Predicting Human Bouncing Behaviors with Reduced-order Models and Simple Objectives

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I. BACKGROUND

Robotic assistive devices hold enormous promise for augmenting and rehabilitating human locomotion (e.g. exoskeletons). Existing control techniques for lower-body exoskeletons, however, take significant time to design and tune because they are dependent on training with human subjects for hours or more [1]. To build a theoretical foundation for faster-tuned model-based exoskeleton control, this work explores simple and fast-to-compute math models for predicting how human behavior will adapt to forcing from external devices.

Specifically, we take a reduced-order modeling approach to find a generalizable model that is dependent on fewer subject-specific parameters. This work investigates the predicted behavior patterns of these models for a simple human locomotion task: bouncing up and down on two feet. We test a variety of minimalist math models and objective functions (used to model hypotheses about human control preferences) and assess the degree to which they explain observed human behaviors.

II. METHODS

Using trajectory optimization, we systematically generate optimal bouncing strategies for each combination of math model and objective function at a variety of bounce frequencies. The work concludes by analyzing patterns in thousands of numerical optimizations of hypothetical bouncing tasks and compares their features to the experimental literature on human bouncing. Our muscle model is structured as the plantar flexor performing a 2D bouncing task (Figure 1). We vary the bouncing frequency, MTU model, and objective function of the model to analyze trends in movement patterns generated by trajectory optimization (Direct collocation, IPOPT solver).

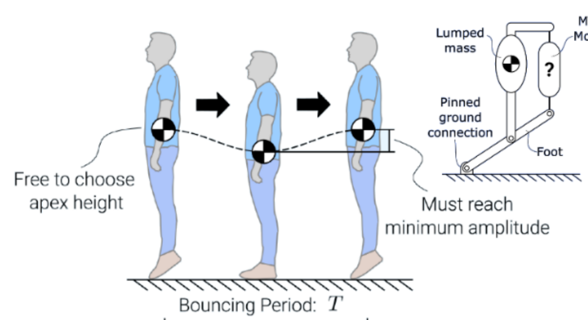

Figure 1: Model-based optimization of a periodic human bouncing task actuated by an MTU model.

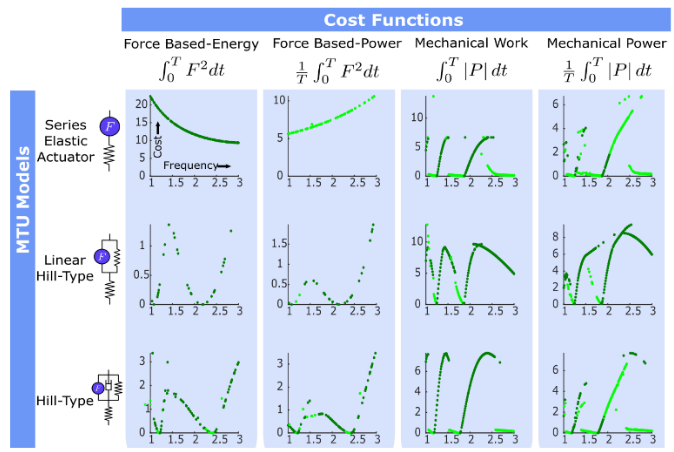

Figure 2: The results of 3,216 trajectory optimizations, showing the cost of bouncing over a range of prescribed frequencies when varying MTU models and cost functions.

III. RESULTS & DISCUSSION

Optimal movement strategies found with the minimal models were able to capture key trends that have been observed in real human bouncing as a function of frequency [2]. The Hill-Type model while optimizing for force-based objectives was able to find a preferred bouncing frequency closest to that observed in human studies. However, the most physiologically accurate behavior was shown when SEA, Linear Hill-type, and Hill-Type models solved for mechanical work and mechanical power objectives. Specifically, near the model's minimum-cost bouncing frequencies, the contractile element would be practically isometric. Moreover, the lengthening of the contractile element would remain in phase with the lengthening of the MTU overall while at the preferred frequency. Therefore, it is possible that a Hill-Type model optimizing for a combination of force-based and work-based objectives could provide an accurate analogue for human bouncing.

IV. ACKNOWLEDGMENTS

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V. REFERENCES

[1] Zhang et al. "Human-in-the-loop optimization of exoskeleton assistance during walking". Science (2017).

[2] Dean & Kuo. "Energetic costs of producing muscle work and force in a cyclical human bouncing task". J. Appl. Physiol. (2011).