# Active Surface Matching Control using an Ankle-Foot Prosthesis Emulator with Two Axes of Torque Control

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## 1 Introduction

For many people with a lower-limb amputation, walking on cross slopes and rough terrain leads to destabilizations in the medial-lateral direction. While able-bodied people can compensate and react to cross slope terrain roughness using active ankle joint control, the majority of modern lower-limb prostheses do not provide the actuation necessary for amputees to comfortably walk on non-uniform surfaces. These prosthetic limitations lead to unstable gaits, a higher likelihood of falling, and higher metabolic energy costs while walking[1]. This study uses a prosthesis emulator with both plantarflexion and inversion-eversion actuation[2] as the hardware framework to investigate how an active controller can assist amputees while walking on uneven terrain. In addition to precisely controlling roll torque, the prosthesis toes can be used to "feel" the ground beneath the device and adjust control parameters to stabilize the amputee at each step. The objective of this study is to fully develop a controller with these abilities and study how amputee subjects operate while wearing it and walking on uneven ground.

## 2 Methods

*Controller Design.* Building off of the state-based dynamic walking controller for our prosthesis emulator[2], the surface matching controller responds to medial-lateral ground variations by actuating spring-like roll torque behavior centered on a neutral roll angle. The neutral roll angle for each step will be calculated during the landing phase, when the two toes of the prosthesis initiate contact with the ground (signified by non-zero plantarflexion torques). Consider a subject wearing the device and walking upright on a cross slope. During the position-controlled swing phase, the prosthesis is aligned with the person's leg and the toes are at the same height. During the landing phase, the independent toes will contact the slopped ground at different times and heights – the uphill toe will contact before the downhill toe. The controller uses use the toe encoders to record the absolute angles at the time of ground contact for each toe. These measurements are used to determine the magnitude of the cross slope and set an appropriate neutral roll angle to provide support during that step. For example, the controller might specify a neutral angle that ensures the prosthesis remains level (with the pylon vertical) throughout the step to reduce hip and knee torques imposed on the amputee subject. This example of control would isolate the subject from the cross slope ground variation and give a stability similar to walking over level ground. Once a neutral roll angle is set, the controller actuates spring-like roll torque behavior as a means of stabilizing the subject during the stance and push-off phases. The net plantarflexion torque during the push-off phase remains unaffected by the inversion-eversion control because the controller is able to distribute torque between both toes.

*Protocol.* Experimental testing will begin with able-bodied subjects before transitioning to amputee subjects. Each subject will experience a defined set of conditions differentiated by stiffness in the roll direction. Medial-lateral ground height variations will be simulated by random placement of short blocks under the toes of the prosthesis. Experimental data will be recorded in the form of torso and lower limb motion capture data (for kinematics), metabolic data (for energy consumption), and treadmill force plate data (for step width variability calculations).

## 3 Future Work

Over the next three months, the surface matching controller development will be completed and pilot testing will begin on able-bodied subjects. Preliminary results will include analysis of prosthesis performance under the new control scheme, kinematic analysis of subject walking gait, and metabolic cost measurements. Beyond pilot tests, a full study will collect experimental data from multiple amputee subjects and trends in subject response will be investigated.

## 4 Long Term Outcomes

The controller developed through this study will give valuable insight into the effectiveness of surface matching control for ankle-foot prostheses. Experimental data will be used to determine how surface-matching control may be implemented on semi-active and fully-active commercial prostheses.

## References

[1] A.D. Segal, et al. "Lower-limb amputee recovery response to an imposed error in mediolateral foot placement," Journal of Biomechanics 2014.

[2] Steve H. Collins, et al, "An ankle-foot prosthesis emulator with control of plantarflexion and inversion-eversion torque", Int. Conf. Robotics & Automation, 2015.