VIACTORS - Variable Impedance ACTuation systems embodying advanced interaction behaviors

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ABSTRACT

VIACTORS addresses the development of safe, energy-efficient, and highly dynamic variable-impedance actuation systems which will permit the embodiment of natural characteristics, found in biological systems, into a new generation of mechatronic systems. Goal of the project is that of obtaining the intended physical interaction and motion behaviors of the robotic system intrinsically by its physical structures to the maximum extent possible. This advance in technology will pave the way towards new application fields, such as industrial co-workers, household robots, advanced prostheses and rehabilitation devices, and autonomous robots for exploration of space and hostile environments.

Keywords

Variable impedance actuators, embodied intelligence, novel actuators, biologically inspired design

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1. MOTIVATION

Most of today's robots have rigid structures and actuators requiring complex software control algorithms and sophisticated sensor systems in order to behave adaptable, compliant, and safe in contact with unknown environments or with humans. The lack of an actuation unit, which can reach the performance of the biological muscle and its neuro-mechanical control system, still remains the most significant barrier for the development of machines which can match the motion, safety and energy efficiency performance of the natural systems and in particular the human. This project aims at developing and exploiting actuation technologies for a new generation of robots that can co-exist and co-operate with people and get much closer to the human manipulation and locomotion performance than today's robots do. At the same time these robots are expected to be safe, in the sense that interacting with them should not constitute a higher injury risk to humans than the interaction with another cautious human.

2. LEADING IDEA OF THE PROJECT

The guiding idea for designing the new robots is embodying in the morphology of the system a substantial part of the necessary intelligence, in such a way that the system should be able to passively be safe, efficient, compliant. The robot motion will be determined not only by an external software program that will give instructions to the machine, but the capability of carrying out certain functions will be directly embodied in the physical form of the machine . One goal is to develop systems with similar functional properties as the neuro-mechanical systems in humans. Another is to examine opportunities offered by such human neuromuscular control for artificial systems and robots.

3. KEY INNOVATION

To tackle the goals described above, the project uses the concept of Variable Impedance Actuation (VIA). The key innovation of the project is the development, exploitation and integration of Variable Impedance Actuator Systems both in manipulation, locomotion and rehabilitation.

4. PROJECT STRATEGY

The embodied intelligence idea will be approached on three levels:
4.1.1) Study of the Fundamental Laws regulating the control of impedance in actuation systems, and derive implications to the design of actuators and robots embodying tin their form the expected behavior
4.1.2) Study of physical and biological principles governing human motor control and learning [2],[3],[4]
4.2) Design of new robot actuators according to the principles described in the paragraphs 4.1.1 and 4.1.2

4.3)Application of the new technology in robotic manipulation [1], bipedal locomotion [4],[5],[6], and rehabilitation robotics.

4.1 Actuation and Human Studies

4.1.1 Actuation Studies

The goal is to define the concept of variable impedance actuation and establish the characteristics needed to embody the expected behavior, including intrinsic safety, robustness, energy efficiency.

4.1.2 Human Studies

Humans learn to coordinate muscles and adapt the force and impedance at the contact points with the environment, in order to compensate for the environment dynamics. They learn to preprogram the muscle mechanics in order to meet the requirements of motor tasks optimally. The project will focus on investigating generalization of concurrent force/impedance learning, how humans deal with redundant systems and relax muscles selectively and how they use elastic energy in their movement and deal with internal and external noise. We will also study how humans control tasks such as grasping and catching.

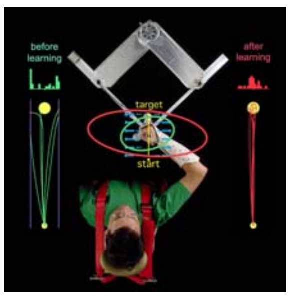

Figure 1: Effect of learning during repetitive motion: muscle activation produces feedforward force and impedance compensating for the interaction force with the environment and its instability.

4.2 Robotic Actuators Development and Application in Humanoid Robots

The goal is to design, realize and evaluate new range of actuators following the biological muscle model and exhibiting variable stiffness, variable damping or full impedance regulation principles. New variable stiffness electrical drives, dielectric elastomer actuators will be developed, and the use of potentially new materials like carbon nanotube actuators will be studied. Finally, the results will be applied to humanoid robots

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Figure 2: New hand-arm design with VIA actuators

4.3 Applications

The fundamentals described above will be applied and evaluated to three distinct aspects, namely robotic manipulation, bipedal locomotion, and rehabilitation. Common to all three application areas is the need for safe, energy efficient compliant actuators, which are robust with respect to external perturbations, while their treatment implies several specific and complementary aspects, which qualifies them as a quite generic candidate set. Based on the fundamental analysis on actuator level specific design and control solutions will be worked out at system level for all three application areas.

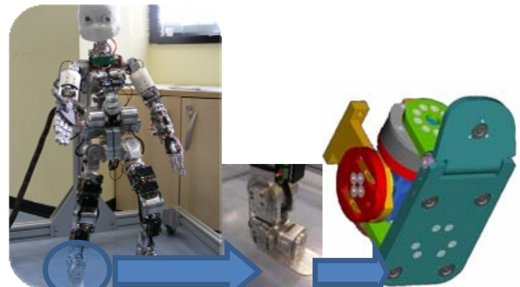

Figure 2: Robot iCub (IIT) with new variable stiffness: ankle

Figure 4: Use of VIA in Knee prosthesis

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