University of Genova – Italian Institute of Technology

Doctoral School on "*Robotics, Neuroscience and Nanotechnology*":

Academic Year 2007-2008

ANNEX A

RESEARCH THEMES

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1 INTRODUCTION TO RESEARCH THEMES

The Italian Institute of Technology (IIT) is a research institution in Italy that is currently in an advanced start-up phase. The fellowships assigned by IIT to the University of Genova are part of the start-up strategy of the Institute and have the specific goal of forming the first generation of IIT's research fellows.

Following the start of the Research Labs in the IIT's Headquarters in Genova Morego and the appointment of the first scientists, this year's research topics are proposed by the Research Directors and their senior collaborators. The candidates are asked to prepare a research project of their choice with explicit reference to the Theme proposed. The soundness of the project will be part of the evaluation process and will be considered preferential for the choice of the individual scientific theme that will be made jointly by the tutor and the candidate.

The themes are structured with reference to the proposing Research Directors:

1. Neuroscience and Brain Technologies (Prof. Fabio Benfenati – fabio.benfenati@iit.it)
2. Robotics, Brain and Cognitive Sciences (Prof. Darwin Caldwell – darwin-caldwell@iit.it)
3. Robotics, Brain and Cognitive Sciences (Prof. Jean-Guy Fontaine – jean-guy.fontaine@iit.it)
4. Robotics, Brain and Cognitive Sciences (Prof. Giulio Sandini – giulio.sandini@iit.it)

Each application must make specific reference to one of the research themes proposed.

2 NEUROSCIENCE AND BRAIN TECHNOLOGIES (PROF. FABIO BENFENATI)

Theme 2.1: Neuronal Determinants of Synaptic Transmission and Plasticity

Tutor: Dr. Andrea Barberis
N. of available positions: 1

The amplitude and the shape of the post-synaptic current are important determinants of information integration in the CNS. Their remarkable variability observed at many synapses in the CNS represents a prerequisite for a fine modulation of the network coding, plasticity and development. Despite intensive investigations, the factors underlying such variability have not been fully elucidated. The amplitude and the shape of the unitary synaptic current are believed to depend upon a number of pre- and post-synaptic factors including i) amount and time course of the agonist released in the synaptic cleft, ii) number and relative location of the post-synaptic receptors at the post-synaptic density, iii) gating properties of the post-synaptic receptors. While there is general agreement that the amplitude of the synaptic current is efficiently modulated by changing the number of post-synaptic receptors, the contribution of pre-synaptic factors remains elusive. It has been shown that, after the release of the vesicle content, the extremely brief neurotransmitter exposure makes the post-synaptic receptors be activated in conditions of strong non-equilibrium. This implies that fine changes in the synaptic neurotransmitter exposures can result in noteworthy changes of the post-synaptic response amplitude and/or duration. The aim of the research will be to understand the interaction and the relative contribution of pre- and post- synaptic factors in shaping the inhibitory and excitatory unitary post-synaptic current. The main topics that will be investigated using a combination of advanced electrophysiology and live imaging techniques are the following: (i) study of the gating properties of the post-synaptic receptors at inhibitory synapses; (ii) study of the variability of the quantal size; (iii) study of the relationship gating-mobility of post-synaptic receptors; (iv) real-time visualization of the synaptic release; (v) lateral diffusion, exocytosis and endocytosis.

For further details concerning the research project, please contact: andrea.barberis@u-bordeaux2.fr

Theme 2.2: Role of GABAergic Transmission in Neuronal Development

Tutor: Dr. Laura Cancedda
N. of available positions: 1

We will investigate the role of GABAergic transmission during cortical development under physiological and pathological conditions *in vivo* and *in vitro*. The project will focus on

1. Role of GABAergic transmission in cortical neuron migration. We propose to use the *in utero* electroporation technique to investigate the role of the different GABA receptors on cortical migration of a subpopulation of newly generated neurons, reducing the risk of potential compensatory mechanisms in treated animals. We will knock down the expression of the different GABA receptors by transfecting neuronal progenitors with small interference RNA to $GABA_{A,}$ $GABA_B$ or $GABA_C$ receptors. Notably, with the *in utero* electroporation technique we will transfect only glutamatergic but not GABAergic cells, allowing us to

examine the function of GABAergic transmission on developing glutamatergic neurons, leaving the endogenous GABA concentration unaffected.
2. Role of GABAergic transmission and mechanism of GABA action in morphological maturation of cortical neurons. Various in *vitro* studies on cell cultures demonstrated that neurite outgrowth is influenced by $GABA_A$ receptor activation in diverse systems, an effect that can be reproduced by agents that elevate GABA synthesis. We will investigate the first issue on cell cultures by treating cortical neurons with agonists and antagonists of GABA receptors and address the possible effect of these drugs on axon\dendrite initiation rather than simply growth by micropatterning of stripes of specific GABA receptor agonists and antagonists on the cell-culture substrates to generate preferential pathways along which neurons may extend their axons/dendrites.
For further details concerning the research project, please contact: cancedda@uclink.berkeley.edu

Theme 2.3: Role of Neurotrophins in Adult Neurogenesis

Tutor: Dr. Marco Canossa
N. of available positions: 1
New neurons are continuously generated from adult neural progenitor cells throughout life in the dentate gyrus of the hippocampus, and become synaptically integrated into the existing neural network. The physiological significance of this continuous renewal is largely unknown, in particular two key questions remain: are new-born neurons contributing in repairing the neuronal network by replacing dying mature neurons? or are they providing specific contributions to hippocampal functions? Brain-derived neurotrophic factor (BDNF) affects neuronal development by signaling through its cognate tyrosine kinase receptor, TrkB. In particular, TrkB is known to regulate the formation of the cerebral cortex, including neuronal dendritic differentiation. While BDNF have been found implicated in regulating the number of newborn neurons in adult dentate gyrus, it is not understood how Trk signaling regulates neuronal differentiation during the different phases of neuronal maturation and, subsequently, neuronal function. In this context we propose to investigate the role of BDNF and its receptors TrkB in adult neurogenesis of the dentate gyrus. Both viral transducing techniques and gene targeting in mouse lines will be used to investigate the role played by TrkB for the demand of functional integration of new born neurons. This will involve several aspects of new born neurons development an function as i) maturation of neuronal excitability, ii) synaptogenesis at both post and pre-synaptic sites, iii) synthesis and release of neurotransmitters and/or neuromodulators. In addition, by using the technology of multi-electrode array, we will investigate: i) the impact of neurogenesis on network activity; ii) the role of BDNF in the network formation; in cultured slices of mouse lines expressing reporter genes necessary to detect new born neurons.
For further details concerning the research project, please contact: marco.canossa@lrz.uni-muenchen.de ; marco.canossa@unibo.it

Theme 2.4: Neuronal Targets for Therapy of Neurodegenerative Diseases

Tutor: Dr. Evelina Chieregatti
N. of available positions: 1
Interest in neural plasticity is not limited to basic research but extends to medicine as well. Investigation in this area has already lead to significant progress, with understanding of basic brain mechanisms which are altered or defective in neurological diseases. The project focuses on two major topics:
1. Physiological role of alpha-synuclein (AS) in the nerve terminal and of the loss/gain of function of its mutated forms. We plan to analyze the effect of AS in processes that require active remodelling of actin cytoskeleton. The rate and the amount of synaptic vesicles exocytosis and recycling will be analyzed in neuroblastoma cells and in hippocampal neurons in which secretory granules and synaptic vesicles will be labelled with fluorescently tagged constructs both after AS transfection and in conditional transgenic AS mice. Investigation on the possible effect of AS on the assembly of intermediate filaments upon AS overexpression and during re-polymerization after disassembly by inhibitory peptides, will be first analysed in cell lines, then the formation of the new growth cones will be evaluated in the regenerating neuron after axotomy. Cells and neurons will be monitored by video-imaging, evanescent wave microscopy and recovery after photobleaching.
2. Identification of the sites of beta-cleavage of the amyloid precursor protein and purification of APP-carrying vesicles. The isolation of APP transport vesicles will be a key step for the molecular and cellular definition of these organelles, in particular to establish the possible presence of the secretases and to discover which proteins participate in their dynamics and in the regulation of their fusion. The aims of the project are to investigate whether BACE cleavage of APP occurs in the intracellular pathway from the Golgi complex to the surface, i.e. prior to its surface exposure and independently of the endocytic traffic and to isolate APP-rich

vesicles addressed to, or generated at the plasma membrane and internalized, from cells in which the two specific pool are enriched, and to establish their properties
For further details concerning the research project, please contact: chieregatti.evelina@hsr.it

Theme 2.5: Development of Neuro-Electronic Interfaces

Tutor: Dr. Marco Dal Maschio
N. of available positions: 1
The research will focus on two kinds of neuroelectronic interfaces: one designed for the "in vitro" studies on neuron networks based on multi transistor arrays and on the mechanism of photoconductive stimulation; the other for high resolution extracellular recordings and stimulation for "in vivo" brain implantations.
With the first approach, the possible applications of the photoconductive stimulation will be investigated as a "true" space-independent stimulation method for the presynaptic neuron, while simultaneously recording from the postsynaptic neuron by means of classical patch-clamp procedure. Particular interest will be focused on the possibility to implement such a stimulation method that needs a silicon substrate and the light excitation, in a custom design for a multi transistor array device in order to obtain a light controlled neuron stimulation while monitoring many cell at the same via transistor recordings. The mechanism of photoconductive stimulation will be studied also in order to evaluate its application for the delivery of molecules of interest inside neurons by inducing a localized electroporation. On the other side, the transfer of transistor array technology from the "in vitro" field to the "in vivo" application will be studied. This kind of research will focus on the development of such technological aspects for the implantation of devices complying with: position and spatial resolution requirements of recording sites, wiring of a high number of transistors, very small device size and design of a custom readout electronic. The experience deriving from 128x128 high resolution transistor array will be considered as the starting platform for the design of this new kind of devices.
For further details concerning the research project, please contact: meteorav@gmail.com

Theme 2.6: Role of miRNAs in Neuronal Function and Plasticity

Tutor: Dr. Davide De Pietri
N. of available positions: 1
The topic of the research will include the investigation of the role played by microRNAs and RNAi in the control of post-natal/adult mouse neurogenesis and neuronal network formation. Several miRNAs have been identified in neuronal cells, and multiple lines of evidence implicate miRNAs activity in the control of neuronal plasticity. The research project will focus on manipulation (by over-expression/inhibition) in primary neuronal cells (either from rat or mouse) the level/activity of specific miRNAs and will consist of the following topics: (i) *in vitro* manipulation of miRNAs in neuronal cells, investigation of the effects on synaptic plasticity and identification of miRNA targets and (ii) manipulation of miRNAs in intact mouse brain by conditional *Dicer* knockout or using techniques such as *in utero* electroporation, viral infection or transgenic mice expressing specific miRNAs precursors.
For further details concerning the research project, please contact: depietri@mpi-cbg.de

Tutor: Dr. Tatiana Tkatch
N. of available positions: 1
The project aims at investigating the function of miRNAs in synapse formation and plasticity and the behavioral consequences of such function. miRNAs that are expressed in synaptosomes will be identified by microarray or differential display. Next, targets of the confirmed candidate miRNAs will be identified. miRNAs sequences will be screened through available databases, and suitable candidates will be picked up. In addition, the 3' UTR regions of mRNAs encoding proteins participating in neurotransmitter release machinery and/or spine formation and maintenance will be searched for possible target sites of confirmed synaptic miRNAs. Finally, the role of a particular miRNA in synaptic plasticity would be tested by inhibition or over-expression of the miRNA in cultured neurons. To evaluate changes in synaptic plasticity, standard tests that evoke LTP and LTD will be employed. Moreover, miRNAs for their role in learning and memory. animals infected with viruses carrying a miRNAs with clear effects on LTP/LTD would be tested in behavioral paradigms.
For further details concerning the research project, please contact: t-tkatch@northwestern.edu

Theme 2.7: Role of Recognition Molecules in Neural Network Formation and Activity

Tutor: Dr. Alexander Ditjatev
N. of available positions: 2
Formation of synaptic connections during development and their modifications by experience are important steps in wiring of the brain. These processes require molecular recognition cues - cell adhesion and extracellular matrix molecules – to guide interactions between the growth cones and environment, through which they navigate. In the last decade, advances in molecular and cellular biology combined with the development of fluorescence microscopy tools to visualize synapses and synaptic molecules in live neurons have revealed many intriguing and unexpected findings regarding the dynamics of synapses formation. Studies by a number of researchers, including my group, have identified several recognition molecules as critical glycoprotein components of synapses. The planned research is targeted to identify recognition molecules involved in formation of specific subtypes of synapses, to dissect their functional roles and use this knowledge to discover drug-like compounds capable to compensate impaired synaptic functions in animal models of major neurological and psychiatric disorders. The main techniques will include patch-clamp, extracellular and multisite electrophysiology coupled with confocal imaging and molecular biology.
For further details concerning the research project, please contact: dityatev@zmnh.uni-hamburg.de

Theme 2.8: Determinants of Neuronal Polarity in Vitro and in Situ

Tutor: Dr. Annette Gartner
N. of available positions: 1
The most critical initial step in the formation of neuronal networks is the establishment of proper axonal-dendritic connections, which must be temporally and spatially tightly regulated. Neurons establish a striking polarity with a single axon transmitting signals and with multiple dendrites receiving them. This neuronal polarity is the base for the establishment of proper connections in the brain and therefore my major goal will be to understand which exogenous and endogenous factors contribute to the determination of the single axon and multiple dendrites and how the site and time of axonal outgrowth is regulated. The main aim of the project is to understand at which developmental stage neurons establish their polarity in the *in situ* situation and by which extrinsic and intrinsic factors this is regulated. The polarity of neurons and their precursors is essential for cell fate decisions, for directed migration within the cortex, and for the wiring of the brain. Thus failures in neuronal polarity establishment and migration lead to several mental diseases. The project includes studies in the development of neuronal polarity *in situ* in cortical embryonic slice cultures in order to understand how the polarity of precursors, migrating neurons and axon-extending neurons are interconnected. It will also investigate the extent to which the relevant extrinsic and intrinsic signals contribute to polarity using reductionistic models such as dissociated neurons, patterned substrates and slice overlay assays.
For more details concerning the project, please contact: Annette.Gaertner@med.kuleuven.be

Theme 2.9: Mechanisms of Experience-Dependent Cortical Plasticity in Vivo.

Tutor: Dr. Paolo Medini
N. of available positions: 1
Ocular dominance, cross-modal and experience-dependent plasticity will be studied *in vivo* with cellular resolution using sensory deprivations or focal lesions in the primary visual cortex (V1) of experimental rodents. Techniques will include electrophysiological recordings (in vivo whole cell recordings allowing assessment of subthreshold and suprathreshold activity of recorded neurons), live imaging techniques (intrinsic signal imaging and voltage sensitive dye imaging to measure the spatio-temporal activation of the neocortex and in vivo two photon calcium imaging) neuroanatomical techniques (3-D reconstructions of dendritic and axonal structure of recorded byocitin labeled neurons).
For more details concerning the project, please contact: Paolo.Medini@mpimf-heidelberg.mpg.de

Theme 2.10: Neurophysiology and Neuropathology of Experience-Dependent Plasticity

Tutor: Dr. Raffaella Tonini
N. of available positions: 1
The research project aims to studying the function of specific receptors and signal transduction pathways for drugs of abuse. The in-vivo exposure to drugs of abuse and their behavioural effects will be used as a model for investigating experience-dependent alterations in neuronal circuits and synaptic plasticity under physiological and pathological conditions. The involvement of specific signal transduction pathways will be tested using transgenic animal models lacking intracellular molecular components and by pharmacological

approaches.Experiments will utilize electrophysiological techniques (intracellular and extracellular recordings) on brain slices combined with in-vitro and in-vivo pharmacology and imaging. Experience in electrophysiology and/or imaging would be advantageous.
For further details concerning the research project, please contact: r.tonini@ucl.ac.uk

3 ROBOTICS, BRAIN AND COGNITIVE SCIENCES (PROF. DARWIN CALDWELL)

The work covered within this research programme will encompass a broad range of engineering and related disciplines with the goal of developing the key technologies and techniques needed to progress research in the area of humanoid robotics

Theme 3.1: Actuation and Power Systems

Tutors: Dr. Nick Tsagarakis, Dr. Bram Vanderborght
No. of available positions: 3
Actuation systems, power sources and storage of energy are vital and often overlooked features of robotic and humanoid systems. Researchers working in this area will explore novel actuation technology (braided pneumatic Muscle Actuators, Polymeric actuators, Shape Memory Alloys, compliant and hybrid actuation) and the enhancement of current technologies (hydraulics, ER Fluids, MR Fluids, piezoelectric motors). The actuation systems will be incorporated into a new generation of robots having the structure, characteristics and behaviour of humans, hominoids, and/or animals. Previous experience with these technologies would be an advantage but the programme is open to researchers with a strong background in any physical science or engineering discipline.

Theme 3.2: Haptics and Advanced Interfaces

Tutors: Dr. Nick Tsagarakis, Dr. Andrea Brogni
No. of available positions: 4
Researchers working in this area will work on the development of multimodal haptic interaction paradigms and hardware/software drawing on simultaneously displayed cutaneous and kinaesthetic experiences, the application of these technologies in human computer interactions and human centred robotics and the key psycho-physical testing of the experiences. The work will draw on expertise in engineering (mechanical and electronic) and computer systems. There may also be a small number of opportunities for researchers from a Psycho-physics and/or Psychology background.

Theme 3.3: Advanced Structures and Materials

Tutor: Dr. J Dai
No. of available positions: 4
This theme will explore new robotic structures through the development of both new materials and novel uses of already existing materials. Successful researchers will work in topics ranging from the development of advanced structures such as high precision end-effectors to new technologies and techniques for self-healing and self repairing systems, biomorphic structures and flexible lightweight structures.

Theme 3.4: Advanced Sensing

Tutor: Dr. Leonardo Mattos
No. of available positions: 4
Within this theme the research will focus on the development of novel sensing technologies based primarily on tactile sensing but also including smell and taste and ultimately encompassing neurological sensing. The research activities will address issues in intelligent, full body tactile sensing, Healing and regenerative skins, growing and “living” materials, artificial skins and new sensing materials and modalities.

Candidates for all the above themes should have a top class degree in Electronic Engineering, Mechanical Engineering, Robotics, Computer Science, Physics, Mechatronics, Biomechanics, Bioengineering, Pschyo-physics, Psychology or a related field.

For further details concerning any of the above projects please contact Floriana.Sardi@iit.it

4 ROBOTICS, BRAIN AND COGNITIVE SCIENCES (PROF. JEAN-GUY FONTAINE)

The core of the program will deal with advanced robotics and innovations. Scientific platforms are addressing two domains of applications namely:

- Tele Mobile Robotics (including mobile platforms and walking machines) to perform Tele-operation/presence/existence (**T³**) studies like sense of presence with robots as a remote body.
- Tele Micro Robotics to perform micro tasks with Tele-presence.

Theme 4.1: Walking machines

Tutors: Dr. Olivier Bruneau, Dr.Teodor Akinfiev
No. of available positions: 1

Extensive studies have been done on walking machines. It addresses mainly hexapods, quadrupeds or bipeds. Few investigations are done with tripods or pentapods. The final aim is to propose a control strategy using a novel mechanical system able to auto adapt its morphology to a particular gait or situation. One of the targets to be handled in this frame is to stabilize walking systems intrinsically without actuators. The particularity of this mechanism will be the capability to transform energy coming from large external perturbation applied in all directions into propulsion energy in a desired walking direction of the robot.
This mechanical system called PULSS (Propulsion Using Large external forces for Self-Stabilization) will be integrated in the HEXAQUABIP robot which is a walking machine able to change its morphology depending on ground and obstacles (hexapod to quadruped, quadruped to biped and inverse processes).

Theme 4.2: Tele-presence with mobile robots vectors

Tutor: Dr. Ryad Chellali
No. of available positions: 1

Most of the time, mobile robotics (in a context of Tele-operation) addresses a mission combining skills of one operator and a robot. “Matrioshka” project is dealing with the development of a system composed by a set of robots. Several robots with different types of locomotion (legs, wheels and flying capabilities) will be considered in a “telescopic” manner to cope with a complex mission. They will be automatically Tele-operated by a single user in a complete Tele-presence context.
SLAM techniques or equivalent may be adapted to deal with this new architecture.

Theme 4.3: Sensory channels for Tele-presence

Tutors: Dr. Ryad Chellali, Dr. Aleh Krivanos
No. of available positions: 2

Tele-operation systems are focusing on sensory feedbacks and improving capture of operators’ commands. The resulting competition leads to technological and technical improvements with the aim to be as close as possible to an ideal Tele-presence system i.e.: a system completely transparent for the operator. Our purpose is to study impacts of several sensory channels with the objective to determine necessary and sufficient conditions to achieve Tele-presence tasks with high performances.
As a first step, studies will concern individual sensory channels. Common developments and experiments will be realised with other teams of IIT (Prof. Th. Pozzo and L. Fadiga) and in close relations with theme 4.2. Targeted projects with telemedicine will also be evaluated.

Theme 4.4: Tele micro/nano manipulation

Tutor: Dr. Nicolas Malet
No. of available positions: 1

By means of virtual reality tools and kinaesthetic feedbacks, the aim is to simplify manipulation tasks at micro or nano-scale. Taken into account physical laws at micro or nano scale, this activity will focus on human to machine interfaces with the aim to develop a realistic and immersive process for Tele-manipulation with high efficiency and accuracy. This subject will be closely related to the neuroscience department activities (Prof. F. Benfenati).

5 ROBOTICS, BRAIN AND COGNITIVE SCIENCES (PROF. GIULIO SANDINI)

Project's proposals are grouped into three main streams: Humanoid Robotics and Cognition, Brain Machine Interface, Human Behavior and Biomechanics. The themes proposed highlight this year's priorities and are to be considered as indications of the research activities planned. As such, research projects within the same areas are welcome and will be also considered.

Stream 1: Humanoid Robotics and Cognition

The themes under this heading group the research activities targeting the humanoid platforms of the lab among which iCub (the platform of the RobotCub project www.robotcub.org) and "James" (a one-arm humanoid build to investigate manipulation and object affordance). The research themes proposed are examples of the planned activities in areas such as cognitive systems, sensorimotor coordination, advanced materials for actuation, sensing and scaffolding.

Theme 5.1 – Machine Learning

Tutor: Prof. Giorgio Metta
N. of available positions: 1

In the development of an advanced robot, such as humanoids, one is expected to encounter very complex problems. Examples of these hard problems are body control and various types of visual processing. Due to the complex nature it can be nearly impossible to solve these problems by traditional engineering methods that rely on exact modelling. A practical example is creating a kinematic and/or dynamic model of a robotic arm, which is very difficult since the model should incorporate many real-world interdependent aspects, such as gravity or friction, backlash of components, tendon stiffness, etc.

A complementary approach is to use modern machine learning techniques (e.g. Support Vector Machines, Artificial Neural Networks, Evolutionary Computing) to tackle these problems in a highly automated fashion.

Further, these techniques can be used to deduce useful models that are derived from biology either because we have observed human behaviour or from the evidence of neural sciences. This biological evidence can give valuable inspiration in the creation of a humanoid robot that shows human-like performance.

However, the biological solutions are generally not directly applicable in a vastly different computational environment. Computational intelligence techniques, such as the ones mentioned before, could help to create abstract models that can be implemented on a computer.

The ideal candidate would have a background on computer science or related disciplines and a strong propension to mix theory and practice to analyze machine learning problems mathematically but to simultaneously devise plausible and viable implementations on the humanoid platforms available at the RBCS labs.

For further details concerning the research project, please contact: giorgio.metta@iit.it

Theme 5.2 – Language and Action

Tutor: Francesco Nori
N. of available positions: 1

Recent scientific theories have suggested that language is not a module independent from other cognitive capabilities. There is in fact strong evidence supporting the idea that language is instead deeply intertwined with action. Moreover, the interaction between action and language has also been hypothesized to have had a crucial role in the evolutionary origins of language.

As a consequence of these theories, the problem of building an artificial system with linguistic capabilities cannot be considered as a purely perceptual task. Motor capabilities are instead as fundamental as the perceptual ones. Within this context, compositionality seems to play a crucial role by creating a wide repertoire of actions trough the combination of a handful of elementary primitives.

The candidate should explore the implications of these novel theories by the implementation on an artificial platform, e.g. iCub. The long term goal is to build an artificial system with some intertwined motor and linguistic capabilities.

The ideal candidate would have a background in computer science or engineering, with good programming skills, propensity to reuse existing tools (e.g. ASR, machine learning) and components (e.g. robot control software) but at the same time to develop new algorithms to solve specific problems which might not be well-structured or formalized.

For further details concerning the research project, please contact: francesco.nori@iit.it

Theme 5.3 – Active Perception in Humanoid Robots

Tutor: Dr. Lorenzo Natale
N. of available positions: 1

Neuroscience and developmental psychology strongly agree on the importance of motor activity for perception and learning. Growing experimental evidence demonstrates how areas directly related to motor production/generation are involved during perceptual tasks (action recognition, speech perception). During development, motor abilities like reaching and grasping allow infants to explore their own body and the environment and extract information using multiple sensory modalities at the same time (e.g. vision, sound and touch). Infants spend a huge amount of their awake life experimenting the rules governing the world and their own body. They move their arm, legs and hands and observe the results of their actions while banging, crashing and biting objects. Researchers in robotics have taken inspiration from these observations and investigated how motor activity shapes and enhance perception in artificial systems.

Artificial perception is an extremely difficult task, which has been challenging researcher in computer vision, robotics and artificial intelligence for several years. Despite great efforts only limited success has been achieved. Robotic applications suffer of these limitations. Today we find robots able to perform sophisticated tasks fast and accurately but only in very controlled scenarios (typical example is industrial robotics), where perception is totally absent or very simplified. But robots are much more brittle in everyday scenarios, where perception is required to cope with unpredictability.

The topic of this PhD is the study of perception in robotics, with the goal to explore how robots can exploit the interaction between their body and the environment. Applications are especially in the context of robot manipulation, with particular interest in vision, auditory and haptic perception and their integration. Possible topics include control of attention, robot self-recognition, grasping, manipulation and object recognition. The optimal candidate should have a background in computer science and engineering, and be interested to study the mechanism underlying perception in biological systems. Background in electronics and mechanics is not a requirement, but considered that the PhD will be carried out working on a robotic platform, the candidate should consider that he might be asked to contribute to system level design and low-level hardware and software development.

For further details concerning the research project, please contact: lorenzo.natale@iit.it

Theme 5.4 – Human-Robot Interaction and the Mirror-Neuron System

Tutor: Prof. Giorgio Metta
N. of available positions: 1

The human mirror neuron system can be probed through human-robot interaction experiments and the measurements of behavioural parameters (kinematics, forces, gaze, etc.). In particular, experiments can be designed to measure gaze during observation of actions performed by a humanoid artefact. Experiments will be devoted to clarify the characteristics of the observed action that evoke pro-active gaze behaviour. The monitoring of eye movements of human participants will be used to reflect the activity of a motor resonance involving a mirror-neuron system. During the experiment we will ask subjects, seated in front of the robot, to merely observe its actions. By using the artefact, we will, for instance, investigate three different cues. (i) Role of the kinematics; (ii) Modulation of the empathic link between the robot and the subject ('enriched familiarization'); (iii) Subjects will be requested to act on some objects (by grasping and displacing them or by putting some of them within a particular container) while the robot looks at their actions.

Simultaneously, studies on the goal of the action and of kinematic parameters (transitive/intransitive actions) can be performed on human subjects. In this set of experiments manipulation of both the plausibility of the goal of the action and of the kinematic parameters of the movement are devised. The experimenter and the subject will be sitting at a table, one in front of the other. Subjects will be given the instruction to watch the action performed by the experimenter and then to repeat it. No explicit instruction on how to imitate the observed action will be given to the subjects. We will present both transitive and intransitive movements, and the demonstrator will execute the movements with different kinematics. These sets of experiments and the corresponding gaze/reaching/grasping kinematic recordings will constitute a database which can be subjected to various modelling efforts, for example through non-parametric and machine learning techniques. The ideal candidate would have a background in human psychophysics and/or related disciplines.

For further details concerning the research project, please contact: giorgio.metta@iit.it

Theme 5.5 – Whole Body Motion for Humanoid Robots

Tutor: Dr. Sophie Sakka
N. of available positions: 1

The kinematics of a humanoid robot is close to humans. Still, some unavoidable differences appear which make the imitation of human motion by a humanoid robot a difficult task. During this Ph.D. program, the

research will focus on whole body motion for humanoid robots, using human captured motion as a basis model, and converting them into motion compatible with the kinematic constraints of a humanoid robot.
After implementing traditional approaches for whole body motion generation, the candidate will work on improved models allowing an autonomous imitation of baby-like locomotion. A special attention shall be paid to the transition between crawling-based displacements, including them into a pertinent definition of variable support polygons during locomotion and control of posture changes (four-leg crawling -> sitting -> four-leg crawling -> standing up using hand grasping for standing up).
The ideal candidate would have a background in computer science or engineering, control theory, modelling and robotics.
For more details concerning the research project, please contact: sophie.sakka@lms.univ-poitiers.fr

Theme 5.6: Composite materials based on Carbon Nanotubes for robotics

Tutor: Dr. Davide Ricci
N. of available positions: 1
The evolution of humanoid platforms designed to collaborate with humans will be from rigid toward soft components specifically addressing technologies of skeletal, actuation and sensorial components in an integrated way. Within this framework, a fundamental technological issue is the development of elastic actuators composed of fibers with mechanical properties similar to those of biological muscles. While the ultimate goal could be considered the development of organic muscles, the intermediate approach this Ph.D. project will follow is the development of more traditional actuators that take advantage of the properties of hybrid nanocomposite materials. The main issues to be addressed are: power/weight and power/volume performance, compliance and stiffness regulation, robustness, control behaviour. To this end, the Ph.D. research work will be devoted to the development of "soft" materials based on an appropriate blending of polymers and carbon nanotubes capable of actuation. Incorporation of other functionalities such as power storage, electron transport and force transfer within a single engineered structure will be also pursued.
The ideal candidate would have a background in one or more of the following fields: material science, sensor and actuators, micromechanics, nanotechnology.
For further details concerning the research project, please contact: davide.ricci@iit.it

Theme 5.7: Dexterous Hand for Humanoid Robots

Tutor: Dr. Lorenzo Masia
No. available positions: 1
Humanoid Robot kinematics must mimick the human motion. In order to reproduce movements and dynamics closest to human's ones, a humanoid must have a high number of DOFs.
Actuaction plays an essential role in dynamics and kinematics; human body is powered by muscles and tendons in a redundant configuration in a variable impedance control strategy.
Available actuators on market are nowadays characterized by a small bandwidth and high weight-power ratio: this means in order to have a system behaving with a dynamic comparable with human's one, it must be actuated by small inertia (and power) actuators. The main idea is to turn around the problem by developing a modular robot in which each module has its own dynamic behavior and actuators: a Hybrid System.
Objective of the research is to design and characterize a 9 DOF biomimetic inspired hand
To be coupled with a humanoid robot available at IIT Robotic Lab. The candidate must design the hardware meeting the requirements and characterize it investigating kinematics and dynamics.
For further details concerning the research project, please contact: lorenzo.masia@iit.it

Stream 2: Brain Machine Interface

The recent advancements in Neuroscience, Robotics, Microelectronics and Control Theory, make today plausible the design and the realization of artificial systems directly interfaced with the brain.
If, on one side, some artificial sensory systems, as artificial retina and cochlear implants, are more and more improving to send visual and auditory signals to the brain, few attempts have successfully been made to work in the opposite way: by extracting and decoding brain signal to drive artificial actuators. Here at IIT we are making a big effort to start a multidisciplinary project aiming at 'reading' the brain to understand and extract motor signals which may be used to control an artificial arm. The project will be run within the 'Robotics, Brain and Cognitive Science' Department and will be coordinated by Pr. Luciano Fadiga. There are, in our view, several fields of research which can be resumed as follows:

Theme 5.8 – The Neural Interface Problem: Enhanced in-vivo electrodes by nanomaterial coatings

Tutor: Dr. Davide Ricci.
N. of available positions: 1
Within the Brain Machine Interface research project of IIT, that has the ultimate goal of extracting and decoding brain signals to drive artificial actuators, a key issue is the investigation on how such brain signals can be extracted from electrical recordings with the necessary temporal and spatial resolutions. Nanomaterial coatings, such as carbon nanotubes, both unmodified or bio-functionalized, offer the possibility to improve the recording properties of traditional metal electrodes. Through direct integration of nanomaterials in the electrode fabrication process, this Ph.D. research project will deal with the following tasks: (1) designing efficient, long-term recording microelectrodes; (2) investigating the possibility to record signals from the surface of the cortex; (3) investigating the problem of input impedance and making attempts to reduce it without loss in signal-to-noise ratio; (4) studying how to minimize tissue reactions, such as glyosis. The ideal candidate would have a background in one or more of the following fields: material science, electrochemistry, micromechanics, nanotechnology, physics.
For further details concerning the research project, please contact: davide.ricci@iit.it)

Theme 5.9 – The Signal Treatment Problem

Tutor: Dr. Gytis Baranauskas
N. of available positions: 1
Any brain signal has to be amplified and processed before it can be used to control a prosthetic device or a robotic manipulator. Moreover, the device that amplifies and elaborates brain signals should be as small as possible. We already have an integrated circuitry that is smaller than a finger nail and that amplifies 64 independent neuronal signals. The goal of this largely electronic engineering project is to build a single chip powered by radio-waves that amplifies and processes signals from hundreds of neurons in such a way that the chip output can be directly fed into the artificial system driving a robotic arm. We expect to test this chip in animals as well as in human patients. Thus, we are looking for a PhD student interested in analog and digital microelectronics for biomedical applications and preferentially with background in physics. The selected student will be working in close collaboration with the project 5.8 team (see above).
For further details concerning the research project, please contact: baranauskas@elet.polimi.it

Theme 5.10: The Brain Signal Decoding Problem

Tutor: Prof. Stefano Panzeri
N. of available positions: 1
A fundamental question in the development of brain-machine-interfaces is how to extract information about sensory stimulus or motor commands from a single-trial observation of neuronal activity. This mathematical-analysis PhD project will aim at addressing this question by investigating systematically which features of different types of recordings of neural activity (such as spike trains of well isolated neurons, field potentials, multiple-unit activity or other) convey the most information about sensory stimuli or motor actions.
We will develop data analysis techniques based on the principles of information theory and then apply them to recordings of brain activity provided by our experimental collaborators, with the goal of determining how best to decode these brain signals. The ideal candidate for this PhD studentship will a have a strong degree in a numerate discipline such as physics, statistics, mathematics or computer science. No previous knowledge of neuroscience is needed, although a strong motivation to contribute to brain research is essential.
For more details concerning the research project, please contact: stefano.panzeri@manchester.ac.uk

Theme 5.11: The Movements vs. Actions Problem

Tutor: Prof. Luciano Fadiga
N. of available positions: 1
Apart from very few exceptions, the research groups currently working at BMI are doing their attempts by recording from the primary motor cortex. Their goal is to decode directional tuning and individual muscles control signals. We consider this approach quite risky. First of all because several researchers are now disputing the idea that the motor cortex codes the direction of reaching in absolute terms, second because recent neurophysiological evidence shows that actions and not movements are mainly coded by the brain. Within this field of research, one PhD student will be involved in cortical electrophysiology to record single neurons' signals. The aim is twofold: to study and understand the motor commands generated by the brain

during goal-directed acts and to set up long-term chronical recording techniques, firstly in monkeys and then in humans. Backgrounds in computer science, electronics and basic neuroscience are required.
For further details concerning the research project, please contact: luciano.fadiga@iit.it

Theme 5.12: The Neurophysiology of the Human Brain

Tutor: Dr. Elisa Molinari
N. of available positions: 1
This work will concern brain imaging (functional magnetic resonance) to investigate the cortical and subcortical activity of the motor system during goal-directed actions. Through this project we will better understand the functional correlates of motor planning/execution by analyzing data and developing new single-subject analysis techniques. This will be done by taking into account both the statistical significance and the intensity (signal-to-noise ratio) of the activations. We are looking forward for one PhD student which should be competent in physics, computer science and basic neuroscience.
For further details concerning the research project, please contact: elisa.molinari@iit.it

Theme 5.13: The Role of Sensory Feedback in Brain Machine Interface.

Tutor: Dr. Alessandro Vato.
N. of available positions: 1
Within this field of research we will study in animal models (and then in human patients) the relevance of sensory afferents for controlling an artificial effector. Somatosensory real-time feedback is fundamental for motor planning and for executing "on-line" errors correction during movements. In people with sensory motor disabilities, the sensory information that cannot reach the brain, can be "substituted" through an intact sensory channel (i.e. eyes or ears) different from the damaged one. Alternatively, the damaged sensory pathway can be "replaced" trying to achieve the same sensation in an artificial way. The goal of this project is to design an encoder interface to stimulate the sensory cortex of behaving rats conveying sensory information related to the state of an external device. The encoder will be part of a Bidirectional Brain Machine Interface System in which neural signals recorded directly from the rat's motor cortex will control an external device and real-time feedback will be provided via electrical stimulation of the sensory cortex. The candidate for this PhD position will be required to have a background in computer science, electronics and basic neuroscience.
For further details concerning the research project, please contact: alessandro.vato@iit.it

Theme 5.14: Machinery for Functional Brain Analysis

Tutor: Dr. Franco Bertora
N. of available positions: 1
In addition, and in parallel with the preceding themes, there is at IIT an ongoing program to investigate the frontiers of functional MRI imaging. Any fMRI of the motor cortex has so far been performed on subjects confined in a supine/prone position in the limited volume of a traditional scanner. There are reasons to think that the analysis of subjects performing motor tasks in a more "natural" environment could produce different and more meaningful results. A study is currently in progress to determine the feasibility of a scanner allowing functional brain analysis of a human adult in a standing or sitting position. We are looking for one PhD student with background in physics, electronics, signal processing and MRI to explore the possibly novel imaging techniques (MRI sequences, data acquisition modalities and image reconstruction) to be included in the development of the scanner.
For further details concerning the research project, please contact: **franco.bertora@iit.it**

Stream 3: Human Behavior and Biomechanics

Theme 5.15: Learning by Observation in Human and Robot

Tutor: Prof. Thierry Pozzo
No. of available positions: 2
The idea that observation can activate motor representation that do not result from observer past executions (i.e., without sensory and motor signal resulting from actual execution, as in the case of new motor abilities), opens innovative learning methods for humans and robots. Ph.D. thesis work will involve students in the fields of motor control (3D kinematic analysis, optimization control) and robotic (machine learning…).
The aim is twofold:

- To study biological motion recognition through several new experimental paradigms that have been developed using the discovery of the mirror system as a starting point and the idea of online action simulation at observation.
- To implement the experimental results performed on human in robot for learning by imitating human movements. For instance the perceived action of a teacher can be mapped onto a set of existing primitives inside the robot.
  Backgrounds in computer sciences, robotic and basic behavioural neurosciences are required.

For further details concerning the research project, please contact: thierry.pozzo@iit.it

Theme 5.16: Robotic Rehabilitation

Tutor: Dr. Lorenzo Masia
No. Positions: 1

Since '80s the haptic interfaces has been used to characterize the human upper limb impedance. These studies showed the great anisotropy of the muscle-skeletal system: the inertia, the viscosity and the stiffness of the arm change with the movement's direction. Also the analysis of the interaction forces, that means that the forces caused from the dynamic coupling between the arm's DOFs and the body's kinematics, gives another anysotropy component that contrasts with the geometrical and cinematic isotropy of the arm's trajectories (Morasso 1981).

The pioneer of Robotic Rehabilitation is MIT-Manus; in this application a customized robot was designed and developed in order to have high back-drivability and soft and stable feel for the user. Using a visual feedback to instruct people in following repetitive task observing their own movements on a screen a greater reduction in impairment was observed in exercised muscles on over 300 stroke patients; the outcomes leads to develop adds-on for the pre-existing robots.

At IIT Human Behaviour Lab new devices have been developed by merging experiences from ideas and know-how from different people who worked in the above mentioned field. The main focuses of the present research are:

1) impedance evaluation of human wrist in passive and active movements (hardware: IIT wrist robot)
2) coordination between wrist and hand movements during grasping (hardware: IIT wrist robot and hand robot)
3) bimanual coordination in reaching and grasping by using a 6 DOF robotic workstation for each arm (hardware: 2 X 2Dof planar robots "Braccio di Ferro" each coupled with IIT wrist (3DOF) and hand robot (1DOF))
4) development of a multi-DOF (at least 5 DOF) haptic interface for multifinger grasping (hardware: to be designed by the candidate)

The PhD students must develop experimental paradigms and control software to acquire and analyze data for the point 1-2-3, mechanical design experience is required for point 4.

For further details concerning the research project, please contact: lorenzo.masia@iit.it

6 TRAINING ACTIVITIES

The multidisciplinary approach of this PhD program will attract students with different backgrounds (biology, chemistry, engineering, medical sciences, cognitive neurosciences, computer science and artificial intelligence, physics etc.). One the main objectives of this doctoral program is to give birth to a new discipline in which all these aspects can contribute to the discovery of new technologies and the implementation of new, hybrid (i.e. bionic), artificial systems.

With this aim in mind the training will start with plans tailored to the need and interests of each individual student and aimed at bringing all students to a common understanding of the key scientific aspects and investigation tools of the three IIT platforms. This will be obtained also by planning exchange of students for 6 to 12 months with laboratories where particularly interesting experimental techniques and/or strategic scientific approaches are well established. As an example, a computer scientist interested in investigating how the brain represents visuo-motor information could be trained in a neuroscience lab and engaged in behavioural or brain imaging studies. Or vice versa a student with a medical background interested in implementing an artificial or hybrid systems (e.g. a prosthetic device) will be given the possibility of acquiring design skills and tools. Hopefully starting from these diversified backgrounds students will be able to develop a common language and contribute to the establishment of new experimental procedures and technologies.