Development of a Transtibial Biarticular Prosthesis with Offboard Actuation and Control

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***Abstract*— People with transtibial lower limb loss exhibit pathological gait, even when using state-of-the-art robotic prosthetic ankles. We hypothesize that a prosthesis with biarticular knee-ankle actuation, replicating the function of the gastrocnemius muscle, could improve amputee gait. To explore this hypothesis, we designed and developed a biarticular prosthesis for transtibial amputees that combines a knee flexion exoskeleton with a powered prosthetic ankle. We plan to actuate and control the biarticular prosthesis with on offboard actuation and control system to explore knee-ankle powered prosthesis behaviors which may improve gait patterns.**

I. Introduction

Transtibial amputees exhibit pathological gait associated with the lack of ankle plantar- and dorsiflexor muscles. We believe a biarticular prosthesis that mimics the biological gastrocnemius might improve amputee gait, and previously designed a device to test this hypothesis [1]. The behavior and function of the prior device was narrowly defined by its specific hardware embodiment, which limited our ability to explore a wide range of potentially helpful behaviors. To improve our experimental capabilities, we are now developing an offboard biarticular prosthesis with flexible behaviors specified in software, which will allow us to more rapidly explore a wide space of biarticular assistance strategies

II. Wearable Device

The current biarticular prosthesis combines an active knee flexion exoskeleton with an active prosthetic ankle. Both devices are actuated independently by an offboard actuation system similar to [2]. Within the control system, the commanded joint torques are coupled to make the overall system behave like a combination of uni- and biarticular elements.

The prosthetic ankle is a Venture Foot (College Park Industries, Warren, MI, USA) that was modified to be Bowden cable driven in plantarflexion. Custom components were retrofitted to provide Bowden cable actuation in parallel with the original elastic elements in the Venture Foot.

The knee exoskeleton is actuated via pulley on the lateral side of the knee. Several of the exoskeleton components were manufactured with a 3D printer (MarkForged, Watertown, MA, USA) with a continuous fiberglass inlay. Struts for the medial and lateral sides of the leg were water-cut from sheets of carbon fiber. Both the prosthesis and exoskeleton measure joint angles with magnetic rotary encoders, and applied Bowden cable forces with through-hole load cells.

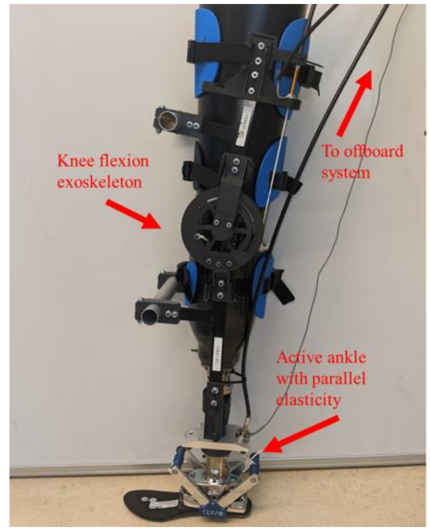

Figure 1: Primary components of the biarticular prosthesis

III. Offboard hardware and Software

The ankle prosthesis and knee exoskeletons are actuated by Bowden cable transmissions and the Kollmorgen AKM74L (5.4 kW rated power, 114 Nm peak torque) and Kollmorgen AKM52H (2.5 kW rated power, 37 Nm peak torque) motors, respectively. The motors are controlled by two servo drives on a high voltage circuit. Motor current commands are sent to the drives by a National Instruments PXI real-time controller running LabVIEW 2018. The real-time controller runs all I/O and a joint torque PID controller at 1 kHz. The controller communicates with a desktop PC that functions as an experimenter interface.

IV. Ongoing and Future work

We are currently benchtop testing the device and have completed pilot walking experiments in the exoskeleton with healthy subjects. Pilot work is ongoing to parameterize and test a biarticular joint torque controller that can be used in future human-in-the-loop optimization experiments.

References

[1] A.M. Willson, et. al., “Design and Development of a Quasi-Passive Biarticular Prosthesis to Replicate Gastrocnemius Function in Walking,” in ASME *J. Med. Devices*, 2020, https://doi.org/10.1115/1.4045879

[2] J. M. Caputo and S. H. Collins, “An experimental robotic testbed for accelerated development of ankle prostheses,” in *IEEE International Conference on Robotics and Automation*, 2013, pp. 2645–2650.

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