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Prostheses and Exoskeletons: Moving From a Mechatronics Bottleneck through a Controls Bottleneck

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Extended Abstract

The human body is an amazing design that is in many ways superior to anthropometric robots, whether throwing a ball [1] or tying a knot. This contrast becomes clear when the person becomes injured and we attempt to augment it with a robotic interface such as a prosthetic limb or a powered exoskeleton to regain mobility. Existing robotic augmentation systems tend to be heavy and have significant inertias due to high transmission ratios [2]. But equally important, anthropometric robots tend to have difficulty rendering accurate forces (again due to their high gear ratios) or achieve stable gait in the presence of environmental perturbations, and these control challenges are amplified when the robot must coordinate activities with the user. This is a complex problem that requires an accurate understanding of interaction between the mechatronic system, the control platform, and the human.

Recent advances by ourselves [3]–[7] and others [8]–[10] have enabled us to transition from a mechatronic bottleneck to a control bottleneck in powered prostheses and exoskeletons. This is an exciting time in the field in which a variety of mechatronic platforms are available to answer a host of clinically relevant controls problems, with an ultimate goal to improve the lives of people who have a disability. This abstract covers our recent work in upper and lower limb control interfaces.

Upper-limb control interface. In the field of upper-limb prostheses we have developed a principled approach that broadly falls within the realm of a nonlinear quadratic Gaussian controller [11] to understand how the user controls a device in light of its noise (myoelectric control signals have substantial multiplicative sensor noise) and reduced feedback (many of the sensors in your arm are lost in amputation). Our modelling approach is able to accurately predict the ways that people compensate for reduced control certainty and reduced visual feedback [12]–[14]. Using essentially an inverse-model approach, we are now predicting optimal control and sensory feedback dynamics in order to minimize uncertainty and maximize performance in light of the user's known control strategies.

Lower-limb control interface. Using nonlinear control approaches, we have taken what is typically a non-autonomous trajectory-defined problem and turned it into an autonomous phase-defined problem through the use of virtual constraints [15]. This has enabled us to achieve stable, robust walking of robotic prosthetic legs that we are currently extending to exoskeleton control. Our approach has been shown to match human-like adaptation [16], demonstrated to be theoretically stable *without* an accurate model of the user or prosthesis [17], [18]; demonstrated robustness in lab-testing even in the presence of speed perturbations [19], and is appreciated by clinicians and patients. We are currently extending this approach to hip control in an exoskeleton.

With the recent development of appropriate hardware, control problems are starting to be addressed at a level that can truly impact patient care within the field of rehabilitation engineering. The fusion of new mechatronic technologies with advances in control theory should result in tangible impacts in clinical care within the next decade.

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