PhD Program in Bioengineering and Robotics

Curriculum Cognitive Robotics, Interaction and Rehabilitation Technologies
Research themes

In the spirit of the doctoral School on Bioengineering and Robotics The PhD Program for the Cognitive Robotics, Interaction and Rehabilitation technologies curriculum provides interdisciplinary training at the interface between technology and biomedicine. The general objective of the program is to form scientists and research technologists capable to deal with multidisciplinary projects at the interface between technology and life-sciences.

The themes offered this year as part of this curriculum are supported by the Robotics, Brain and Cognitive Sciences Department of the Italian Institute of Technologies (RBCS) and by the Department of Informatics, Bioengineering, Robotics and System Engineering (DIBRIS).

In particular, the science of action and interaction is the research stream unifying the multidisciplinary environment of the "Robotics, Brain and Cognitive Sciences" (RBCS) department of IIT (www.iit.it/rbcs). After establishing iCub as one of the more successful humanoid robot and fostering the birth of the iCub-Unit at IIT, the focus of RBCS has evolved toward the study of the embodied and cognitive interaction between humans and machines and its technological and social outcomes. In the spirit of the doctoral School on Bioengineering and Robotics, in RBCS we are merging top-level neuroscience research and top-level robotics research by sharing fundamental scientific objectives arising from the study of speech recognition and language, the technological development of Brain Machine Interface, the foundations of physical and social interaction, the exploitation of sensory and motor rehabilitation. RBCS is where the iCub humanoid robot is used to investigate the language of embodied, human-human and human-robot communication and it is also the place where studies of how visual, haptic and tactile integration develops in normal as well as sensory-impaired children. RBCS is where technologies for robotic rehabilitation devices are developed and tested in joint labs established in clinical environments, and it is also the place where electrophysiological experiments are performed to study human-machine interaction at the neural level to realize bi-directional direct communication between the brain and artificial systems.

DIBRIS (www.dibris.unige.it) has a long date tradition in investigating and applying embedded approaches to perception, cognition, and action to build autonomous and semi-autonomous intelligent systems operating in the real-world in close cooperation - or even in symbiosis -- with humans. In this general spirit, research at DIBRIS focuses on different problems, methodologies and application scenarios, ranging from visual perception and knowledge representation to the interpretation of social cues in living beings, from autonomous exploration in unstructured or crowded scenarios to assistive and interactive technologies for assessment and rehabilitation of sensorimotor and motor skills.

The ideal candidates are students with a higher level university degree willing to invest extra time and effort in blending into a multidisciplinary team composed of neuroscientists, engineers, psychologists, physicists working together to investigate brain functions and realize intelligent machines, rehabilitation protocols and advanced prosthesis.

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

1. Tactile sensory supplementation systems

Tutors: Dr. Luca Brayda

Department: RBCS (Istituto Italiano di Tecnologia)
http://www.iit.it/rbcs

Description: Multisensory perception is at the basis of construction of cognitive maps of our surroundings. However, sensory deprivation, such as blindness or deafness, prevents efficient multisensory integration. To solve this issue, residual sensory abilities can be enhanced, but the way to do it is far from being clear, especially for the tactile modality, which is common to individuals affected by visual or hearing impairment. Touch-based displays are a growing class of sensory aids, which are gaining more and more attention, because technological solutions are today lighter, cheaper, more efficient, and because touch is a private way of delivering information. However, there is no agreement about the optimal location and stimulation pattern.

The objective of this project is to study how tactile feedback on different parts of the human body can reinforce residual visual or acoustic information about maps surrounding a person. Rather than traditional sensory substitution systems, the research will focus on sensory supplementation, where the tactile modality serves to enhance poor vision or weak hearing capabilities.

The candidate will review and extend the state of the art in assistive solutions and devices in the field of touch. (S)he will design and carry on psychophysical tests with both normal and sensory impaired subjects and validate prototypes of assistive devices in a clinical setup.

Requirements: Ideal candidates should have a degree in Psychology, Cognitive Neuroscience, Biomedical Engineering or equivalent and have strong communication and team-working skills. Good programming skills and ability to use statistical toolboxes (Matlab,R) will represent a preferential title.

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2. Creation and evaluation of new audio devices for visually impaired people

Tutors: Dr.Monica Gori, Dr.Luca Brayda

Department: RBCS (Istituto Italiano di Tecnologia)
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Description: supporting smart and personalized inclusion of persons with sensory and motor disabilities is one of the big societal challenges of our society. Visual disability is associated with spatial and mobility impairments leading to social exclusion. In particular our recent scientific results show that in absence of vision also some auditory and tactile skills are impaired (e.g. Gori et al. 2014). The main goal of this project is to gain knowledge about how acoustic spatial cues can maximize information about the spatial structure of the environment. The passive or active nature of sound production, its spectral and temporal characteristics and its ergonomic features will be investigated. Within the RBCS department our team is now developing new technologies and related rehabilitation procedures based on audio feedback to improve the spatial cognition of visually impaired people. Therefore, a second objective of the project is to integrate acoustic cues into potential rehabilitation devices. The ultimate goal of the research is to reduce the risk of exclusion for disabled individuals.

Requirements: The PhD student will be involved in designing and performing psychophysical experiments in adults with and without visual disability with the goal of creating rehabilitation programs and evaluate the benefit obtained. A background in biomedical engineering and basic neuroscience and programming skills are required.

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3. Cooperation/Competition in a haptic dyad

Tutor: Prof. Pietro Morasso, Dr. Jacopo Zenzeri

Department: RBCS (Istituto Italiano di Tecnologia)
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Description: There is a growing interest in physical coupling between humans. For example, it was found that haptic interaction with a human partner leads to a better performance than individuals in tasks involving either motor or force control [1]. One reason may be that mutual haptic feedback can enhance the process of intention integration between the two partners at an implicit level. Moreover, physical interactions are consistently beneficial to the interacting individuals and enable them to improve their motor performance both during and after interactive practice [2]. This makes dyadic interaction extremely appealing from a motor learning perspective, since the use of paradigms that promote dyadic motor adaptation can be of great advantage during training and also in rehabilitation. However, it is not yet clear how dyadic physical interaction shapes motor adaptation and the mechanisms that mediate intention understanding are still poorly understood. A deeper knowledge in these areas is fundamental to advance into the development of haptic platforms for interactive systems and protocols for effective haptic communication, with the goal of modeling interactive strategies & adaptation mechanisms and ultimately designing in an optimal way haptic systems that support effective and versatile dyadic paradigms of physical interaction.

Requirements: a degree in Computer Science Engineering, Bioengineering or equivalent, with high interests in human sciences. Expertise in Virtual Reality, Assistive Technologies and Haptics will constitute factors of preference.

References: J. Masumoto and N. Inui, “Two heads are better than one: both complementary and synchronous strategies facilitate joint action.,” J. Neurophysiol., vol. 109, no. 5, pp. 1307–14, Mar. 2013.

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4. Acoustic-articulatory modeling for automatic speech recognition

Tutors: Dr. Leonardo Badino, Prof. Lorenzo Rosasco, Prof. Luciano Fadiga

Department: RBCS (Istituto Italiano di Tecnologia)
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Description: State-of-the art Automatic Speech Recognition (ASR) systems produce remarkable results in some scenarios but still lags behind human level performance in several real usage scenarios and often perform poorly whenever the type of acoustic noise, the speaker's accent and speaking style are "unknown" to the system, i.e., are not sufficiently covered in the data used to train the ASR system.

The goal of the present theme is to improve ASR accuracy by learning representations of speech that combine the acoustic and the (vocal tract) articulatory domain as opposed to purely acoustic representations, which only consider the surface level of speech (i.e., speech acoustics) and ignore its causes (the vocal tract movements). Although in real usage settings the vocal tract cannot be observed during recognition it is still possible to exploit the articulatory representations of speech where phonetic targets (i.e., the articulatory targets necessary to produce a given sound) are largely invariant (e.g., to speaker variability) and complex (in the acoustic domain) speech phenomena have simple descriptions (King et al. 2007).

Joint acoustic-articulatory modeling will be applied in two different ASR training settings: a typical supervised machine learning setting where phonetic transcriptions of the training utterances are provided by human experts, and a weakly supervised machine learning setting where much sparser and less informative labels (e.g., word-level rather than phone level labels) are available.

Requirements: The successful candidate will have a degree in computer science, bioengineering, physics or related disciplines, and a background in machine learning.

Reference: King, S., Frankel, J., Livescu, K., McDermott, E., Richmond, K., Wester, M. (2007). "Speech production knowledge in automatic speech recognition". Journal of the Acoustical Society of America, vol. 121(2), pp. 723-742.

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5. Group sensorimotor communication and interaction

Tutors: Dr. Alessandro D'Ausilio, Dr. Leonardo Badino, Prof. Luciano Fadiga

Department: RBCS (Istituto Italiano di Tecnologia)
http://www.iit.it/rbcs

Description: Human perception, action and cognition are geared to enable successful coordination and communication with others. The MNIlab devises computational methods to quantify the information flow between kinematic signals acquired from a small group of interacting participants (D'Ausilio, Badino et al. Plos One 2012; Badino, D'Ausilio et al. Neuropsychologia 2014). In fact, body movement is the key component of non-verbal communication (Fadiga, Craighero, D'Ausilio, Ann NY Acad Sci 2009; Riley et al., Front Psychol 2011).

The successful candidate will work on the extension and consolidation of this methodology to different scenarios (i.e. small group behavior during meetings or sport activities) and the development of the analytical tools to extract in real-time the quantitative flow of sensorimotor communication. The research program will be complemented by basic neurophysiological research (i.e. TMS, EEG, tCS) on how, why and when humans send and receive implicit non-gestural messages during behavioral coordination (Nummenmaa et al., J Neurosci 2014; Bourguignon et al., Neuroimage 2011). All these aspects will be critical to implement the next generation of biologically inspired automatic action and communication recognition systems. These automatic systems will be essential to enhance or establish (in case of disabilities or social deviance) an augmented human-human coordination and human-robot interaction.

Requirements: The successful candidate will have a background in computer science or engineering, programming skills as well as a strong motivation in bridging the gap between technology and cognitive neuroscience. Neural and kinematics signal processing skills are a plus. Attitude for problem solving.

Reference: Badino L., D'Ausilio A., Glowinski D., Camurri A., Fadiga L. (2014) Sensorimotor communication in professional quartets. Neuropsychologia, 55(1), 98-104.

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6. Control of multi-body dynamics with compliant contacts

Tutors: Dr. Francesco Nori

Department: RBCS (Istituto Italiano di Tecnologia)
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Description: state of the art robotic applications such as industrial assembly lines involve robots fixed to the ground. Foreseen applications ask for autonomous robots capable of freely moving across the environment and, quite often, balancing on multiple contact points to cope with uneven and unstable terrains. In order to bridge the gap between future applications and the current state of the art, research in robotics has been recently focused on the problem of controlling free-floating articulated bodies. Within this context, the iCub humanoid recently acquired the capability of simultaneously controlling its body posture in relation to the interaction forces at several contact points (https://www.youtube.com/watch?v=jaTEbCsFp_M). Current state of the art does deal with rigid contacts and rigid body dynamics [1]. Yet, novel robotic research on impact dynamics shows that rigid contact models may lead to unrealistic predictions of rigid body motions, which raises the question of whether or not a compliant contact may avoid these predictability problems. Nevertheless, controlling soft robots is still an open problem. In this research project, the candidate will advance the state of the art by studying how to deal with non-rigid dynamics subject to compliant contacts. Case studies concern the problem of dealing with elasticity in series with the actuator (i.e. SEA) and the problem of controlling forces at non-rigid contacts. Validation scenarios include walking on soft carpets and grass (like terrain), sitting and standing up from a soft sofa. The implementation of the above control strategies will be conducted on the iCub humanoid robot, which represents an ideal experimental platform for the research goal thanks to its whole-body distributed force and tactile sensing.

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

Reference: Righetti, Ludovic, et al. "Optimal distribution of contact forces with inverse-dynamics control." The International Journal of Robotics Research 32.3 (2013): 280-298.

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7. Simultaneous multimodal force and motion estimation

Tutors: Dr. Francesco Nori

Department: RBCS (Istituto Italiano di Tecnologia)
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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 a prototype of a force and motion capture system for humans. In order to overcome the limitations of available technologies, the system will be based on multiple sensor modalities (e.g. vision, touch, force, gyro, accelerometers, electromyography) fused in a Bayesian sense. The project is highly interdisciplinary and technological. As such, it will be conducted in collaboration with other departments such as PAVIS (sensor calibration and modeling, Alessio Del Bue and Vittorio Murino), iCub Facility (touch sensor, Lorenzo Natale and Giorgio Metta), IIT@POLITO (electromyography, Paolo Ariano e Marco Paleari) and ADVR (exoskeleton implementation, Jody Saglia).

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: (at most one ref)
[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

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8. Biocompatible, soft and low noise in-vivo neural electrodes

Tutor: Dr. Davide Ricci, Prof. Luciano Fadiga

Department: RBCS (Istituto Italiano di Tecnologia)
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Description: To carry out really long term neurophysiological and Brain Machine Interface studies, improvements in the properties of chronic electrode implants are required. Several issues, involved in acute and chronic term tissue reactions, have been identified and need to be addressed: support and electrode mechanical stiffness, insertion techniques, tethering forces, materials biocompatibility.

Project: The candidate will be involved in the design, fabrication and test of microelectrode arrays - intracortical and epicortical - for both recording and stimulation in rats and primates. Activities will include the development of: variable stiffness biocompatible polymers for electrode support and insulation, nanomaterials for low noise electrical interfaces, biocompatible hydrogels for nanomaterial encapsulation and tissue interface, ultrathin flexible and compliant conductors for wiring. In-vivo validation will be carried-out within the research team.

Requirements: we are preferably seeking candidates with a background in Material Science, Chemistry, Bioengineering or Physics. Previous experience in wet lab, polymer processing or clean room techniques is strongly welcomed. A basic neuroscience knowledge is a plus.

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9. Multimodal recording of neurophysiological data from the human cortex

Tutors: Prof. Luciano Fadiga, Prof. Mirian Skrap

Department: RBCS (Istituto Italiano di Tecnologia)
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Description: Recording/decoding the information from the human brain represents an interdisciplinary challenge of primary relevance. Mainly because of the invaluable applicative consequences that this will produce on clinical practice and on neurophysiological knowledge. In recent times has become possible to record brain signals from the exposed cortex of awake patients by multielectrode microarrays. Despite some invasivity, this approach allows to extract more information than that of classical EEG recordings, particularly for the realization of brain-computer interfaces. An efficient signal analysis is fundamental to optimize the recording systems, particularly as far as the optimization of temporo-spatial resolution is concerned. The candidate will therefore be involved in recording and analyzing neurophysiological data from sensorimotor areas of the human brain of awake patients. Electrophysiological data will be correlated with neuroimaging and behavioral observations as well (intracortical microelectrodes, epicortical electrocorticography, fMRI, DTI).

Requirements: Degree in Medicine, Biology, Engineering, Computer Science, Physics together with programming capabilities (C++, Matlab, Labview) and basic knowledge on neurophysiology. Attitude for problem solving.

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10. Learning visual cues of interactions for humanoid robots

Tutors: Prof. Francesca Odone
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Tutors: Prof. Giulio Sandini, Dr. Alessandra Sciutti
Department: RBCS (Istituto Italiano di Tecnologia)
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Description: Since the earliest stage of their development, humans learn how to interact with other people. More specifically, babies begin to decode their own movements by acquiring visual evidence of the result of their motor commands. Then, as soon as they learn to perform a given action they also start to anticipate its outcome even when they see it executed by others.
Hence, the knowledge accumulated by acting is exploited to understand and predict someone else's intention.

The general goal of this project will be to provide iCub with a similar ability that will guarantee a more natural and proficient interaction with human users.

The pipeline of the computational system includes an attentional module able to localize the portion of the scene containing biological motion. Then, iCub exploits this information to focus on the selected area and to describe it more precisely using its stereo system.

The visual properties of the observed movements will be used by the robot to decode the intentionality of the interacting partner by using machine learning techniques.

View-invariance will be one of the crucial aspects of the system, together with the capability of inferring information about the 3D orientation of an agent.

Requirements: degree in robotics, bioengineering, computer science, computer engineering, or related disciplines, attitude for problem solving, basic skills on c++ programming. A background on computer vision and machine learning is an asset.

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11. Development of devices and methods for investigating lower limbs impairment in individuals with multiple sclerosis at the neural, behavioral and muscle synergy level.

Tutors: Maura Casadio
Department: DIBRIS, University of Genoa
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Prof. Matilde Inglese
Department of Neurology, Radiology and Neuroscience
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Description: Multiple sclerosis is the most common cause of non-traumatic neurological disability in young adults. Lower limbs impairment has a huge impact on locomotor disability and quality of life in MS patients. Although both brain and spinal cord are affected by the disease-related pathological processes, the mechanisms leading to irreversible disability or recovery are poorly understood. This is in part due to the lack of precise metrics for the clinical assessment of the lower limbs.

This project aims at developing quantitative measures and devices to evaluate lower limbs function at neural, muscular, and behavioral level. These newly developed metrics will be used to understand the mechanisms leading to disability and to monitor lower limbs function changes over time and in response to medical and rehabilitative treatments. MS patients with gait impairment will be evaluated during over-ground, treadmill-based and robot-assisted walking and with different levels of weight support to take into account the effect of fatigue. We will study movement reorganization and exploitation of motor system redundancy as well as the effects of sensory-motor deficits and of different feedback on both patients' motor performance and rehabilitation outcome.

Finally, the research will have a special focus on the development of MRI-compatible devices to evaluate the brain and spinal cord neural correlates of motor performance and treatment-induced changes.

Requirements: Knowledge of Neuroscience, Biomedical Engineering, Physiology, Neuroimaging

Reference: Waubant E, Cross A. MS and related disorders: groundbreaking news.Lancet Neurol. 2014 Jan;13(1):11-3

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12. Technology-assisted rehabilitation inspired by the cooperative strategies observed in physical human-human interaction

Tutors: Prof. Vittorio Sanguineti

Department: DIBRIS, University of Genoa
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Description: Robots (and other interactive technologies) are used in neuromotor rehabilitation to facilitate the development of compensatory strategies that counteract or minimize the effects of the actual impairment. It is unclear, however, what modalities of human-robot interaction are most effective in maximizing the amount of recovery and in making it more permanent.
The proposed research will address the design of 'optimal' control strategies for rehabilitation robots by taking inspiration from the cooperative strategies that emerge in physical human-human interaction tasks. The research will involve experiments with human subjects (physical human-human interaction between both healthy and impaired subjects) using haptic interfaces, on-line analysis of movements and their neural correlates (EMG, EEG). To characterize interactions strategies we will formulate computational models, based on optimal control, game theory and reinforcement learning.
Based on these findings, we will then develop biomimetic robot controllers that mimic the observed human 'optimal' interaction capabilities, with the aim of maximizing neuromotor recovery.
The expected outcome will be a novel type of rehabilitation device, which gradually develops an internal model of the user's motor capabilities and on its basis it is capable of delivering optimal, highly personalized types of exercise that continuously adapt to user's performance.

Requirements: background in bioengineering, computer and/or electronic engineering, computer science, physics or related disciplines. Interest in understanding/learning about sensory and motor neuroscience. Attitude for experimental work, problem solving, computational modeling.

Reference: N Jarrasse, V Sanguineti and E Burdet (2014), Slaves no longer: review on role assignment for human-robot joint motor action. Adaptive Behavior. Published online before print September 2, 2013, doi: 10.1177/1059712313481044

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