Preliminary Results of a Reaction Force Series Elastic Actuator for Powered Knee and Ankle Prostheses

Matthew E. Carney
Biomechatronics, MIT Media Lab
Massachusetts Institute of Technology
Cambridge, MA 02139, USA
mcarney@media.mit.edu

Hugh H. Herr
Biomechatronics, MIT Media Lab
Massachusetts Institute of Technology
Cambridge, MA 02139, USA
hherr@media.mit.edu

***Abstract*— We present the design and preliminary results of a reaction force series elastic actuator that aims to replicate the biological kinetics and kinematics of level-ground walking in human knee and ankle powered prostheses. The actuator presented is tunable to different user mass and actuator requirements, offering potential improvements in battery runtime, mass, acoustic noise, and comfort. The design is based on kinematically clamping biological-gait data to actuator dynamics and searching for a configuration of hardware components that minimize the electric cost of transport, while subject to physical constraints such as motor, power electronics and fatigue-life estimates. The result is a single actuator capable of achieving both knee and ankle torque and power requirements, and that which is adjustable toward optimality for specific individuals and applications. The hardware presents a gait research platform with knee mass of 1.6kg, ankle mass of 2.0kg, peak repeatable torques of 175Nm, range of motion of 110 degrees, maximum torque controllable bandwidth of 6Hz, and output power over 500W.**

Powered ankle and knee research is limited in hardware availability. The only commercial powered ankle [1] and knee [2] systems are closed source and have limited capabilities. Research platforms exist but all have divergent actuator designs for ankle or knee [3]–[8]. Simplification of design can improve reliability and maintainability of hardware platforms so that more time can be spent on science. Further, designs that incorporate low-reflected-inertia, or low-impedance drivetrains can enable greater closed-loop torque control.

The detail design of the reaction force series elastic actuator, TF8-RFSEA, is based on actuator simulation and design methods described in [9]. Following protocols approved by the MIT IRB we performed experiments with N=3 above knee and below knee volunteer subjects with amputation. For preliminary demonstration the walking controllers are impedance-based finite-state machine controllers following methods described in [7], [10].

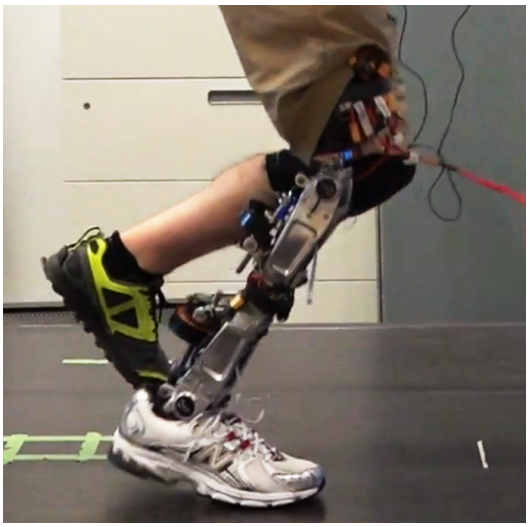

Fig. 1. The TF8-RFSEA shown configured as both an ankle and knee powered prosthesis.

References

[1] Bionx, "The BiOM Advantage - BionX Medical Technologies," 2017.
[2] Össur, "Össur Dynamic Solutions Power Knee™," 2018.
[3] A. F. Azocar, L. M. Mooney, L. J. Hargrove, and E. J. Rouse, "Design and Characterization of an Open-Source Robotic Leg Prosthesis," *Proceedings of the IEEE RAS and EMBS International Conference on Biomedical Robotics and Biomechatronics*, vol. 2018-Augus, pp. 111–118, 2018.
[4] E. J. Rouse, L. M. Mooney, E. C. Martinez-Villalpando, and H. M. Herr, "A Clutchable Series-Elastic Actuator: Design of a Robotic Knee Prosthesis for Minimum Energy Consumption," in *Proceedings of the IEEE International Conference on Rehabilitation Robotics*, 2013.
[5] B. E. Lawson, J. Mitchell, D. Truex, A. Shultz, E. Ledoux, and M. Goldfarb, "A robotic leg prosthesis: Design, control, and implementation," *IEEE Robotics and Automation Magazine*, vol. 21, no. 4, pp. 70–81, 2014.
[6] P. Cherelle, V. Grosu, A. Matthys, B. Vanderborght, and D. Lefeber, "Design and validation of the ankle mimicking prosthetic (AMP-) Foot 2.0," *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, vol. 22, no. 1, pp. 138–148, 2014.
[7] S. K. Au and H. M. Herr, "Powered Ankle-Foot Prosthesis," *IEEE Robotics & Automation Magazine*, no. September, pp. 52–59, 2008.
[8] T. Lenzi, M. Cempini, L. J. Hargrove, and T. A. Kuiken, "Design, Development, and Testing of a Lightweight Hybrid Robotic Knee Prosthesis," *International Journal of Robotics Research*, vol. in press, 2018.
[9] M. E. Carney, "Design and Evaluation of a Reaction-Force Series Elastic Actuator Configurable as Biomimetic Powered Ankle and Knee Prostheses by," PhD, Massachusetts Institute of Technology, 2020.
[10] F. Sup, H. A. Varol, J. Mitchell, T. J. Withrow, and M. Goldfarb, "Preliminary Evaluations of a Self-Contained Anthropomorphic Transfemoral Prosthesis," *IEEE/ASME Transactions on Mechatronics*, vol. 14, no. 6, pp. 667–676, dec 2009.

Financial support: the MIT Media Lab Consortia, the USAMRMC (W81XWH-14-C-0111) and DARPA (W911NF-17-2-0043).