Design of a Multidirectional, Multi-Contact Robotic Gait Perturbation System

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Summary

Falls are a growing medical and financial problem on a global scale. Many previous attempts to study stability in at-risk populations, such as the elderly and amputees, have been hindered due to an inability to properly induce falls in a laboratory setting. We propose a robotic system capable of delivering "bump" perturbations to the pelvis in the mediolateral and anteroposterior directions, "trip" perturbations to the ankles in the posterior direction, as well as slip-like belt disturbances. Using this perturbation system to accurately recreate slip, trip, and bump-induced falls in a laboratory setting, we will identify an improved metric for stability. Additionally, we will use this system to develop devices to improve stability in target populations and explore fundamental aspects of gait, such as the relationship between stability and efficiency.

Introduction

Approximately 1 in 3 older adults (aged ≥ 65) fall each year [1]. Many falls are fatal or result in serious injuries such as fractures [2]. Falls cost the U.S. healthcare system $50 billion annually and the cost is expected to rise with the aging population [3]. Perturbations such as trips and slips account for 60% of outdoor [4] and 35% of indoor falls [5] in the elderly. Previous attempts at creating perturbation systems to study falls in a laboratory setting have shown promising results [6, 7, 8]. We believe a system able to render an interaction accurately representing a real slip, trip, or bump at multiple contact points on the body and from a variety of directions while walking will be extremely useful, as subjects will not be able to rely on simple anticipatory adaptations that address a single type of perturbation.

We expect perturbing subjects and studying their responses to yield a predictive metric for stability because we will be able to accurately recreate real-world perturbation falls and study the kinematic, kinetic, and neuromuscular responses. Based on compelling simulations and modeling work [9, 10], we hypothesize that subjects' control strategies, such as foot placement, ankle plantarflexion torque, and modulated joint stiffness, will serve as predictive components in our stability metric. We also hypothesize that there will be a tradeoff between stability and efficiency.

System Design

Our proposed perturbation system consists of multiple tethers connecting the user to off-board motors to perturb them as they walk on a split-belt treadmill. The current design uses strain gauges in series with the tethers to enable closed-loop force control. Additionally, specially designed sensors based on [11] measure the amount of slack in the tethers. These slack sensors allow us to minimize rise time of our perturbations while reducing unintended force on the user between

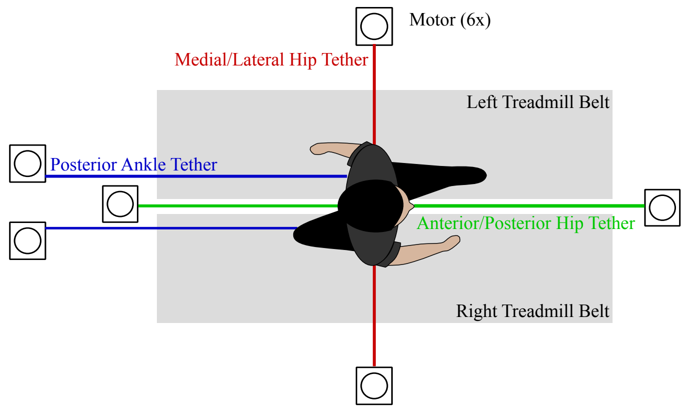

Figure 1: Top view of the robotic perturbation system.

perturbations. Reducing tether force between perturbations helps the user walk with a natural gait until perturbed. Minimizing the perturbation rise time prevents the user from detecting the onset of a perturbation and reacting in ways that an individual experiencing a real fall would not be able to.

The current system design is modular. Each tether location and direction can be installed independently of the others. This modularity is an important aspect of the design, as it facilitates reconfiguring the system as needed to fulfill experimental requirements. Additionally, the system utilizes off-the-shelf components whenever feasible and the design files will be made freely available online. The open access design files, off-the-shelf components, and modular design facilitate adoption by other researchers and clinicians.

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