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BALANCE RECOVERY SIMULATION USING A NOVEL BIOLOGICALLY-INSPIRED MUSCULOSKELETAL CONTROL SYSTEM

Reference:
Kistemaker DA, Van Soest AK, Bobbert MF, Wong JD, Kurtzer I, Gribble PL. Control of position and movement is simplified by combined muscle spindle and Golgi tendon organ feedback. J Neurophysiol 109: 1126-1139, 2013.
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Abstract:
Introduction:
Numerical simulations including the control of biological systems have the potential to play a major role in medical decision-making. Balance and walking are among the most challenging tasks for patients dealing with motor control deficits. Central nervous system (CNS) feedback control strategies are a combination of low-level spinal and high-level supraspinal control signals. Our objective was to design a controller based on the CNS to test simulation-based hypotheses related to balance recovery and movement control.
Methods:
We used musculoskeletal modeling, biologically-inspired controller [1], and optimization methods to design the control system for balance recovery (Figure 1). We interfaced OpenSim and MATLAB through a Simulink S-function block. We used a full-body human model with 23 degrees-of-freedom and 92 muscle-tendon actuators as the plant. We used elastic foundation contact to model foot-ground forces. The CNS-based controller consisted of two levels. The high-level controller used computed muscle control (CMC) to estimate muscle activations for quiet standing posture. The low-level controller used a combination of muscle spindle (muscle length and velocity changes) and Golgi tendon organ (tendon force changes) feedback to reject postural disturbances. We tracked the center-of-mass (CoM) to follow the experimental displacement path due to the perturbation. The low-level controller length and velocity gains were selected using non-linear least squares optimization minimizing kinematic errors between the model and experimental movements. Forward dynamic simulations were performed to investigate balance recovery following support-surface perturbations (6 cm, 18cm/s in either the anterior or posterior direction).
Results and Discussion:
The biologically-inspired control system was able to stand quietly within 0.07 degree RMS error joint angle deviations. The low-level stretch-reflex controller successfully rejected anterior/posterior disturbances and recovered balance within 2.5s. The differences between the simulation and experimental CoM trajectories can be explained by the role of supraspinal control in fine-tuning movement. Differential use of muscle spindles and Golgi tendon organs feedback during balance recovery provides insights to understand the role of each to control posture. Our simulation frame work and the biologically-inspired control system provide a powerful computational basis for studying complex movement abnormalities seen in patients with neurological disorder such as cerebral palsy and stroke.

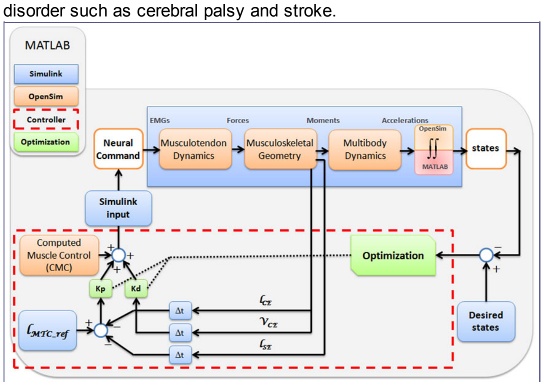

Figure 1: Schematic of the control system in MATLAB. The Simulink input, or neural command, is calculated based on the low and high-level feedback control system. k_p and k_d control constants were selected by a non-linear least square optimization minimizing postural sway of the musculoskeletal model plant. l_{MTC_ref} is the reference muscle-tendon complex (MTC) length, l_{CE} is the contractile element (CE) length, l_{SE} is the series elastic (SE), or tendon, slack length, V_{CE} is the CE velocity, and Δt, stretch-reflex monosynaptic latency, is 25ms.
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Presentation Preference (Complete): Unsolicited Podium Presentation (no more than 2 total per speaker)
Awards (Complete):
I would like to be considered for the PhD Podium Competition: Yes

Track (Complete): Motor Control
Presentation Preference 2. (Complete):
Please select: Yes

Status: Complete