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Neuromechanical Modeling for Personalized Assistive Robotics

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ABSTRACT

Human dexterous motor behavior and locomotion are the results of complex activation patterns of our muscular system orchestrated by the central nervous system (CNS). CNS controls the muscle activations and therefore the forces applied to our skeletal system and modulates the viscoelasticity of our limbs through co-activations of agonist-antagonist muscles. This task-based modulation of limb viscoelasticity enables us to have a smooth and stable interaction with the environment. The active modulation of viscoelasticity, however, is disrupted in individuals with neurological conditions such as stroke patients and individuals with spinal cord injury and result in a subject-specific decrease of the motor function and movement stability. Motivated by the above, this work presents our new algorithmic and mechatronic developments in understanding the limb viscoelasticity, modeling it at the joint level as joint variable mechanical impedance, and use it in the control of assistive robotic systems.

To identify the joint mechanical impedance, perturbation experiments need to be conducted and the perturbed movement kinematics and kinetics need to be matched and compared with unperturbed trajectories. However, the movement variability can worsen our estimate of the representative unperturbed trajectories which in turn adds bias to the estimation of joint mechanical impedance. To address this issue, we developed a clustering-based identification technique that can identify a better match baseline to the perturbed trajectories and improve joint impedance identification. The proposed technique was tested both in simulations and perturbation experiments and the results demonstrate the superiority of this technique to the conventional joint impedance identification techniques. The proposed algorithm also reduces the number of needed perturbation trials for accurate impedance identification. Besides, we developed a mechatronic system and an identification technique for hip impedance estimation during quasi-static tests. The results in 10 healthy subjects showed the feasibility of our mechatronic setup and identification technique.

Furthermore, this work presents an optimal personalized assistive controller which uses the obtained joint mechanical impedance models to adjust itself to the needs of each individual. Preliminary results of this controller, implemented in a wearable lower-limb exoskeleton, demonstrate its feasibility and potential to improve the gait of individuals with incomplete spinal cord injury.