

ABSTRACT

Millions of individuals with lower limb amputations encounter considerable challenges in maintaining postural stability as compared to able-bodied individuals due to the loss of sensory feedback and limited joint movement in passive prostheses. This instability leads to frequent falls and hinders rehabilitation progress. It is understood that a prosthetic device with a suitable torque delivery is necessary to avoid such complications. This dissertation focuses on estimating the corrective torque required from external assistive devices, such as powered exoskeletons and prosthetics, by utilizing postural control techniques to enhance inter-limb coordination.

In the context of powered exoskeletons and prostheses, a prior assessment of corrective action using a computational method facilitates the selection of an appropriate actuator that delivers necessary joint torque while maintaining postural stability. Consequently, an effective computational model of gait initiation that incorporates neuromuscular system parameters becomes essential prior to the design of such prosthetic devices. Estimating the required corrective torque is a recognized challenge in this field. As an initial study, an inverted pendulum (IP) model-based approach of healthy individuals was explored to model the postural dynamics in individuals with lower limb amputation. The main objective of the current study was to estimate the external torque required from an external assistive device using a postural model-based control technique to maintain the postural balance. The IP model and a suitable control strategy were validated through simulation studies using kinematic data recorded from four healthy individuals and four individuals with lower amputation.

To compensate for postural balance asymmetries during inter-limb coordination, individuals with lower extremity amputation over-depend on visual inputs and somatosensory information from the intact limb. This additional demand leads to higher mental engagement and an additional flexion and extension torque in the sound limb, resulting in the asymmetrical weight distribution between the limbs and the unacceptability of current passive prostheses. To address such issues, a biomechanically relevant ankle-foot prosthesis model with a suitable model-based control approach was explored to estimate the required control torque on the prosthetic ankle joint during dynamic balance tasks in different visual conditions. The postural model and the control technique were validated through simulation studies using kinematic data recorded from six individuals with lower amputation. The results

indicate that the effectiveness of the proposed approach has a significant potential to accommodate balancing uncertainties in different visual conditions by addressing the design-oriented challenges in prosthetic solutions.

While estimating desired corrective torque, existing prosthetic-based postural control approaches acknowledge challenges in accounting for diverse biomechanical variations in real-time, further impacting the efficacy of the rehabilitation outcomes. To address this, a novel biomimetic motor-driven ankle-foot prosthesis prototype was initially developed to follow the intact limb trajectory collected from three amputated individuals by delivering corrective action. Later, a data-driven adaptive control-based bench-top model was designed and implemented to achieve real-time closed-loop trajectory tracking performance. Specifically, this approach aimed to record the reference trajectory from the intact limb and deliver the required torque to the prosthetic side by utilizing a data-driven adaptive control method to enhance inter-limb coordination. The benchtop model was tested through simulated scenarios using kinematic data recorded from ten individuals with different levels of unilateral lower amputation. Results illustrate that the proposed approach could reduce the asymmetrical weight bearing on the intact limb and enhance rehabilitation outcomes in prosthetic users.

It is crucial to validate the concept of the closed-loop data-driven adaptive control mechanism in a clinical setting. Furthermore, it is essential to investigate the performance of such a training approach on different levels of amputation (transtibial and transfemoral), different visual conditions (eyes open and eyes closed), and different directions for balancing exercises. To address these aspects, an innovative in-house training platform was designed and fabricated to explore the application of corrective feedback on the postural balance in unilateral lower limb amputees. The training platform employs a data-driven, model-independent control architecture to deliver corrective torque to the prosthetic limb based on measurements taken from the intact limb during balancing tasks. Consequently, the corrective torque facilitates the prosthetic limb to enhance inter-limb coordinated control. Eight participants with lower limb amputations consented to participate in this study. The efficacy of the proposed training platform was assessed using different performance matrices between the intact and prosthetic limbs. The findings indicate that corrective feedback delivered by the proposed training platform is more efficacious in unilateral lower limb amputees during balancing tasks.