MODULAR CONTROLLER FOR PREDICTIVE SIMULATIONS OF HUMAN STANCE AND GAIT

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Introduction

Predictive musculoskeletal modelling is a useful tool for deriving biomechanical data in different scenarios. Gait models have been shown to be able to replicate physiological data [1, 2]. However, these models are specific to the gait task and their physiological plausibility is questioned. In the present work, a modular controller for predictive simulations is presented. In this controller, a hypothetical mesencephalic locomotor region (MLR) sends descending control signals to two different internal models, that organize five synergies to accomplish quite stance or gait.

Methods

The musculoskeletal model used in the simulations is based on that presented by Geyer and Herr [1]. The head, arms, torso, and the lower limbs are modelled as seven segments articulated by six pin joints, hips, knees, and hips. Seven actuators induce torques in these joints: hip flexors, gluteus, hamstrings, vastus, gastrocnemius, soleus, and tibialis anterior. Synergies, modeled as function-specific polysynaptic reflexes, send excitatory outputs to the actuators, based on synergy activation patterns modulated in amplitude and frequency, in a task-dependent way, by task-specific internal models (IMs). The IM for gait uses five synergies: *compliant leg behaviour*, *leg propulsion*, *hip unloading*, *swing*, and *leg retraction*, while the IM for stance only uses the *compliant leg behaviour* synergy. The output of the synergies is triggered and prolonged by different sensorial afferents, and is described as:

$$u_i = \alpha\big(1 + cos(2\pi\eta\vartheta u_o + \pi + \phi)\big) \qquad (1)$$

where u_i is the output of the synergy, u_o is the control signal from the MLR, Φ is a phase coupling signal, ϑ and α are the modulation in frequency and amplitude of the internal model, and η is the sensorial modulation of the frequency. We developed simulations where the first 5 seconds were controlled by the stance IM and the following 25 seconds by the gait IM. The model was implemented in Simulink (MATLAB R2022a). The CMAES algorithm was used to optimize the synergy-specific parameters (13 for stance and 30 for gait) during 300 iterations [3].

Results

The model was able to keep balance at a physiological metabolic cost of 1.2 W kg^{-1} [4]. After 5 s, 10 s of steady walking was achieved at 0.8 and 1.3 m s^{-1} with physiological metabolic cost of 5.5 and 3.5 J kg^{-1} m^{-1}, respectively [5]. Figure 1 shows the muscle activation and kinematics of the gait at 1.3 m s^{-1}.

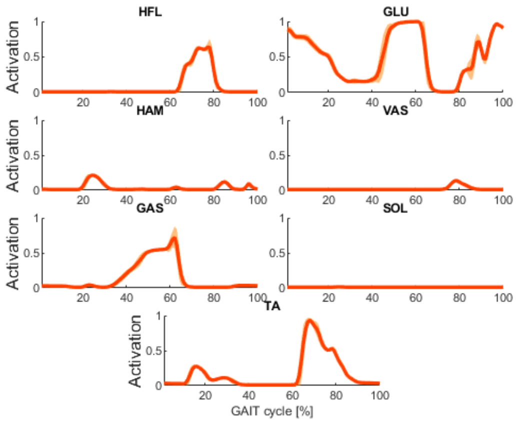

Figure 1: Muscle activation for the seven actuators along the gait cycle.

Discussion

We examined whether signals triggered by sensorial events but driven by tonic inputs can execute motor tasks. The resultant model is a hybrid of a central pattern generator (CPG) and a reflexive controller that can switch from stance to gait. Even though muscle activation do not fit physiological patterns, we expect those variables to be adjusted in further optimizations. Also, the model is intended to switch between different types of gaits while the stability is tested in a noisy environment.

References

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