Toward a Three-Dimensional Forward Model of Human Walking

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The Problem: Our goal is to develop a morphologically realistic forward model of human walking that agrees with biological data on how center-of-mass behaviors and joint kinematics vary with speed.

Motivation: Our broad aims are (a) to test biological models of mechanics and control of walking and running, and (b) to apply these models to robust control schemes for artificial limbs and orthotic braces. In addition to technological innovation, this approach may improve our fundamental understanding of the neuromechanics that determine human gait performance.

Previous Work: Despite recent advances in control [4] [6] and computational modeling [1], important questions remain about how to implement legged systems that are stable and biologically realistic. More classical models of walking are able to predict some features of gait, but are highly simplified in their assumptions of structure and control [2] [3].

Approach: The structure of the model represents the legs and trunk of a male of average height and weight. We also plan to build a female model. The model has seven rigid links, 12 actuated degrees of freedom, and a realistic mass distribution. The equations of motion are generated and solved based on Newtonian mechanics. Kinematic and force-plate data acquired from healthy, young subjects are used to test three different virtual-element control architectures for walking: (a) a "granny-walker", (b) a compliant-wheel design, and (c) a rolling multi-dimensional surface. Preliminary data used for this study were collected previously [5]. The data suggest that in normal walking the stance leg behaves as a spring in two separate stages, as evidenced by the maximal compressions of the virtual leg coinciding in time with the maxima in ground force (Fig. 1, upper and middle). The data also show that the angular velocity of the virtual leg is approximately constant with time (Fig. 1, lower). These data suggest that the stance limbs in walking may be modeled as compliant spokes of a rolling wheel or surface, where the center-of-mass characteristics are the outputs. The reason for including a granny-walker controller in our tests is that this architecture has been shown to effectively stabilize a two-dimensional bipedal robot [4]. We want to answer the question of whether this type of control produces biologically realistic trajectories.

Impact: Our eventual goal is to implement control of "smart" external lower-limb prosthetics and orthotics. These technologies would allow amputees and patients with gait pathologies (e.g., muscular weakness) to walk in a more natural and stable manner. An accurate and detailed forward model of human walking is an important tool in assessing control methods for orthotic and prosthetic components. This work also contributes to understanding the neural control and mechanics of normal and pathological gait.

Future Work: We will test the control schemes described above for stability and biological realism at the three different walking speeds. Further, we will attempt to blend the schemes into a single model that predicts the dynamics of acceleration from the slowest speed to the fastest speed. New data will be collected to test this model.

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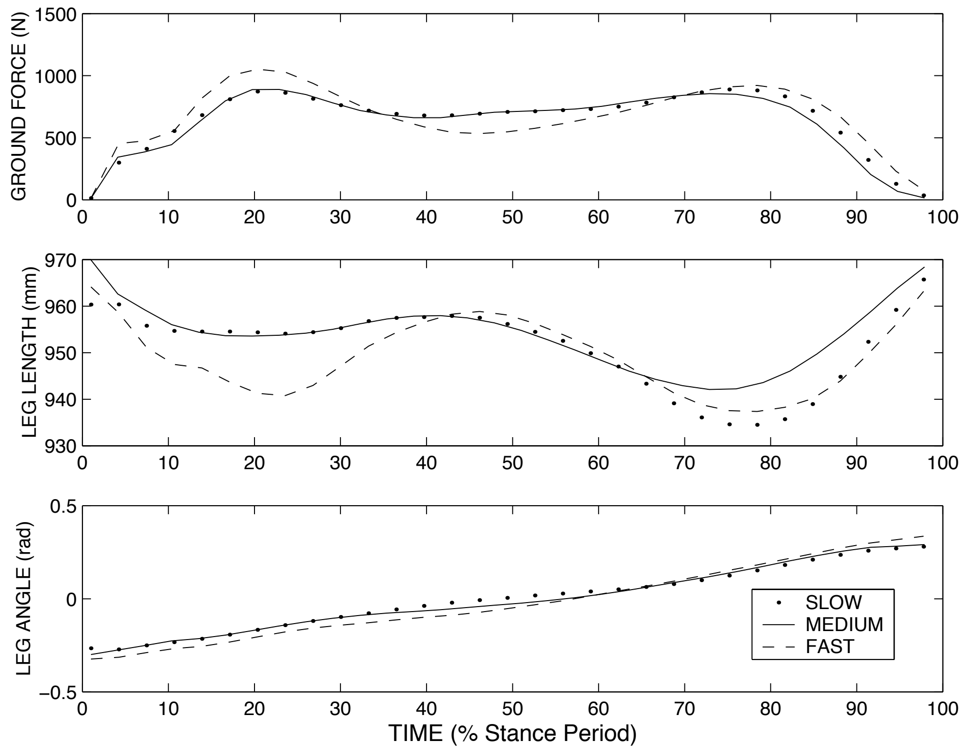

Figure 1: Measurements of ground-reaction force (upper), virtual leg length (middle), and virtual leg angle (lower) plotted versus percentage of stance time. Data are shown for one subject at three walking speeds. The virtual leg extends between the hip and the center of pressure. Leg angle is the angle of the virtual leg with respect to vertical. Ground force is computed along the axis of the virtual leg.

References:

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