A neuromuscular model of human locomotion that combines flexibility and stability

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I. Introduction

Human locomotion is amazingly flexible. We walk effortlessly in varied environments, choosing gaits and avoiding obstacles of different sizes and shapes. To achieve that impressive flexibility, human walking requires sophisticated stabilization because the human body is mechanically unstable during locomotion and body configuration changes throughout the gait-cycle. Combining flexibility and stability is a challenge. Avoiding an obstacle, for instance, involves not only steering the foot over the obstacle, but also anticipating interaction torques and stabilizing the gait pattern that is disturbed by the avoidance maneuver. Various sensory systems must therefore estimate the state of the body in space and initiate adaptations of the movement plan to those disturbances. Changes of the movement plan must then be realized by adjustmenting the motor commands that are integrated with the biomechanics, muscle dynamics and the reflex pathways of the spinal cord. Here, we present a neural process model of human locomotion that is able to generate movement plans for steady state locomotion that are open to updating and integrated with muscle physiology, biomechanics and established spinal reflex pathways such as the stretch reflex.

II. Model & Results

We present a 3D-neuromuscular model of human locomotion that combines the flexibility to execute different movements with the swing leg, for instance, to avoid an obstacle, with the stability that is required for robust locomotion. The model organizes movement plans on the task level. During swing, vestibular feedback is used to determine a target joint angle coordination for foot placement on each step that generates stable walking [1]. A movement plan is generated towards that target configuration as a minimal jerk trajectory [2]. This movement plan is updated during the movement based on sensory information. The supraspinal controller uses an inverse internal model of the biomechanics, of muscle force generation and of spinal reflexes to generate descending commands that realize the task-level motor plan. On the spinal level, the descending commands during the stance phase are integrated with the stretch reflex and further spinal reflex circuits that are adopted from [3], [4]. The biomechanical model comprises 8 degrees of freedom, realistic moment arms and 22 Hill-type muscles [3]. Muscles are innervated by α-motorneurons and are controlled shifting the threshold of the stretch reflex [5]. Our model is able to combine stable locomotion at different speeds with varied movements of the swing leg, enabling it to avoid obstacles of different sizes. The model can walk on uneven terrain and resist to external pushes at different phases of the gait.

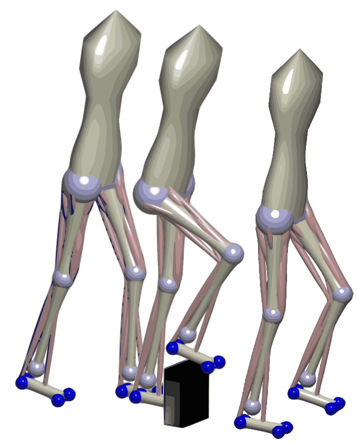

Fig. 1. Sketch of the neuromuscular model avoiding an obstacle.

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