Development and evaluation of a powered knee stumble recovery controller for transfemoral prosthesis users

Shane T. King[1], Maura E. Eveld[1], Leo G. Vailati[1], Karl E. Zelik[1], Michael Goldfarb[1]
[1]Department of Mechanical Engineering, Vanderbilt University, Nashville, TN, USA
Email: shane.t.king@vanderbilt.edu

Introduction

Individuals with transfemoral amputation are 200 times more likely to fall from a stumble [1, 2], which leads to an increase in fall-related injuries and lower community engagement.

The current standard of care is a microprocessor knee prosthesis, which relies upon the user's hip to drive the motion; however, these low-impedance knee joints are easily displaced from their trajectory by an obstacle. A powered device is able to overcome this issue. Inclusion of a motor to drive the knee joint allows the device to actively recover from perturbations.

To test if implementing healthy recovery strategies on a powered prosthesis will reduce users' fall incidence and improve stumble recovery, we have replicated the two primary healthy recovery strategies (i.e., elevating and lowering) [3] on the Vanderbilt Knee (Fig 1, B). However, the most critical component is choosing which strategy to use, which has not been done before. This decision is important because an incorrect selection would lead to a mismatch between the device and the user, making recovery more difficult. We propose that the key to successfully improving stumble recovery for transfemoral prosthesis users is allowing them to drive the actions of the device such that they are able to move together in a coordinated fashion. Thus, the objective of this work is to present the formulation and validation of this controller design.

Methods

The goal of the controller is to follow the initial dynamics of the user's residual limb several milliseconds after the perturbation. This allows the device to ensure its response is in coordination with the user's movement, while still responding quickly enough to recover. For example, if a user continues to flex their hip shortly after the perturbation, then the powered device has time to use an elevating strategy and bring the leg up and over the obstacle as the user continues to swing their leg. However, if the user stops flexing their hip or begins extending, the device must use the lowering strategy to extend the knee, support the user, and assist as they clear the obstacle in the next step.

To determine the initial response of the user's residual limb, an inertial measurement unit (IMU) on the prosthesis shank and an encoder on the prosthesis knee joint are used to observe the user's thigh and shank angle configuration space which forms a portion of an ellipse during swing phase (Fig. 1, A).

The use of this configuration space was piloted with healthy stumble recovery motion capture data that was collected using an in-house treadmill stumble apparatus [3] (Fig. 1, C). The data showed a distinct bifurcation in the response of the configuration space during a perturbation. Perturbations that resulted in an elevating strategy showed the configuration space trajectory exiting from its typical ellipsoid path towards the exterior of the ellipse, while perturbations that result in a lowering strategy showed the configuration space trajectory exiting towards the interior of the ellipse. The controller uses this bifurcation by analyzing the error of the current configuration space trajectory compared to the typical configuration space ellipse trajectory. This allows the device to determine which strategy to use to recover from a perturbation.

Testing with the powered prosthesis was performed on one healthy subject using an able-body adaptor (Fig. 1, A) to determine if the trends were the same when using the powered prosthesis with IMU/encoder signals compared to the healthy motion capture data. Additionally, the controller was tested to see if using the bifurcation to choose the recovery strategy allowed for an improved recovery.

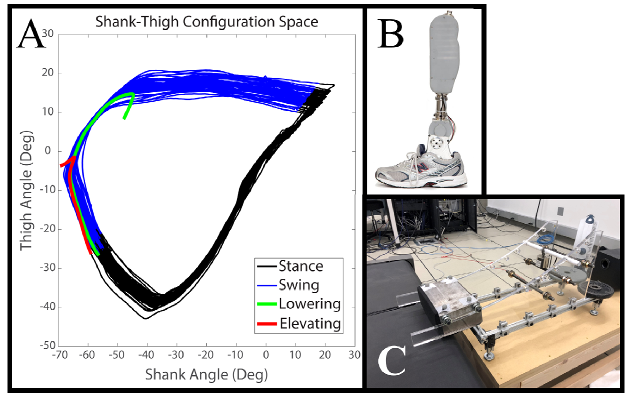

Figure 1: A) Thigh-shank angle configuration space data. **B)** Vanderbilt Powered Prosthesis. **C)** Treadmill stumble apparatus.

Results and Discussion

Preliminary results collected from the healthy subject using an adaptor have matched the initial configuration space trajectory bifurcations of the original healthy stumble recovery data set. An example of this bifurcation is shown in Fig. 1, A. The controller allowed for the subject to successfully recover from stumble perturbations across a range of timings from early to late swing phase using an appropriate stumble recovery strategy. The next step will be testing the controller on transfemoral prosthesis users to ensure the control system is able to coordinate with their current stumble recovery reflex; data from which will be presented at the conference. Metrics will include ability to recover from the perturbation, time to return to steady state walking, and knee angle trajectory comparisons to healthy recovery data to show the benefits of the control system.

Significance

Overall, the control system described herein has the potential to substantially reduce the risk of falling and improve stumble recovery for people with transfemoral amputation. By following the dynamics of the user's body, the controller works in concert with the user's recovery instead of impeding it.

References

[1] Kahle JT et al. (2008). *J Rehabil Res Dev*, **45**: 1-14.
[2] Talbot LA et al. (2005). *BMC Public Health*, **5**: 86.
[3] King ST et al. (2019). *J NeuroEng Rehab*, **16**: 69.