Towards a Testbed for Robotic Neuromuscular Controllers

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1 Motivation and State of the Art

Current control approaches to robotic legged locomotion rely on centralized planning and tracking or pattern matching of predefined joint motions extracted from normal human gait. The first approach is used in humanoids [1], but cannot be applied to robotic assistance wherein the central state of the human user is unknown. As a result, the second approach prevails in rehabilitation robotics. For instance, exoskeletons developed for paralyzed patients enforce a limited set of pre-defined motion patterns of normal human gait [2]. This severely restricts a user's functional dexterity. To improve dexterity, motions libraries have been combined with pattern recognition techniques to control speed and slope adaptation in prosthetics [3]. However, control strategies that generate the stability, maneuverability, and adaptability seen in biological systems have not been identified with this approach. Neuroscientific experiments reveal that biological systems realize dexterous segmented leg performance largely via local feedback controls that bypass central processing, and by biomechanical structures that encode functional leg responses [4,5]. For example, decerebrate cats seamlessly adapt to different locomotion speeds on a treadmill and autonomously transition between gaits, despite having no brain control over their legs [6]. Recent neuromuscular models that are controlled by autonomous local feedbacks without central planning adapt to their environment and show substantial robustness of locomotion [7,8]. Part of this feedback control has been implemented in a powered ankle-foot prosthesis, enabling it to adapt to the environment without requiring explicit terrain sensing [9].

2 Own Approach

Generalizing neuromechanical controllers to powered segmented legs has the potential to greatly improve the functional dexterity of users that rely on robotic rehabilitation devices. We approach this goal by developing a robotic gait testbed that can implement and rigorously test neuromuscular controllers for assistive devices (Fig. 1a-b). For cost and safety considerations, we target a testbed leg size and weight that is half the size and a quarter of the weight of a human leg. To ensure that the dynamic behavior of the robotic neuromuscular leg (RNL) matches that of human legs, we use dynamic scaling and define actuator performance envelopes based on human physiology of major leg muscles. Based on these requirements, we built an initial prototype that consists of two custom, cable-driven series elastic actuators (SEAs)

(a)
(b)
(c)

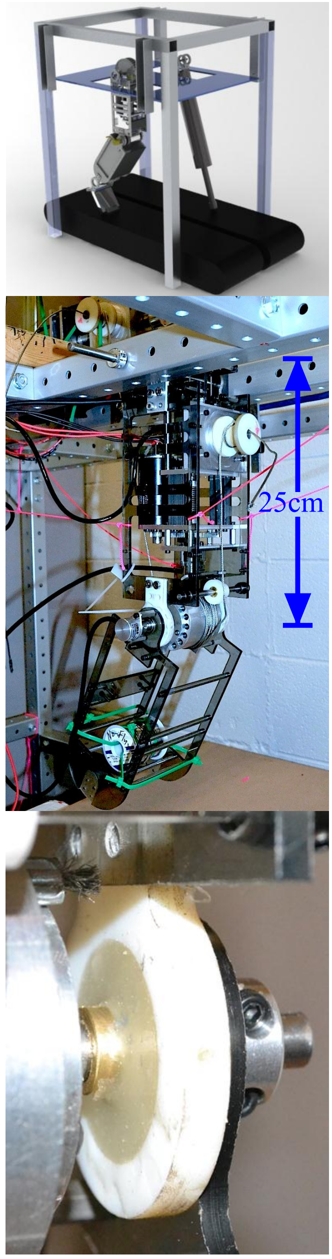

Figure 1: Gait testbed for neuromuscular controllers of segmented legs. (a) Envisioned testbed. (b) Initial prototype of antagonistically actuated leg. (c) Floating compliant knee joint.

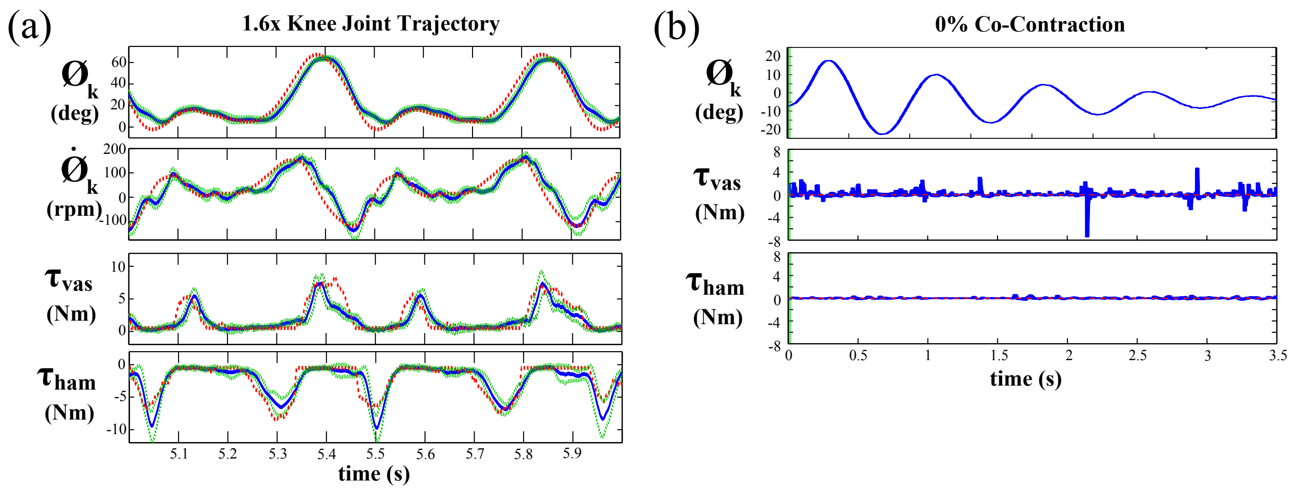

Figure 2: Experimental results. (a) Leg motions are tracked by RNL with high fidelity. Mean trajectories over 10 trials (blue) are close to commanded trajectories (red) and have small s.d. (green). (b) SEAs allow RNL to execute near passive motions (blue) after an external impulse (green).

which antagonistically actuate RNL's knee. In addition to RNL's electro-mechanical design, we developed the antagonistic actuators' low level torque control using a velocity-based SEA control scheme. Velocity-based torque control automatically compensates for frictional losses in the drive train [10]. However, the original formulation of this control by [10] requires load inertia to be known and fixed. In contrast, we formulated an alternative velocity-based SEA controller that is independent of load inertia.

To verify if our design and control implementation achieves human-like performance, we devised two experiments. In the first experiment, we used biomechanical data of human walking to generate RNL knee joint trajectories that correspond to speeds between normal human walking speed (1.0x) and the theoretical maximum knee joint velocity (2.0x). We observed that RNL tracks joint position with high fidelity up to 1.6x, and joint velocity with high fidelity up to 1.8x (Fig. 2a), corresponding to 90% of the maximum joint velocity the actuators were designed for. In the second experiment, we tested antagonistic co-contraction. We calculated actuator pre-load torques and knee rotational stiffness corresponding to vastus co-contraction at human muscle activation levels between 0-15% and compared RNL's behavior to that of an equivalent driven physical pendulum. RNL tracks zero torque (0% co-activation) within the resolution limits of the SEAs (Fig. 2b). Higher levels of co-contraction were possible, but produced oscillations in SEA torque patterns due to low shank mass.

3 Discussion & Open Questions

Our results indicate that RNL will be able to generate high fidelity motions similar to humans. However, RNL is still in its early design stages and our goal is to receive feedback from other researchers about how the leg design and control can be improved. In particular, we are currently pursuing nonlinear spring designs for the custom SEAs to improve torque resolution at low commanded torques while maintaining high bandwidth at large commanded torques.

4 Keywords

Locomotion, Neuromuscular control, Series elastic actuators.

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