Muscle-Reflex Control of Robust Swing Leg Placement

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I. Motivation

Swing leg placement is vital to dynamic stability in legged robots and animals. The most common approaches to generating swing leg motions in robotics use either position or impedance tracking of defined joint trajectories. While these approaches suffice in humanoids, they severely limit swing leg placement under large disturbances in prosthetic limbs, for which stabilizing reactions cannot be planned centrally.

II. State of the Art

The common approach to generating swing leg motions in humanoids relies on trajectory planning and tracking. Trajectories for all the leg joints are planned either based on cost optimization [1] or by interpolation between consecutive placement targets [2]. Once generated, these reference trajectories are tracked via proportional-derivative control at each joint. This approach to swing leg motions requires central control over all leg joints, making it difficult to use in prosthetic limbs which replace only part of the human body. Although alternative approaches have been explored in rehabilitation robotics [3], tracking predefined joint patterns remains the state of the art in the control of powered prosthetic legs [4]. In effect, prosthetic legs show only limited dexterity in recovering gait after disturbances.

III. Our Approach

We previously developed a control for a double pendulum leg in swing that is based on local feedbacks and does not require predefined trajectories to robustly place the leg into target points on the ground in the presence of large disturbances [5].The control uses a target leg angle α_{tgt} and a clearance leg length l_{clr} as inputs, and it implements a natural sequence of three control tasks which comprise flexing the leg to the clearance length, advancing the leg to the target angle, and extending the leg until ground contact (Fig. 1A).

To compare the identified control with human swing leg behavior at the level of muscle activations, and to prepare a transfer to powered prosthetic legs that react like human limbs, we here develop a neuromuscular model of the human leg in swing and interpret the identified control with local muscle reflexes. We add a foot segment to the double pendulum model and use nine hill type muscles to actuate this three segment model. The muscle stimulations are generated by local proprioceptive feedbacks from the same or other muscles. We further find that length of biarticular muscles encode leg angle α and monoarticular knee muscles encode leg length l. As a result, by measuring proprioceptive feedback from these muscles, we are able to stimulate muscles in accordance to the identified feedback control, which used only α and l.

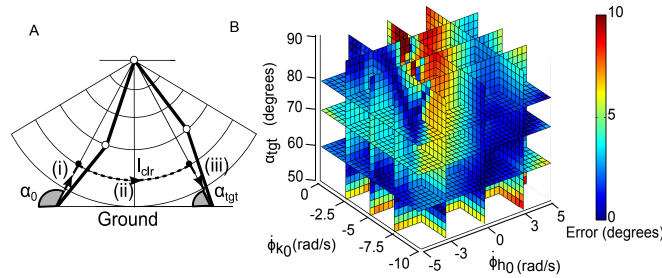

Fig. 1. (**A**) Sequence of natural control tasks for reaching a target leg angle α_{tgt} while guaranteeing foot ground clearance l_{clr}. (**B**) Swing leg placement error for neuromuscular control model

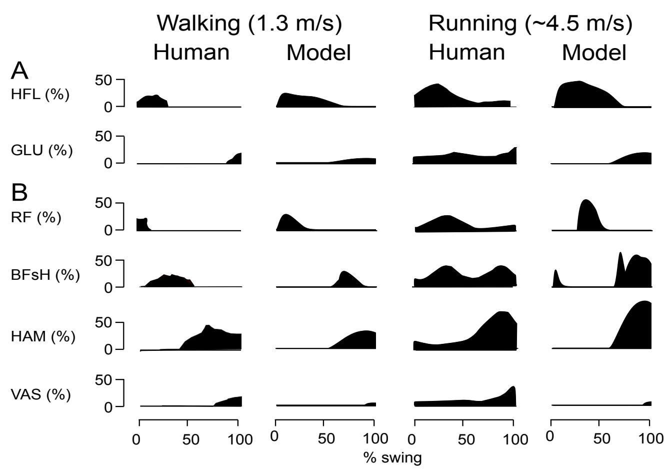

Fig. 2. Observed and predicted muscle activations at hip (**A**) and knee (**B**) in walking and running. Human data adapted from [6].

IV. Current Results

In walking, the model captures the activation for the hip muscles in terms of timing and magnitude when compared to humans. Although the knee muscle activation patterns show a similar trend (Fig. 2), some deviations occur with respect to the onset time for BFsH, which is delayed. In running, humans have an increased tonus for all muscles that is absent in the model. In addition to this muscle tonus, the activities of BFsH and GAS show different characteristic features. Inspite of these variations, the neuromuscular implementation preserves the robustness behavior of the control (Fig. 1B).

V. Best Possible Outcome

We plan to integrate the current control into an existing neuromuscular model to study disturbance reactions in humans. Preliminary results shows that it extends the capabilities of existing neuromuscular model on rough terrains [7]. We will further validate the muscle activations of the model via thorough experiments on human subjects. In addition, we plan to transfer the autonomous swing control to robotic legs in humanoid and rehabilitation robotics, for which we are currently developing a robotic leg testbed [8].

Acknowlegment

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