PREDICTIVE MUSCULOSKELETAL SIMULATIONS OF INCLINED WALKING

Tim W. Dorn, Jack M. Wang and Scott L. Delp
Department of Bioengineering, Stanford University, USA; email: twdorn@stanford.edu

The purpose of this study was to generate predictive muscle-driven simulations of normal and inclined walking that capture the characteristics of human-like motion. The value of synthesizing human-like motion lies in its ability to predict the human response to model augmentations, which can provide understanding about motor recruitment strategies without the need for experimental motion capture data. The 2D musculoskeletal model had 9 degrees of freedom which were driven by 8 muscle actuators per leg (iliopsoas, gluteus-maximus, hamstrings, rectus-femoris, vasti, gastrocnemius, soleus and tibialis-anterior). The force generating properties of each muscle were governed by physiological force-length-velocity properties and first order excitation-activation dynamics (Fig-A). The excitation control structure for each muscle was based on a combination of force feedback and length feedback control [1]. A total of 74 design variables fully prescribed a closed loop forward simulation (53 muscle controller parameters and 21 initial conditions). Optimization was used to solve for these design variables by parallelizing simulations across 48 nodes on a cluster using a gradient-less, stochastic evolution strategy called Covariance Matrix Adaptation. The components of the objective function were to: (i) minimize the sum of metabolic energy across all muscles; (ii) minimize the maximum velocity of the proximal trunk point; and (iii) achieve an average target speed of 1.45 m/s without falling for a simulated duration of 10 seconds. We first generated a predictive simulation of normal walking (on flat ground) to evaluate the fidelity of our model and control structure, which produced sagittal-plane hip, knee, and ankle kinematics within one standard deviation of experimental walking kinematics (Fig-B/C). We then introduced a 10 and 20 degree incline into the model, respectively, and re-ran the optimizations. Our results predicted the major kinematic trends seen in human inclined walking: (i) increased trunk tilt during the stride; (ii) increased hip flexion in early stance and late swing; (iii) increased knee flexion (crouch) in early stance and late swing; and (iv) increased ankle dorsiflexion in early stance. In conclusion, we have demonstrated an optimal control framework that can accurately predict normal walking kinematics and make informed predictions of simulated gait on inclined surfaces.

[1] Geyer H, et al. *IEEE Trans. Rehab Eng.* **18**:263-73, 2010.

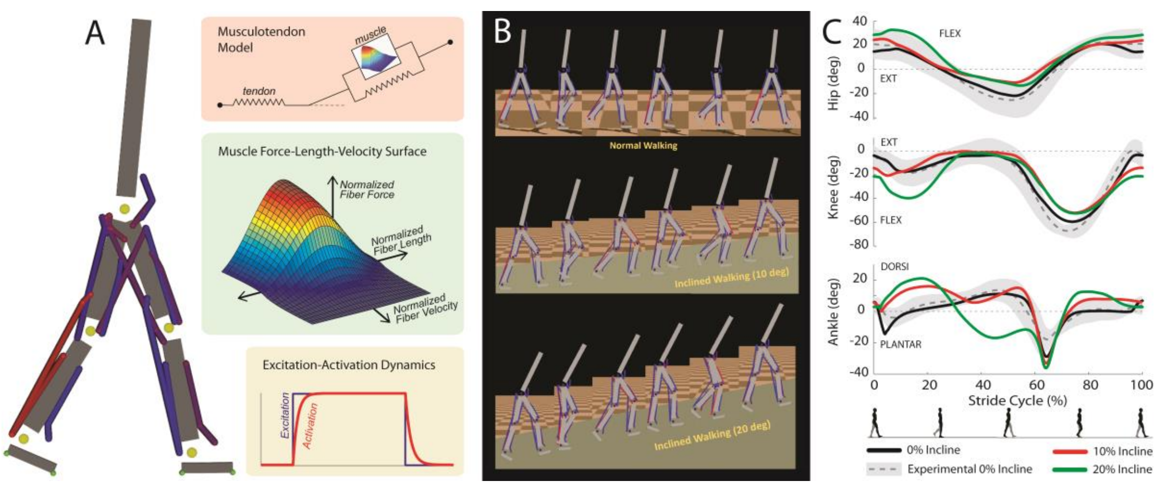

Figure 1: (A) Musculoskeletal model; (B) Simulated predictions of the gait cycle of normal walking and inclined walking at 10 and 20 degree inclines; (C) Sagittal hip, knee, and ankle gait kinematics of normal walking and inclined walking at 10 and 20 degree inclines.