Project Name: Biomedical Devices & Technologies: Hybrid Human-Machine Systems

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Faculty involved:
Prof. Dava Newman (MIT), Dr. Steve Massaquoi (Harvard-MIT), Prof. Hugh Herr (MIT), Prof. H.Correia (UMinho), Profs. P. Lima and J. S. Victor

Students Involved:
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Project Overview:
Year 2 Research Efforts included assessment of multiple areas in Biomedical Devices under the theme of the Hybrid Human-Machine Systems. Four research proposals were submitted in this area and prioritized in terms of most significant research potential, resulting in the following ranking: Powered Ankle-Foot Prosthesis; Musculoskeletal Gait Analysis and Exoskeleton Design; and Wearable Brain Cap. The first two are detailed herein as funding was received and collaboration between MIT, Minho and IST have been identified. The Wearable Brain Cap project proposed by Minho provides a doctoral research project for a Portugal student to be advised by faculty members at Minho, and is funded from the Portuguese side.
The goal of the Powered Ankle-Foot Proshthesis work is to develop an algorithm and sensory suite for detecting terrain variations experienced by a walking transtibial amputee using only local mechanical sensors located on the external transtibial prosthesis. We seek a prosthesis design that accurately detects when an amputee transitions between level ground and stair/slope ground surfaces. To better mimic the human ankle-foot complex and to improve clinical efficacy, a prosthetic ankle-foot mechanism has been developed that actively controls joint impedance and non-conservative motive power during stance, while at the same time not exceeding the weight of the missing limb.
In a proposed three-year investigation, a powered ankle-foot prosthesis with a terrain control system will be designed and built. The system will comprise sensors for the measurement of ground reaction force, relative ankle angle, and absolute prosthetic angles (pitch, roll, yaw). Using these local sensory inputs, we will compute the vertical position of the prosthetic foot relative to the foot position during a previous ground contact period. From this estimated vertical position, we will be able to determine if the amputee is stepping down or up versus walking on a level surface. Human ankle-foot data will be used to train a neural net terrain prediction function. The function inputs will be leg pitch, pitch velocity, and foot vertical position, and the function output will be

ankle relative position. Once the terrain prediction function has been trained, the prosthetic terrain control system will employ the function to control prosthetic ankle angle from sensory input measures of prosthetic pitch, pitch velocity and vertical foot position.

The Expected Deliverables are:
- Build an autonomous transtibial system having an active ankle system capable of position, impedance and nonconservative torque control, and develop finite state control algorithms for human-like, inter-gait behaviors for level-ground and stair terrains.
- Measure human leg pitch, pitch velocity, ankle angle, and vertical foot position during level-ground, slope and stair transitions.
- Develop powered ankle-foot prosthesis with a controller capable of detecting terrain transitions. The second high priority research focus under the Hybrid Human-Machine includes Musculoskeletal Gait Analysis and Exoskeleton Design. This research effort investigates human locomotor control, musculoskeletal loading, and the design of a loading suit and/or an exoskeleton that incorporates variable stiffness joints. We will study human locomotion and musculoskeletal performance for normal, altered and enhanced gaits (i.e., due to pathology or orthoses). The objectives include musculoskeletal modeling, and suit development, design and testing. Expected Deliverables include: The development of a simulation tool as well as the proposed exoskeleton and loading suit hardware to study locomotion will be beneficial to the area of biomechanics and for educational tutorials on movement, gait, biomechanics, and control theory. The deliverables of this research effort include:
• Biomechanical and musculoskeletal models and simulations
• Exoskeleton design and development
• Analysis of control strategies used by humans when coupled with exoskeletons and orthoses, Exploration of variable-stiffness exoskeleton concepts for aiding people with reduced range of joint motions and reduced muscle strength
• Musculoskeletal variable loading suit for locomotor control.

Timeline:
At MIT, Professor Hugh Herr of the Media Lab and the Harvard-MIT Health, Sciences and Technology program has joined our team. Prof. Herr is the Director of the Biomechatronics Group in the MIT Media Laboratory. Our Year 3 plan includes extending our collaboration to Profs. Lima and J. S. Victor of IST from the Associated Laboratory Institute of Systems and Robotics and Department of Electrical Engineering and Computers.
Awards: Profs. Newman and Herr both were named by Time Magazine for the Best Inventions of 2007 for their work on the BioSuit™ and Ankle-Foot Prostheses, respectively. Biomedical Devices faculty are actively planning the Annual Workshop scheduled for May30-31, 2008, in Braga. This is a collaborative effort between the Bioengineering Systems and EDAM focus

areas.2 MPP doctoral students will be hosted in the Herr Biomechatronics lab and the Newman lab (MVL) during Year 3.