Amputees face a number of gait deficits due to a lack of control and power from their mechanically-passive prostheses. Of crucial importance among these deficits are those related to balance, as falls and a fear of falling can cause an avoidance of activity that leads to further debilitation. In this thesis, we investigate the role that prosthesis control strategies play in maintaining balance with a powered robotic transfemoral prosthesis. Our approach involves comparing state-of-the-art prosthesis controllers on a common platform and learning from this experiment to propose two new prosthesis control strategies that directly address observed causes of falls in both the swing and stance phases.

We begin by designing and manufacturing our own powered transfemoral prosthesis capable of large torques for stumble recovery and accurate reproduction of desired torques from different control strategies. We also propose a pair of optimization methods that allow us to select prosthesis control parameters using qualitative preference feedback from the user.

Next, we test a hypothesis that a stance control approach based on a model of the human neuromuscular system may help improve gait robustness and user satisfaction over the commonly used impedance control method. This hypothesis stems from previous research applying neuromuscular control to simulated biped models and to powered ankle prostheses that suggests that this approach can adapt to changes in speed, incline, and rough ground. While our experiment did not find a significant reduction in falls using neuromuscular control, it did reveal that a lack of robust gait phase estimation caused a large number of falls for the impedance control strategy and that both controllers suffered from trips during swing.

Therefore, we next proposed and tested two new control strategies that directly address these causes of falls. In the first, we use information from an inertial measurement unit and LIDAR distance sensor to estimate the position, orientation and future trajectory of the hip. This information is then used to plan trajectories for the prosthesis’ knee and ankle that avoid tripping during swing. Second, we propose using an extended Kalman filter to improve phase estimation during stance. We show the resulting control strategy significantly reduced the number of falls compared impedance control when users step on uneven terrain. These results demonstrate the importance of state estimation for improving gait stability.