Simulation of leaning standing after spinal cord injury

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1 Introduction

Closed-loop neuroprostheses to restore advanced functions after spinal cord injury (SCI) require robust estimation of feedback [1]. A networked neuroprosthetic system (NNPS) [2] is under development at Case Western Reserve University that includes implantable modules for power, stimulation, and biopotential sensing distributed throughout the body. Each module contains a tri-axial accelerometer (*Kionex*, KXTE9, ±2g) available for feedback. One possible configuration (**Fig 1A**) for restoring standing function with this system would locate modules bilaterally in the upper-torso, mid-flanks, pelvis, and mid-thighs. Accelerometer-based estimates of total-body center of mass (CoM) kinematics have been previously utilized as feedback to restore standing balance after SCI with functional neuromuscular stimulation (FNS) at the erect posture [3]. The objective of this simulation study was to investigate the potential of utilizing the proposed NNPS architecture with a simplified model of stance (**Fig 1B**) to estimate CoM position and acceleration for maintaining standing balance with FNS at *leaning* postures.

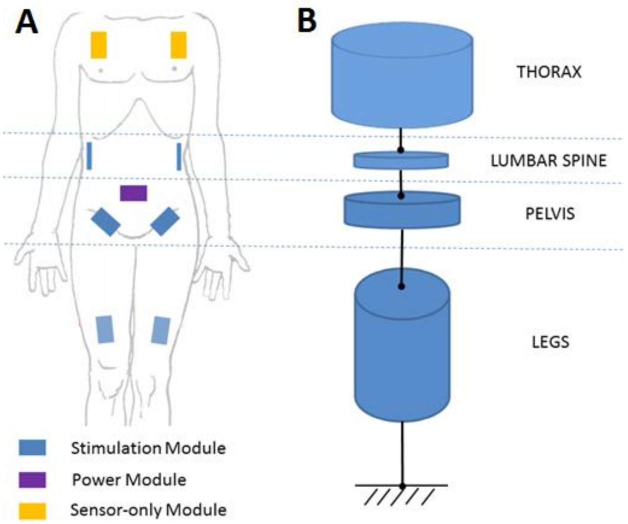

Figure 1: **(A)** Possible configuration of NNPS for standing, **(B)** Simple serial-tilt model of standing for estimating feedback variables of total-body center of mass position and acceleration

2 Methods

An anatomically realistic 3-D computer model of human bipedal stance after SCI was created for testing FNS feedback controllers in simulation [4]. This model included upper extremity actions mimicking those for stabilizing posture with an assistive device and 16 muscle groups adjusted to SCI to be activated under feedback control consistent with those targeted by an implantable stimulator [5]. Similar to [3,4], a feedback controller based on CoM kinematics was developed to maintain posture against balance perturbations, simulated as external force-pulses applied to the torso, pelvis, or thigh. Feedback CoM kinematics were estimated from simulated accelerometer signals created by adding typical noise and drift errors [6] plus gravitational acceleration (g) to the local 3-D linear acceleration at proposed NNPS module locations. The accelerometer readings were presumed to represent either 2-D tilt orientation (during quiet standing) or 3-D acceleration (during perturbation) of the affixed segment. A simple 4-segment serial-tilt model (**Fig 1B**) was used for estimating feedback that then drove balance control, i.e., changes in muscle excitations, of the anatomical model. Perturbation simulations were performed with the model leaning leftward, rightward, and forward of erect.

3 Results

Using the simulated accelerometer signals during perturbation simulations, CoM position and acceleration could be estimated on average to within 1.79±1.66 cm and 0.11±0.14 m/s^2, respectively, of true model values. Standing performance was measured by the assistive loading necessary from the upper extremities to stabilize against the force disturbances. Feedback control using the estimated values of CoM kinematics produced a notable (>20%) reduction in assistive upper extremity loading compared to the clinical analog of optimal constant activation of the paralyzed muscle groups.

4 Discussion

Obtaining accurate estimates of CoM position and acceleration during SCI standing from only accelerometer signals at proposed NNPS locations appears feasible in simulation. These estimates are potentially robust in producing effective feedback control of muscle excitation levels to improve standing balance performance at leaning postures. In the future, similar controller approaches will be developed and evaluated during laboratory testing with subjects actively using an NNPS.

References

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