis@iit.it

12. Robot Interaction Control: Human-Robot Collaborative Control of a Hybrid Legged/Wheeled Manipulation Robot

Tutors: Nikos Tsagarakis, Arash Ajoudani,

Humanoid and Human Centred Mechatronics Research line
https://www.iit.it/research/lines/humanoids-human-centered-mechatronics
Department of Advanced Robotics, Istituto Italiano di Tecnologia

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.

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

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13. Robot Design/Control: Modeling and Control for Plug & Play Modular Torque Controlled Robots – From Gentle to Harsh

Tutor: Jörn Malzahn, Nikos Tsagarakis

Humanoid and Human Centred Mechatronics Research line
https://www.iit.it/research/lines/humanoids-human-centered-mechatronics
Department of Advanced Robotics, Istituto Italiano di Tecnologia

Description: The Humanoid and Human Centred Mechatronics research line is one of the world leading research labs in the development and new robot actuation systems, ranging from series compliant actuators to actuators with variable physical 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 can 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. The institute is renowned for its humanoids and legged robots built with these actuators, that can display the full spectrum from soft and gentle to harsh and impulsive physical interactions. On the shoulders of our previous work, the successful candidate will play a central role in the research and development aiming at the extension of the developed hardware towards modular "plug-and-play" torque controlled robots. The application domains are modular, efficient, flexible co-bots that pair high performance manipulation skills with soft human-robot interaction and meet the requirements of small human-centered production lines with substantial task fluctuations. Beyond that, the vision is to bring the modularity concept also to legged robots that can cope with difficult terrains and harsh environments in disaster response scenarios. In close collaboration with our interdisciplinary research team, the successful candidate will develop, implement and deploy control algorithms for a novel generation of modular torque controlled robotic systems, from individual joint link modules to entire "plug-and-play" robotic systems in the described applications.

Requirements: We are seeking for highly motivated candidates with a background in Mechanical or Electrical engineering, Control Theory or Robotics. This is a multidisciplinary topic where the successful candidates have strong competences in robot dynamics and control. Excellent programming skills in C/C++, Python, Matlab complete the portfolio of the candidate. Traceable experience in open source software development and ROS are desirable.

References:

Giusti, A., Malzahn, J., Tsagarakis, N. G., & Althoff, M. (2017, May). Combined inverse-dynamics/passivity-based control for robots with elastic joints. In Robotics and Automation (ICRA), 2017 IEEE International Conference on, pp. 5281-5288.

Baccelliere, L., Kashiri, N., Muratore, L., Laurenzi, A., Kamedula, M., Margan, A., ... & Tsagarakis, N. G. (2017, September). Development of a human size and strength compliant bi-manual platform for realistic heavy manipulation tasks. In Intelligent Robots and Systems (IROS), 2017 IEEE/RSJ International Conference on, pp. 5594-5601.

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

14. Robot Design/Control: Agile Robot Design and Actuation Principles

Tutor: Nikos Tsagarakis,, Navvab Kashiri

Humanoid and Human Centred Mechatronics Research line
https://www.iit.it/research/lines/humanoids-human-centered-mechatronics
Department of Advanced Robotics, Istituto Italiano di Tecnologia

Description: The Humanoid and Human Centred Mechatronics research line is one of the world leading research labs in the development and new actuation and robotic systems powered by torque controlled compliant actuators to actuators. 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.
The aim of this topic is to develop and demonstrate break-through robot design and actuation principles targeting to achieve agile motion performance and resilient interaction capacity that goes far beyond the current state of art. To achieve this the project will explore both the mechatronic technological limits (lightweight structural materials, customized high power density actuation and transmission systems) and new actuation control philosophies to overcome of the actuator physical velocity limitations to eventually lead to enhanced agile performance. The energy storage capacity of the transmission system will be also explored through the elastic energy recycling to further increase the robot agility during explosive motions. The developed robot design concepts and controllers will be applied to walking, hopping and in general legged robots performing high power bursts such as kicking and jumping.
Requirements: We are seeking for highly motivated candidates with a background in Electronic/Mechanical engineering, Physical Sciences or Robotics. Candidates should have competencies in CAD mechanical design and/or robot dynamics and control. (Mechanical design 60%, Dynamics/Control %40).

Reference:
W. Roozing et al., “Design optimisation and control of compliant actuation arrangements in articulated robots for improved energy efficiency,” IEEE Robotics and Automation Letters, vol. 1, no. 2, pp. 1110–1117, 2016.
W. Roozing et al., “Development and control of a compliant asymmetric antagonistic actuator for energy efficient mobility,” IEEE/ASME Transactions on Mechatronics, vol. 21, no. 2, pp. 1080–1091, 2015.
Contact: nikos.tsagarakis@iit.it, navvab.kashiri@iit.it

15. Robot Design/Control: Efficient Robot Design and Actuation Principles

Tutor: Navvab Kashiri, Nikos Tsagarakis

Humanoid and Human Centred Mechatronics Research line
https://www.iit.it/research/lines/humanoids-human-centered-mechatronics
Department of Advanced Robotics, Istituto Italiano di Tecnologia

Description: The Humanoid and Human Centred Mechatronics research line is one of the world leading research labs in the development and novel robotic platforms ranging from child-size humanoid Coman to Hybrid centaur-like HalfMan. Legged robots demonstrate unique potentiality of passing over various terrains and entering unstructured environments. Despite the development of a variety of actuation units enhancing the system's energy efficiency, on the basis variable/fixed compliance and damping units in series and/or parallel, the energy associated characteristics of floating based platforms is subject to additional criteria that are often omitted, thereby preventing long time performance required for real world applications. This research will exploit advancement in robotic actuation and energy recycling techniques, investigate state-of-the-art transmission units and research limb/structure design aspects. The outcome of this study will be a novel quadrupedal robot performing energy efficient dynamic motions such as trotting and jumping.
Requirements: We are seeking for highly motivated candidates with a background in Mechanical/Mechatronic/Electrical engineering, Physical Sciences or Robotics. Candidates should have competencies in CAD mechanical design and understanding of robot dynamics/kinematics and control. (Mechanical design 60%, Kinematics/Dynamics/Control %40). *Note: It is compulsory to prepare a research proposal on this topic.

Reference:
W. Roozing et al., “Design optimisation and control of compliant actuation arrangements in articulated robots for improved energy efficiency,” IEEE Robotics and Automation Letters, vol. 1, no. 2, pp. 1110–1117, 2016.
W. Roozing et al., “Development and control of a compliant asymmetric antagonistic actuator for energy efficient mobility,” IEEE/ASME Transactions on Mechatronics, vol. 21, no. 2, pp. 1080–1091, 2015.
Contact: navvab.kashiri@iit.it, nikos.tsagarakis@iit.it

16. Perception And Planning: 3D Perception, Path Planning, and Mapping for Legged Robot Navigation

Tutor: Dimitrios Kanoulas, Nikos Tsagarakis

Humanoid and Human Centred Mechatronics Research line
https://www.iit.it/research/lines/humanoids-human-centered-mechatronics
Department of Advanced Robotics, Istituto Italiano di Tecnologia

Description: Enabling robots to deal with unstructured environments and replace humans in hazardous tasks is one of the main is an open challenge in robotics. Rapid advancements in actuation and control over the last few years enabled articulated legged robots to walk in uneven terrain. Still, the problem of foot placement in rough terrain for navigation using 3D perception remains one of the main challenges in robotics and is the key aspect for completing locomotion and manipulation tasks in unknown environments.
The aim of this topic is to develop new geometric or machine learning (e.g. deep learning) methods for environment reconstruction and cognition that enable legged robots, such as WALK-MAN (http://www.walk-man.eu/), CENTAURO (https://www.centauro-project.eu) , or CogIMon (https://cogimon.eu) to perform legged locomotion in unstructured environments using 3D perception for foot placement, path planning, and mapping (SLAM). Several exteroceptive (stereo/event/RGB cameras, RGB-D sensors, 2D/3D Lidar scanners) will be used on our limbed robots, to acquire RGB images and dense 3D point cloud. Geometric simplifications for reasoning the contact between the robot's foot and the environment will need to take place. Moreover, path-planning methods need to be developed to extract primitives for locomotion. The development and testing will take place on our full-size quadrupedal/humanoid robots in real-world environments.
Requirements: This topic lies in the intersection of Vision and Robotics. Ideal applicants should have strong C++ (Python and Matlab is a plus) programming. Machine learning and computer vision skills are required. A background in any of Robotics, Computer/Robotic Vision, Path Planning, and Robot Learning is desirable, while knowledge of the Robot Operating System (ROS) and the Point Cloud Library (PCL) is a very big plus. The applicants should be fluent in English and team players.

Reference:
Kanoulas et. al., *"Vision-Based Foothold Contact Reasoning using Curved Surface Patches"*, Humanoids 2017.
Kanoulas et. al., *"Footstep Planning in Rough Terrain for Bipedal Robots using Curved Contact Patches"*, ICRA 2018.
Contact: dimitrios.kanoulas@iit.it , nikos.tsagarakis@iit.it

17. Perception And Planning: 3D Perception and (Deep) Learning for Humanoid Robot Tool Manipulation

Tutor: Dimitrios Kanoulas, Nikos Tsagarakis

Humanoid and Human Centred Mechatronics Research line
https://www.iit.it/research/lines/humanoids-human-centered-mechatronics
Department of Advanced Robotics, Istituto Italiano di Tecnologia

Description: Rapid advancements in actuation and control over the last few years enabled humanoid robots to manipulate several objects. Still, the problem of tool manipulation and reasoning in uncertain setups using 3D perception remains one of the main challenges in robotics and is the key aspect for completing several tasks in unknown environments. The aim of this topic is to develop new geometric or machine learning (e.g. deep learning) methods for environment reconstruction and cognition that enable limbed robots, such as WALK-MAN (http://www.walk-man.eu/), CENTAURO (https://www.centauro-project.eu) , or CogIMon (https://cogimon.eu) to perform manipulation in unstructured environments using 3D perception for hand/arm/whole-body placement. Several exteroceptive (stereo/event/rgb cameras, RGB-D sensors, 2D/3D lidar scanners) will be used on our limbed robots, to acquire RGB images and dense 3D point cloud. Geometric simplifications for reasoning the contact between the robot's body (e.g., hands, arms) and the environment will need to take place. The development and testing will take place on our full-size quadrupedal/humanoid robots in real-world environments.
Requirements: This topic lies in the intersection of Vision and Robotics. Ideal applicants should have strong C++ (Python and Matlab is a plus) programming. Machine learning and computer vision skills are required. A background in any of Robotics, Computer/Robotic Vision, Path Planning, and Robot Learning is desirable, while knowledge of the Robot Operating System (ROS) and the Point Cloud Library (PCL) is a very big plus. The applicants should be fluent in English and team players.

Reference:
1. Kanoulas et. al. *"Center-of-Mass-Based Grasp Pose Adaptation Using 3D Range and Force/Torque Sensing"*, IJHR 2018.
2. Nguyen et. al., *"Object-Based Affordances Detection with Convolutional Neural Networks and Dense Conditional Random Fields"*, IROS 2017.
Contact: dimitrios.kanoulas@iit.it , nikos.tsagarakis@iit.it

18 Hydraulic Quadruped Robots with arms: Multi-contact Optimization for Cluttered Environments

Tutors: Michele Focchi, Claudio Semini

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

Description:
IIT's Dynamic Legged Systems (DLS) lab developed the Hydraulic Quadruped robot HyQ to traverse complex and unstructured terrains for search and rescue missions in natural disaster scenarios. Traditionally, quadrupeds have been limited to load-carrying or sensing tasks, as they have no manipulation ability. To overcome this limitation, we have been working on a combination of quadruped locomotion stability with the ability to perform manipulation tasks, i.e. HyQ-Centaur [1].
However, introducing additional limbs that can be in contact with the environment (e.g. an arm to open doors) can pose some challenges because the force that is realizable from the arm is limited by the stability requirements of the mobile platform. The robot configuration and posture can be optimized to better realize a certain force at the environment (e.g. to operate a power tool to force open a door in a rescue mission, as in our INAIL-funded Teleoperation project). Additionally, when locomoting through cluttered environments, exploiting contacts in points different from the feet [2] can be the only option to succeed with the task.
This position will focus on optimization of postures for manipulation, force realization and selection of contacts (multi-contact optimization [3,4]) to enhance locomotion and make a quadruped with arm (INAIL teleoperation project) able to traverse cluttered environments.

Requirements:
Background in robotics, computer science, electrical engineering or mechanical engineering. *Mandatory:* Basic knowledge on control and signal processing. Understanding of robot kinematics and dynamics, strong C++ skills. Creativity, problem-solving skills. Passionate for robotics and legged locomotion. Experience in Matlab. *Desired but not mandatory:* basic knowledge on optimization, 3D mapping, experience in ROS and Python.

References:
[1] B. U. Rehman, M. Focchi, J. Lee, H. Dallali, D. G. Caldwell, C. Semini. *Towards a Multi-legged Mobile Manipulator.* IEEE ICRA, 2016.
[2] B. Henze, A. Dietrich, M. A. Roa and C. Ott. *Multi-contact balancing of humanoid robots in confined spaces: Utilizing knee contacts*. IEEE IROS, 2017.
[3] J. Carpentier and N. Mansard. *Multi-contact Locomotion for Legged Robots.* submitted to IEEE Transaction on Robotics, 2017. (https://hal.laas.fr/hal-01520248)
[4] J. Carpentier, S. Tonneau, M. Naveau, O. Stasse, N. Mansard. *A Versatile and Efficient Pattern Generator for Generalized Legged Locomotion.* IEEE ICRA, 2016.

19 Hydraulic Quadruped Robots: Recovery Strategies for Dynamic Locomotion on Irregular Surfaces

Tutors: Michele Focchi, Victor Barasuol, Claudio Semini

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

Description:
The Hydraulic Quadruped robot - HyQ - is a fully torque-controlled hydraulically actuated quadruped robot, capable of locomotion over rough terrain and performing highly dynamic tasks such as jumping and running with a variety of gaits, e.g. [1,2]. It is a unique research platform, designed for unstructured environments, e.g. outdoors and disaster sites. These environments present several challenges to locomotion. Using a vision feedback, it is possible to plan appropriate motions that are taking into consideration the features of the terrain. Long term planning methods could deal with these terrains, but they reach their limits because they are inherently unable to cope with accumulation of errors. There errors can be due to tracking/filtering delays, inaccuracy of the 3D map, modeling errors, sensor calibration errors, unforeseen events (external pushes, slipping, rock falling) or simply by the fact that terrain can be changing (e.g. rolling stones). These errors would make the robot state drift away from the original plan. Recovery strategies (based on a map of the environment) can help to mitigate these errors [3].
This position will focus on designing successful recovery strategies for stabilization to deal with a variety of terrain (e.g. climbing stairs, pile of rubble) in face of unpredicted situations (e.g. external pushes, stepping on rolling rocks or slippery surfaces).

Requirements:
Background in robotics, computer science, electrical engineering or mechanical engineering. *Mandatory:* Basic knowledge on control and signal processing. Understanding of robot kinematics and dynamics, strong C++ skills. Creativity, problem-solving skills. Passionate for robotics and legged locomotion. Experience in Matlab. *Desired but not mandatory:* basic knowledge on neural networks and machine learning, 3D mapping, ROS and Python.

References:
[1] V. Barasuol, J. Buchli, C. Semini, M. Frigerio, E. R. De Pieri, D. G. Caldwell, *A Reactive Controller Framework for Quadrupedal Locomotion on Challenging Terrain.* IEEE ICRA, 2013.
[2] M. Focchi, A. del Prete, I. Havoutis, R. Featherstone, D. G. Caldwell, C. Semini, *High-slope terrain locomotion for torque-controlled quadruped robots.* Autonomous Robots, 2017.
[3] V. Barasuol, M. Camurri, S. Bazeille, D. Caldwell, C. Semini, *Reactive Trotting with Foot Placement Corrections through Visual Pattern Classification.* IEEE/RSJ IROS, 2015.

20. Robot-Assisted Microsurgery

Tutors: Dr. Leonardo Mattos, Dr. Nikhil Deshpande

Department of Advanced Robotics (ADVR – IIT)
https://www.iit.it/research/lines/advanced-robotics

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 microsurgery. It will build upon results from IIT's Biomedical Robotics Lab to create the next generation of robotic systems for high precision / high quality microsurgeries. This will involve the mechatronic design and control of a new robotic instruments, as well as the evaluation and testing of new systems in collaboration with our partner surgeons. Application areas include ENT and pediatric surgery. During this PhD program 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 would be beneficial for this PhD. The candidate must be fluent in both spoken and written English.

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21. Sensing and Automation in Robotic Surgery

Tutor: Dr. Leonardo Mattos, Dr. Veronica Penza

Department of Advanced Robotics (ADVR – IIT)
https://www.iit.it/research/lines/advanced-robotics

Description: Technology can go a long way toward improving the safety and quality of surgeries. At IIT's Biomedical Robotics Laboratory, we are pursuing these goals through the development of novel robotic devices, sensors, automatic controllers and supervisory safety systems. The PhD program will be part of ongoing research on enhancing the detection and microsurgery operations for the treatment of diseases in the upper airways. Currently the group is developing robotic technologies for micro-laparoscopy and for endoscopic surgery. Both applications offer a vast opportunity for research in sensing and automation. The specific research topic of the successful candidate will be selected based on the students background and interests. It may involve, for example, research in real-time tumor detection, surgical planning, surgical automation, shared-control, and augmented reality. The research will involve close collaboration with partner clinicians and technology end-users, allowing the student to develop expertise both in engineering (biosensors, actuators, control systems) and ergonomics (human factors, usability, human-computer interaction).

Requirements: background in engineering, computer science or related disciplines; interest in the design, implementation and evaluation of assistive systems for surgical applications. Experience in one or more of the following areas will be considered a plus: Computer vision, robotics, medical devices. The candidate must be fluent in both spoken and written English.

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22. Tele-Microsurgery over 5G

Tutors: Dr. Leonardo Mattos, Dr. Nikhil Deshpande

Department of Advanced Robotics (ADVR – IIT)
https://www.iit.it/research/lines/advanced-robotics

Description: Research and development towards telesurgery has started over 30 years ago with the conception of robots specifically designed for surgical procedures. From the beginning this has been a highly multidisciplinary work involving, by necessity, progress and innovation in robotics, surgical science and telecommunications. Currently, robot-assisted surgery is routinely performed in hospitals all over the globe, but telesurgery is still far from being commonplace – it is still limited to a few meters distance, with the surgeon sitting on a master console typically located in the same room as the slave robot and the patient. The reasons for this are varied, but a major bottleneck currently preventing long distance telesurgery is the available telecommunications infrastructure. Fortunately this is expected to change soon with the new 5G telecom systems. At the IIT we are collaborating with major telecom companies currently designing and implementing 5G systems. Together we are developing and customizing both robotic and telecom systems with the goal of demonstrating effective tele-microsurgery over 5G networks. This PhD topic will contribute to this work through research on the development of tele-mentoring and teleoperation systems, with special focus on adaptive, robust and safe controllers for the critical application of remote surgical care. This will involve the design and development of software and interfaces to "teleport" the surgeon to the operating room by offering an immersive, intuitive and safe teleoperation interface. The primary surgical application will be transoral laser microsurgery, which will be benefit from IIT's advanced system for robot-assisted laser microsurgery and from its long-standing collaboration with renowned ENT surgeons.

Requirements: background in engineering, computer science or related disciplines; interest in the design, implementation and assessment of teleoperation systems for tele-mentoring and tele-surgery. Experience in teleoperation, software development and augmented-reality would be beneficial for this PhD. The candidate must be fluent in both spoken and written English.

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23. Robot-Assisted Microsurgery

Tutors: Dr. Leonardo Mattos, Dr. Nikhil Deshpande

Department of Advanced Robotics (ADVR – IIT)
https://www.iit.it/research/lines/advanced-robotics

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 microsurgery. It will build upon results from IIT's Biomedical Robotics Lab to create the next generation of robotic systems for high precision / high quality microsurgeries. This will involve the mechatronic design and control of a new robotic instruments, as well as the evaluation and testing of new systems in collaboration with our partner surgeons. Application areas include ENT and pediatric surgery. During this PhD program 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 would be beneficial for this PhD. The candidate must be fluent in both spoken and written English.

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

24. Sensing and Automation in Robotic Surgery

Tutor: Dr. Leonardo Mattos, Dr. Veronica Penza

Department of Advanced Robotics (ADVR – IIT)
https://www.iit.it/research/lines/advanced-robotics

Description: Technology can go a long way toward improving the safety and quality of surgeries. At IIT's Biomedical Robotics Laboratory, we are pursuing these goals through the development of novel robotic devices, sensors, automatic controllers and supervisory safety systems. The PhD program will be part of ongoing research on enhancing the detection and microsurgery operations for the treatment of diseases in the upper airways. Currently the group is developing robotic technologies for micro-laparoscopy and for endoscopic surgery. Both applications offer a vast opportunity for research in sensing and automation. The specific research topic of the successful candidate will be selected based on the students background and interests. It may involve, for example, research in real-time tumor detection, surgical planning, surgical automation, shared-control, and augmented reality. The research will involve close collaboration with partner clinicians and technology end-users, allowing the student to develop expertise both in engineering (biosensors, actuators, control systems) and ergonomics (human factors, usability, human-computer interaction).

Requirements: background in engineering, computer science or related disciplines; interest in the design, implementation and evaluation of assistive systems for surgical applications. Experience in one or more of the following areas will be considered a plus: Computer vision, robotics, medical devices. The candidate must be fluent in both spoken and written English.

Contacts: leonardo.mattos@iit.it; veronica.penza@iit.it

25. Tele Human-Machine Interaction Interfaces for Advanced Robotic Teleoperation

Tutors: Dr. Nikhil Deshpande, Prof. Darwin Caldwell

Department of Advanced Robotics (ADVR – IIT)
https://www.iit.it/research/lines/advanced-robotics

Description: In some work environments, e.g., nuclear, chemical, search-n-rescue, construction/demolition, submarine tasks, there can be extreme risks to the health and safety of workers. Robots and robotics can be an obvious solution to the human risk. Although the robot may be able to physically perform most of the tasks, it lacks the cognitive ability to problem solve in complex environments. An advanced, intelligent user interface(s) linked to dexterous walking and manipulation 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 augmented reality and virtual reality systems as part of the master teleoperation station software and hardware, providing an immersive 3D user interaction experience. The project will use, develop, and integrate advanced technologies on tele-locomotion and haptic tele-manipulation for robots in high-risk environments. The project will build on the strong existing technological capabilities in the Department of Advanced Robotics (ADVR), acquired through the successful implementation of various high-tech projects in this field. The technical know-how of previous projects, including HyQ, WearHap, µRALP, Robo-Mate, and WalkMan, will contribute to the development of an advanced, intuitive teleoperation user interface.

Requirements: The successful candidates will have a Master's degree in Computer Science, Computer Engineering, Mechatronics, Robotics, or equivalent and will be able to work both in a team and independently. Strong competencies / interest in human-machine interface design, C/C++ programming, and mechatronics are required for admission. The candidates must be fluent in both spoken and written English. Experience with haptic teleoperation devices and/or with Virtual Reality development, Augmented Reality interfaces, Qt, Unity 3D, ROS, is a plus. *Note: It is compulsory to prepare a research proposal on this topic.

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26. Improving Reproducibility in Learning Physical Manipulation and Interaction Skills

Tutors: Darwin Caldwell, Fei Chen

Department Autonomous Mobile Manipulation Group (AutoMAP), Department of Advanced Robotics (ADVR)
https://www.iit.it/it/research/lines/advanced-robotics

Description: The acquisition of manipulation skills in robotics involves an elaborate combination of object recognition, action-perception coupling and physical interaction with the environment and even human beings. Several learning strategies have been proposed to acquire such skills. As for humans and other animals, such acquisition requires the robot learner to be exposed to varied situations. The robot needs to try and refine the skill many times, and/or needs to observe many attempts of successful movements by other agents, in order to be able to adapt and generalize the learned skill to new situations. Such skill is typically not acquired in a single training cycle, motivating the need to compare, share and re-use the experiments conducted each day by each individual robot.
The target of this topic is to enable the learning of manipulation skills from simulation to physical world, with an innovative toolset of components comprising: 1) a simulator with realistic rendering of variations allowing the creation of datasets and the evaluation of algorithms in new situations; 2) an interface (e.g., bilateral robot, or mind control device) to intuitively interact with a mobile manipulator robots within their virtual environments, in order to teach robots various object manipulation skills in a shared-control manner; 3) Deep reinforcement learning methods allowing learning action-perception coupling with the image input and 4) Transfer learning enabling robots to adapt learned skills from virtual simulators to physical scenario, e.g., robotic manipulation, human and robot collaboration.
As use case, we will study the scenario of remote maintenance work in hazardous environment (CERN: http://www.euroc-project.eu/index.php?id=automap) and agriculture robot application for grapevine winter pruning (VINUM: vinum-robot.eu).

Requirements: background in robotics, computer science, electrical engineering or mechanical engineering. Understanding of robot kinematics and dynamics, basic experience using game engines (e.g., Unity3D, Unreal Engine), strong background in computer vision and deep learning, programing skills with TensorFlow using Python and C++ skills. Spirit of team working and passionate for robotics. (Robotics and simulation: 30%, Robot vision and deep learning: 50%, Robot Learning: 20%)

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27. Skippy: The Superhuman Athletic Robot

Tutors: Roy Featherstone

Department of Advanced Robotics (ADVR – IIT)
https://www.iit.it/research/lines/advanced-robotics

Description: If the best electric motors can pack the power of a horse into the mass of a squirrel, and the best composite materials are far stronger and lighter than bone, then why aren't our best robots already exhibiting superhuman athletic performance? This project aims to close the gap between the actual performance of today's robots and the amazing performance that they ought to have. The key is to design and build an extremely simple robot, called Skippy, always with the idea of achieving the greatest possible performance out of its component parts. Skippy will be able to hop 4 metres high, somersault, balance on a point, and exhibit many other difficult motor skills (see http://royfeatherstone.org/skippy). It will also be able to crash-land on its head after making a mistake, and get up again unaided and undamaged. Skippy is a pioneer of physical performance. It is not designed to perform economically or socially useful tasks, but simply to reach and explore the limits of physical performance that should be possible with today's technology.

Requirements: background in robotics, mechatronics, computer science, or related subjects, familiarity with tools such as Matlab and Simulink, and an aptitude for practical dynamics and control.

Contacts: roy.featherstone@iit.it

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

Tutors: Ferdinando Cannella, Carlo Canali, 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: Nowadays the manufacturing is facing an urgent demand on automation upgrade to meet the requirements from various types of manufacturing industry. One of the key features is replacing robots with human beings. Robotic manipulator, widely used in industry, plays an important role to accomplish this task. As a consequence, it is very important to design novel End-effectors or robotic grippers/hands with variety of functionality so that the robot can grasp and manipulate different assembly objects. Goal of this PhD is to design and build novel industry-level robotic end-effector based on the new concept developed by customers and researchers. That means a virtual prototype of this device will be done in order to simulate the manipulation, so the best solution will be found quicker, because few physical prototyping will be necessary.
The manipulator design will be based on the experience obtained from previous projects, but also is inspired from the nature of human beings hands or other similar bio-mechanisms. Since it is very complicated to design a bio-inspired robotic mechanism, virtual prototyping development (co-simulation that involves multi-body and finite element and control) is required as a basic skill.
Moreover the research is carried out within the ADVR that concentrates on an innovative, multidisciplinary approach to humanoid design and control, and the development of novel robotic components and technologies. This encompasses activities from both the hard and soft systems areas of robotics. Thus the industrial developments exploit these advances that permit to design the humanoid-like robots suitable for the industrial plants. 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 (Fameccanica, AvioAero, EuroC, Autorecon, Archaps, etc.) inspired from the nature of human beings hands, arms and/or other similar bio-mechanisms.
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). 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.

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

Reference:

- Nahian Rahman, Luca Carbonari, Carlo Canali, Darwin Caldwell and Ferdinando Cannella, "Dexclar: A Gripper Platform for Payload-Centric Manipulation and Dexterous Applications" accepted to the Proceedings of IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), 2017, Vancouver, Canada, September24 - September 28.
- Ferdinando Cannella, Mariapaola D'Imperio, Carlo Canali, Nahian Rahman, Fei Chen, Daniele Catelani, Darwin G. Caldwell, Jian S. Dai, "Origami carton folding analysis using flexible panels", (2016) Mechanisms and Machine Science, 36, pp. 95-106. DOI: 10.1007/978-3-319-23327-7_9,

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

29. 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.

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