Toward Tip-Top Testbeds: Biomechatronics for Accelerated Development of Assistive Devices

Steve Collins[1]
[1]Dept. Mechanical Engineering, Carnegie Mellon University, Pittsburgh, PA, USA, stevecollins@cmu.edu

INTRODUCTION

Biomechatronic devices, such as robotic prostheses and exoskeletons, show promise for restoration and rehabilitation of human biomechanical performance [1,2]. Development has been made slow and inefficient, however, by the need for new designs of high-performance, autonomous devices prior to testing benefits of proposed functionalities. This high cost, often requiring years of design and refinement, has severely limited exploration within and across intervention strategies.

Laboratory testbeds, by contrast, have often been used as versatile exploratory tools in basic research on, e.g., human neuromechanics [3]. Such systems typically serve as probes, requiring only moderate mechatronic performance to gain useful insights. With improved fidelity, perhaps such tools could also be used to emulate specialized, wearable robots [4].

MECHATRONIC DESIGN

We have developed a testbed suitable for rapid assessment of gait interventions. This system (Figure 1) comprises: i. powerful motor and control hardware, ii. a flexible tether, and iii. lightweight, instrumented end-effector(s) worn by a person. Off-board motor control components can be large and heavy, allowing simpler designs with higher performance. Only one drive and tether is needed for a wide variety of end-effectors. These light, wearable elements can take any form, with design made simple by leveraging off-board power. A single end-effector, such as an ankle-foot prosthesis, can emulate many control behaviors and mechanical elements.

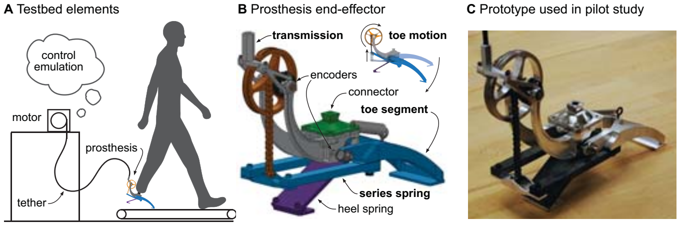

Figure 1: Experimental biomechatronic testbed.

We used an electric motor drive and a Bowden cable tether, and designed two ankle end-effectors, one prosthesis and one orthosis. A 1.6 kW 3-phase AC servomotor (Baldor Co.) is commanded by a 1GHz control package (dSPACE). Power is transmitted through a 3 m Bowden cable with 0.006 m Vectran cable. Each end-effector uses a fiberglass leaf spring for series elasticity while transforming cable tension into joint torque (Figure 1). Ankle joint angles are measured directly, while joint torque is inferred either from spring deflection or strain.

SYSTEM PERFORMANCE

We performed a series of benchtop tests to gage mechatronic performance, and found significant improvements over prior platforms (Table 1). In particular, this system has an unusual combination of low worn mass and high closed-loop torque bandwidth, key to emulation of specialized biomechatronic devices. We also performed walking trials to gage dynamic torque control and versatility. For example, we applied an impedance law relating joint angle and velocity to desired torque, and widely varied net ankle work (Figure 2).

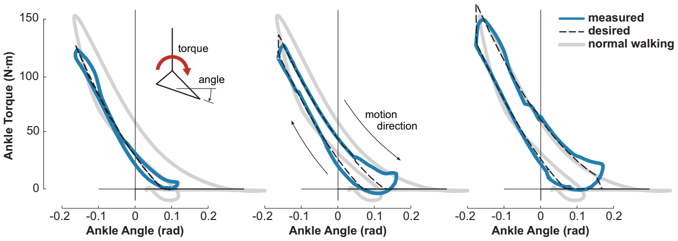

Figure 2: Impedance-based torque tracking during walking.

APPLICATIONS

We will use these ankle simulators to investigate the effects of robotic prosthesis and orthosis design on human energy use, stability, and adaptation. In one pilot study, we systematically varied net ankle work and measured metabolic cost. Increased ankle push-off work could reduce human energy cost [2,3], but also requires larger, heavier motors and batteries, or shorter range, in autonomous devices. Delineating this trade-off will inform autonomous designs that suit targeted patient groups.

REFERENCES

[1] Herr HM and Grabowski AM (2011). Bionic ankle-foot prosthesis normalizes walking gait for persons with leg amputation. *Proc. Roy. Soc. Lon. B.* Vol **279**(1728); p. 457-64.
[2] Collins SH and Kuo AD (2010). Recycling energy to restore impaired ankle function during human walking. *Public Library of Science ONE*, Vol **5**, e9307.
[3] Sawicki GS and Ferris DP (2008). Mechanics and energetics of level walking with powered ankle exoskeletons. *J. Experimental Biology* Vol **211**; p. 1402-1413.
[4] Flowers WC and Mann RW (1977). An electrohydraulic knee-torque controller for a prosthesis simulator. *J. Biomechanical Engineering* Vol **99**(1); p. 3-9.

ACKNOWLEDGEMENTS

Thanks to J. Caputo, M. Eicholtz, and R. Jackson for their work on the prosthetic and orthotic testbeds.

Table 1: Mechatronic performance determined from benchtop tests. The best values collected from other lower-limb biomechatronic devices are provided for reference. * These are from a variety of tethered and un-tethered systems at various joints.

	Worn Mass (kg)	Bandwidth (Hz)	Torque (N·m)	Power (peak, W)
Prosthesis testbed	0.86	12	225	800
Best reported values *	1.37	7.5	175	630