QUANTIFYING PHYSICAL INTERFACE DYNAMICS: HUMAN-PROSTHESIS AND HUMAN-EXOSKELETON POWER TRANSMISSION

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INTRODUCTION

Prostheses and exoskeletons are (electro)mechanical systems that transfer power to and absorb power from the human body in a time-varying fashion in order to augment movement capabilities. However, these devices are only beneficial if the mechanical power (or force) they provide is effectively transferred to/from the human body. We currently lack assessment methods to fully measure or understand physical human-device power transmission.

Here we discuss our recent efforts to quantify human-device physical interface dynamics, specifically power transmission. Mechanical power may be received by the body in a variety of ways: absorbed through soft tissue deformation, absorbed via active antagonistic muscle contractions, or transferred to generate motion of the body segments. We are generally interested in maximizing the latter, the ability of a person to use device power to facilitate movement (e.g., the ability of an amputee to use prosthetic power to facilitate walking). We would like to minimize the energy dissipated in soft tissues and energy that is counteracted (absorbed) by muscles that are actively contracting to fight against the device power. It is therefore imperative to develop and apply quantitative methods that can capture not only how much device power is produced, but also where this device power is transmitted, and to what degree it does or does not effectively augment human movement.

METHODS

We employ a combination of measurement modalities (motion capture, force transducers and electromyography) in conjunction with advanced 6 degree-of-freedom biomechanical analysis methods to investigate human-device interaction and to quantify the effectiveness of human-device power transmission. In this symposium we will present quantitative methods and results from (A) bionic foot prostheses, and (B) rigid exoskeletons and soft exo-suits. We will discuss how conventional biomechanical estimates may be adapted to study human-device power transfer.

RESULTS & DISCUSSION

Power absorbed via active muscle contractions may be assessed indirectly from inverse dynamics joint kinetics (and potentially electromyography). For instance, we found evidence that lower limb amputees were not able to fully utilize the power generated from a bionic foot prosthesis: increasing positive power from the prosthesis led to simultaneous increases in the magnitude of negative power about the knee during walking [1]. Thus a substantial portion of the prosthetic power appeared to be absorbed by the knee musculature. Amputees must compensate for power transmission losses by altering their gait pattern, often in unhealthy ways, which may contribute to long-term health and mobility problems.

Prosthetic power may also be lost in transmission due to residual limb deformation and relative motion ("pistoning") within the prosthetic socket. This absorption detracts from prosthetic power that would otherwise be transferred to the body to assist movement. We are now adapting and applying 6 degree-of-freedom biomechanical analysis techniques [2] to estimate this soft tissue power absorption within the socket. Preliminary results will be presented and discussed.

Similar power transmission challenges exist for human-exoskeleton systems. It has been estimated that as much as 50% of the mechanical power generated by exoskeletons may be lost in transmission to the body [3]. Rigid exoskeletons (e.g., [4]) often exert forces that are normal to human body segments and power is absorbed through the compression of soft tissues. Soft exo-suits (e.g., [5]) typically apply larger shear forces to body segments, and therefore also dissipate power through skin/tissue stretch and relative motion of the device interface with respect to the human body. We have recently begun testing of both rigid exoskeletons and soft exo-suits to characterize human-device interface dynamics [6]. We are now adapting conventional biomechanical analyses to estimate energy losses during transmission. Methodological challenges and preliminary results will be discussed.

CONCLUSION

Despite marked advances in human augmentation technology, limited attention has been paid to human-device power transmission. There remains a large knowledge gap in our understanding of human-device interface dynamics, specifically related to how effectively device power is transferred to the human user to augment movement capabilities. Current empirical evidence indicates that power transmission problems exist for prostheses and exoskeletons, which undermine their functional benefits. Given the trend in human augmentation technology towards higher power devices, it is becoming increasingly important to understand and optimize human-device power transfer. We explore how conventional biomechanical analyses may be adapted to provide useful and practical estimates of power transmission in human-prosthesis and human-exoskeleton systems. Advancing knowledge of human-device interface dynamics will inform assistive device design and control, and the manner in which exoskeletons and prostheses are physically coupled to the human body.

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