Design of an Agonist-Antagonist Knee Prosthesis for Experiments in Human Locomotion

James Gabriel, Steve Collins
Carnegie Mellon University, Pittsburgh, PA USA
JamesCGabriel@cmu.edu

1 Motivation

The goal of this research is to further the community's knowledge of prosthetic knee control and inform the design and prescription of trans-femoral prostheses. Additionally, our device expands the CMU emulator system from the ankle-foot prosthesis, allowing for future work in full foot-ankle-knee emulation.

2 State of the Art

We previously developed an ankle-foot prosthesis emulator with exceptional versatility [1]. It is lightweight, capable of producing large torque and power, and can quickly change behaviors [2]. However, it cannot fully address the needs of trans-femoral amputees. In the commercial market there are many active knees such as the Ottobock C-leg and Össur Power Knee. These are successful products, but not ideal for basic biomechanics experiments needed to identify optimal assistance strategies.

3 Our Approach

We designed and built a lightweight, versatile knee end-effector for the CMU emulator system. This is an instrumented, mechanical system weighing less than 1.1 kg and driven by two Bowden cables. The knee is composed of a pyramidal adapter and upper knee which rigidly attaches to the amputee's socket adapter. The lower knee and tibia rotate via a pinned joint. Knee angle is measured by an encoder at the pinned joint. A unique feature of this knee is the dual tibia design, with the lower leg split into two tubes. This allowed for the incorporation of series elastic elements and reduced the overall package size.

Knee flexion and extension torques are generated by the two Bowden cables routing around a cantilevered kneecap in an agonist-antagonist configuration. The torques themselves are measured by sets of strain gauges connected in full-bridge configurations at two places on the kneecap.

System control is achieved through a three-layered control scheme. The highest level is a walking controller which takes information on the subject and their gait and commands net knee torques. The middle level controller takes these full knee torques and translates them into velocity signals which are split and sent to their respective flexion or extension motor. The lowest level regulates motor velocity using voltage control.

The benefit of this tiered system is that it allows for the top level controller to be switched out at any time. This flexibility is what gives the emulator systems its unique effectiveness as a research tool.

4 Future Opportunities

Our future work on this system is first to prove it out in benchtop testing. It will undergo bandwidth and power testing to characterize the system. We will then complete the controller design. Finally, we will use the knee in pilot tests on participants who have trans-femoral amputation.

5 Desired Outcome

The goal of this system is to prove a test-bed that allows for research into new knee control schemes. These schemes would be designed to give a reduction of metabolic energy cost, improve amputee balance, and improve fall recovery.

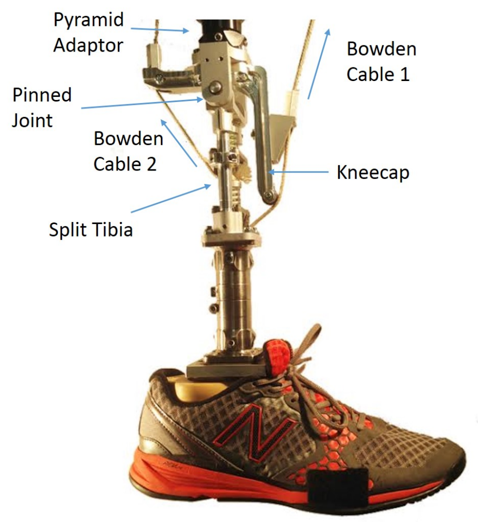

Figure 1: Photograph of the prosthetic knee end-effector

References

[1] J.M. Caputo, S.H. Collins. (2014) "A universal ankle-foot prosthesis emulator for human locomotion experiments" *Journal of Biomechanical Engineering*, **136**:035002

[2] J.M. Caputo, S.H. Collins. (2014) "Prosthetic ankle push-off work reduces metabolic rate but not collision work in non-amputee walking." *Nature Scientific Reports*, **4**:7213