Mechanical Engineering Doctoral Defense

Towards Robot-aided Gait Rehabilitation and Assistance via Characterization and Estimation of Human Locomotion

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Abstract

Walking and mobility are essential aspects of our daily lives, enabling us to engage in various activities. Gait disorders and impaired mobility are widespread challenges faced by older adults and people with neurological injuries, as these conditions can significantly impact their quality of life, leading to a loss of independence and an increased risk of mortality. In response to these challenges, rehabilitation, and assistive robotics have emerged as promising alternatives to conventional gait therapy, offering potential solutions that are less labor-intensive and costly. Despite numerous advances in wearable lower-limb robotics, their current applicability remains confined to laboratory settings. To expand their utility to broader gait impairments and daily-living conditions, there is a pressing need for more intelligent robot controllers.

In this dissertation, these challenges are tackled from two perspectives: First, to improve the robot's understanding of human motion and intentions which is crucial for assistive robot control, A robust human locomotion estimation technique is presented, focusing on measuring trunk motion. Employing an invariant extended Kalman filtering method that takes sensor misplacement into account, improved convergence properties over the existing methods for different locomotion modes are shown.
Secondly, to learn safe and effective robot-aided gait training, this dissertation proposes to directly learn from physical therapists' demonstrations of manual gait assistance in post-stroke rehabilitation. Lower-limb kinematics of patients and assistive force applied by therapists to the patient's leg are measured using a wearable sensing system which includes a custom-made force sensing array. The collected data is then used to characterize a therapist's strategies. Preliminary analysis indicates that knee extension and weight-shifting play pivotal roles in shaping a therapist's assistance strategies, which are then incorporated into a virtual impedance model that effectively captures high-level therapist behaviors throughout a complete training session. To integrate safety constraints into the learned controllers, a safety-critical learning framework is introduced and subsequently evaluated through simulations.

August 3, 2023; 11 AM; ECG G320