

Research Statement

My research interests focus on three topics:

- **Humanoid Robotics:** Development of anthropomorphic manipulation and locomotion systems.
- **Bio-inspired Control Architectures:** Synthesis of combined classical and biomimetic control strategies to enhance the behavior and the adaptation of robotic systems in unstructured and time-variant environments.
- **Haptic Interfaces and Artificial Exoskeletons:** Design and control of haptic interfaces capable to evoke touch and force feedbacks during the interaction with a synthetic or tele-operation scenario.

A significant part of my work is strongly related with the field of computational neuroscience. The approach I follow is to use the knowledge on the nervous system of a biological organism (e.g. a functional model of the human peripheral nervous system) to synthesize the low-level control of a robot intended to reproduce some of its behaviors and manipulation capabilities. In particular I applied this methodology to control a humanoid artificial arm, [1] (Figure 1-d) and the forearm joint of a wearable exoskeleton (Figure 1-g) intended for tele-robotics applications [2]. The implemented controllers are based on the architecture of specific neural circuits located in the human spinal cords and responsible to implement reflexes (e.g myotatic, inverse-myotatic) and regulate/coordinate the articulations and muscles of the limb. The control scheme allows further to directly integrate biosignals (e.g EEG, EMG, temperature, interaction force, etc.) in order to modulate its behavior and to better harmonize with the human nervous system. This paradigm is of particular importance for robotics systems that need to work in strict contact with the human body. Further research effort will be dedicated to furnish the controller with an adaptation mechanism that will tailor the interface behavior on the basis of the operator's neuro-functional characteristics and perception capabilities [3].

Another research topic I am currently interested deals with the formalization and implementation of real time adaptive models intended to enhance the control of time-variant, nonlinear dynamic systems (e.g. hydraulic actuation systems). The block-oriented models have a Wiener-Hammerstein architecture, and integrate a linear static part based on a Auto Regressive eXogenous system (ARX), and a memoryless nonlinear part based on a multi-layers B-spline Neural Networks (BSNN). The adaptation relays on error-driven local adaptation mechanisms for the BSNN part, and a recursive least square algorithm

for the ARX part. This particular combination shows better performances compared with Wiener-Hammerstein models having as static part a polynomials or a fuzzy-logic function. Furthermore, the learning step of the BSNN requires lower computational resources in comparison with the widely used least squared method and it is therefore more suitable for real time applications. The main problematics, that arise when integrating such adaptive models into real time control systems, are related with finding good stability and adaptation-stop criteria. Future effort will be dedicated to integrate an adaptive gain in the learning mechanism of the BSNN.

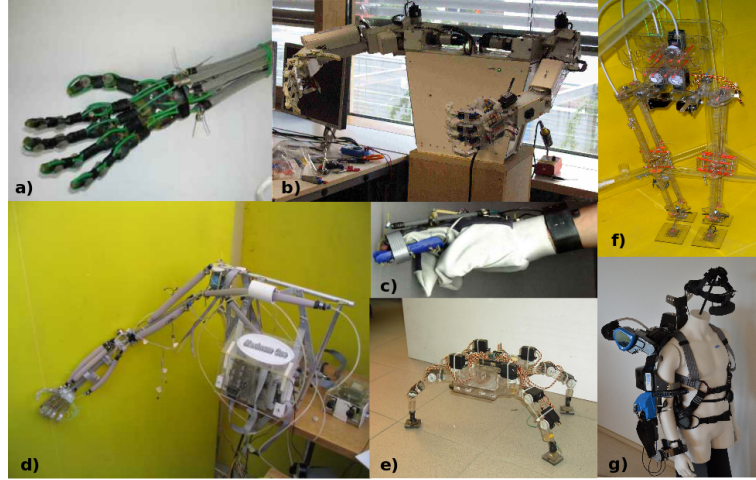


Figure 1: Some of the robots I designed and I worked on in the past: a) "Blackfingers" artificial hand, Politecnico di Milano 2000. b) Dual arm humanoid manipulation systems, sold to the University of Applied Sciences in Frankfurt 2007. c) Glove for electro-tactile haptic feedback, Politecnico di Milano 2002 [4, 5]. d) Anthropomorphic arm actuated with pneumatic artificial muscles, Politecnico di Milano 2004. e) Quadruped Robot, Politecnico di Milano 2005. f) Biped robot tendons actuated, Politecnico di Milano 2004. G) Vi-Bot Exoskeleton, hydraulic actuated, DFKI 2010.

Future directions and long term goals: My long term research activity and vision is oriented toward the study and the development of a full-size, low-cost, humanoid robot with motor and manipulation capabilities comparable with those of a human being. The approach I will follow in defining the robot architecture differs in many ways from the approach used so far to design most of the state-of-the-art robotics systems. Generally, today industrial and humanoid robots, are intended to perform tasks with high precision and repeatability. Due to this, their mechanical structure is often rigid and the actuation system does not allow a precise impedance modulation. On the contrary, I want to pursue other features that I consider more critical for a humanoid robot, namely adaptability, automatic failure recovery and safe operability in human environments. This will be achieved by using state-of-the-art-materials and design processes, innovative actuation and sensory systems, and organizing the inevitable high complex

control system in a modular and hierarchical fashion. In particular at the bottom level a set of modules will emulate the behavior of the principal motor-circuits present in the human spinal cords. They will implement different types of reflexes and coordinate the robot actuator's in a human like fashion. In the higher level of the control architecture, other modules will compute the robot inverse kinematics, identify the robot dynamics, and implement the robot learning and cognitive capabilities. These circuits will be mainly based on recurrent dynamical neural networks (RNN). These classes of artificial neural networks were proved to be computationally more powerful than other adaptive models such as feed-forward neural network, hidden Markov models and support vector machine. Indeed they allow to represent continuous internal states. RNN can converge to the optimal solution more quickly than other models; more importantly, due to their dynamical properties they can operate on-line, in real time, and in an unsupervised manner. Most of the movement primitives of the robot cannot be evaluated on the basis of a single point in time, but need to be represented through multiple states. RNN together with a mechanism of long and short term memory will be able to recognize temporal patterns, to generate stable cyclic patterns useful to coordinate movements, to extract information from the robot's sensory system and to recognize events separated in time. Due to the complexity and the ambitious nature of this project I will split it in different sub-tasks with separated sub-goals. The kinematic and dynamic models of the robot will be developed together with its mechanical design. This will allow to test its functionalities and the behavior of its control strategies in advance by simulation, boosting therefore the development phase of the real system.

Selected References

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