

Model-based impedance modulation of antagonistic pneumatic artificial muscles

Xinyao Wang, Tuo Liu, Jonathan Realmuto

Department of Mechanical Engineering, University of California Riverside, CA, USA

Introduction

Joint impedance adjustments are crucial for interacting with dynamic environments in daily life [1,2,3]. Therefore, impedance modulation is crucial for assistive soft wearable robots. Inspired by biological motor systems, our research utilizes antagonism to effectively modulate joint equilibrium and stiffness, advancing control of impedance characteristics in soft wearable robots.

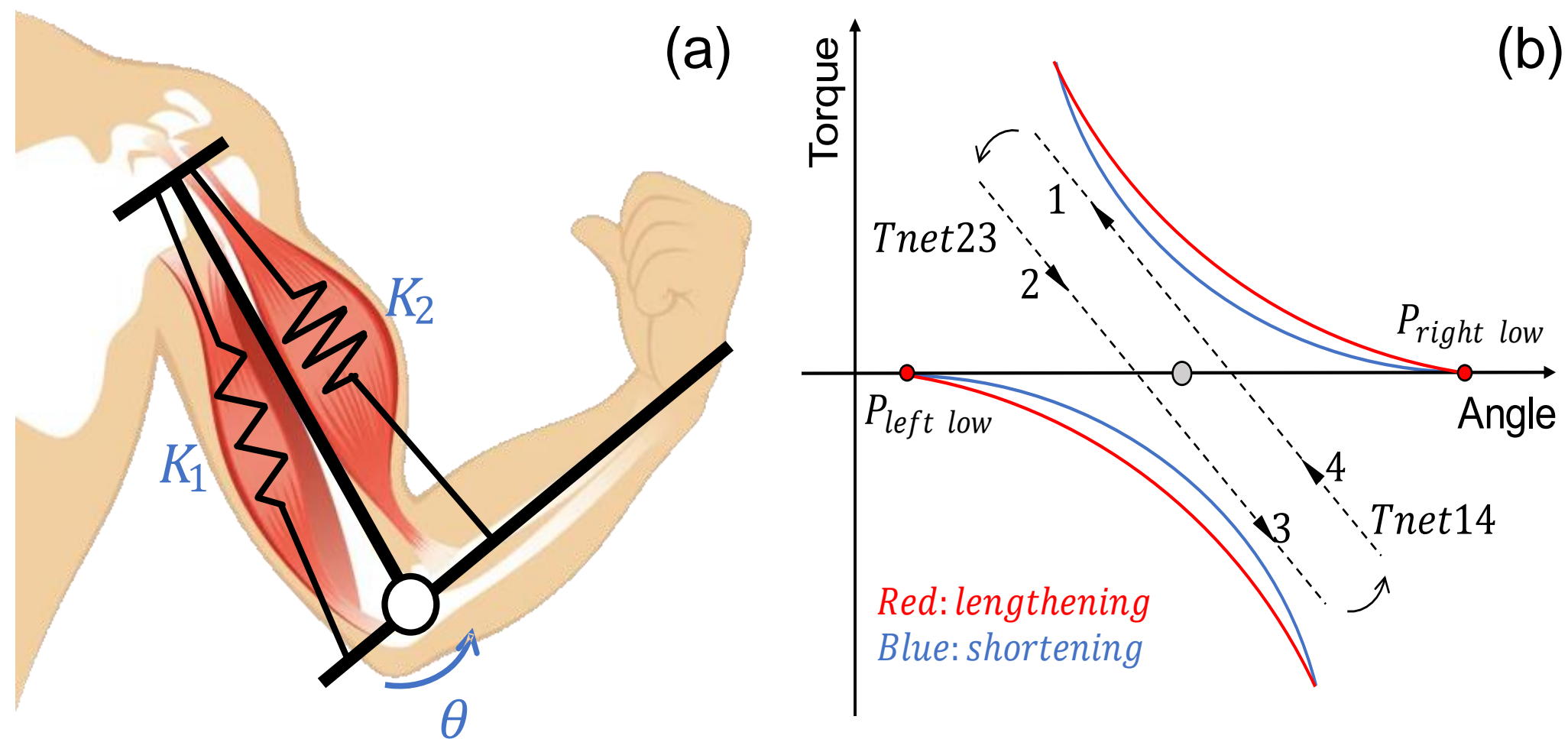


Figure 1. Human elbow can adapt to different daily tasks by adjusting the length and stiffness of the muscles. (a) Simplified diagram of human elbow anatomy. (b) Theoretical force-deflection curves.

Research Objectives

- Generate a theoretical model for direct impedance control, which could adjust joint angle and stiffness as command.
- Generate this theoretical model based on single actuator properties, without building up the hardware.

Methods

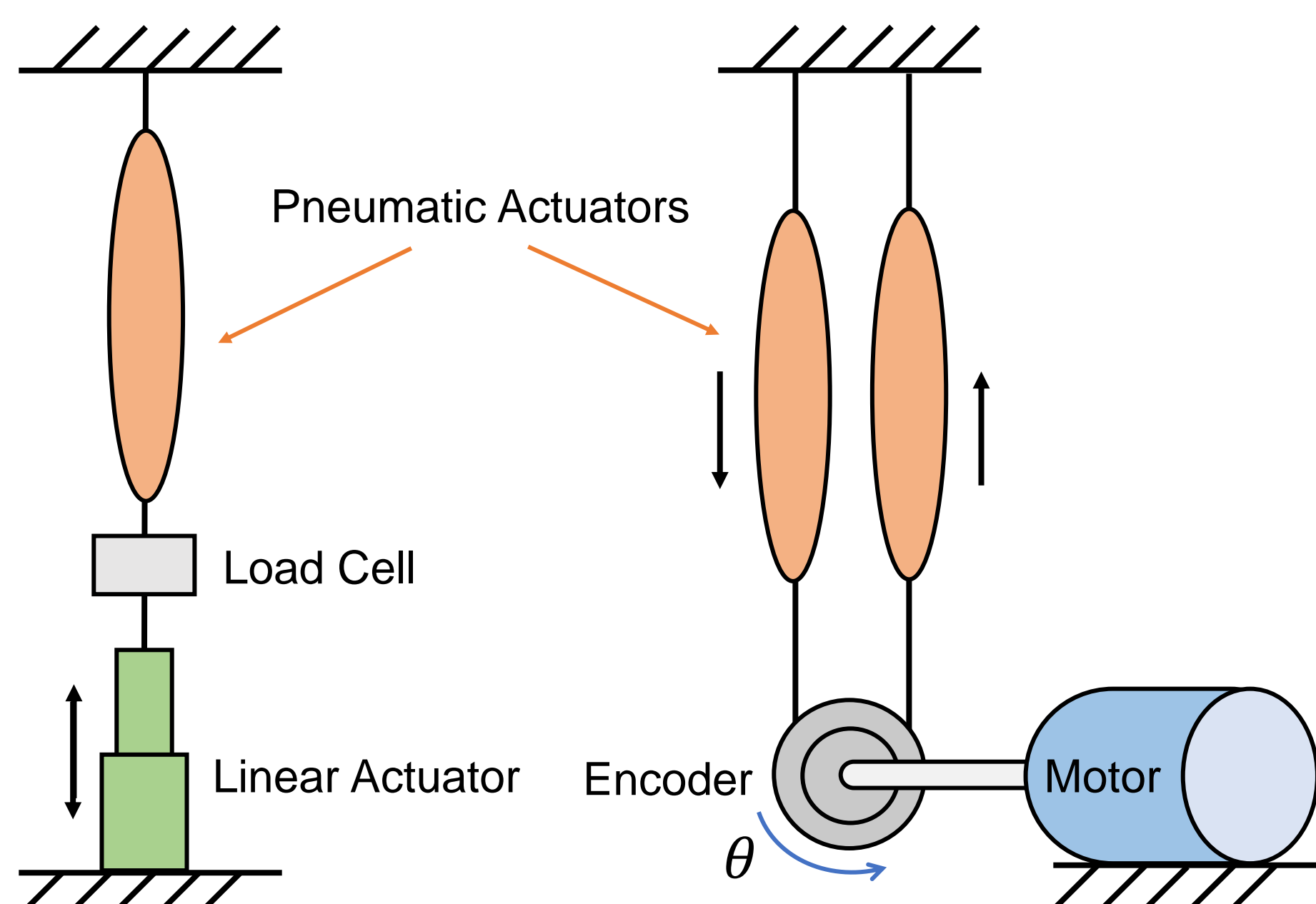
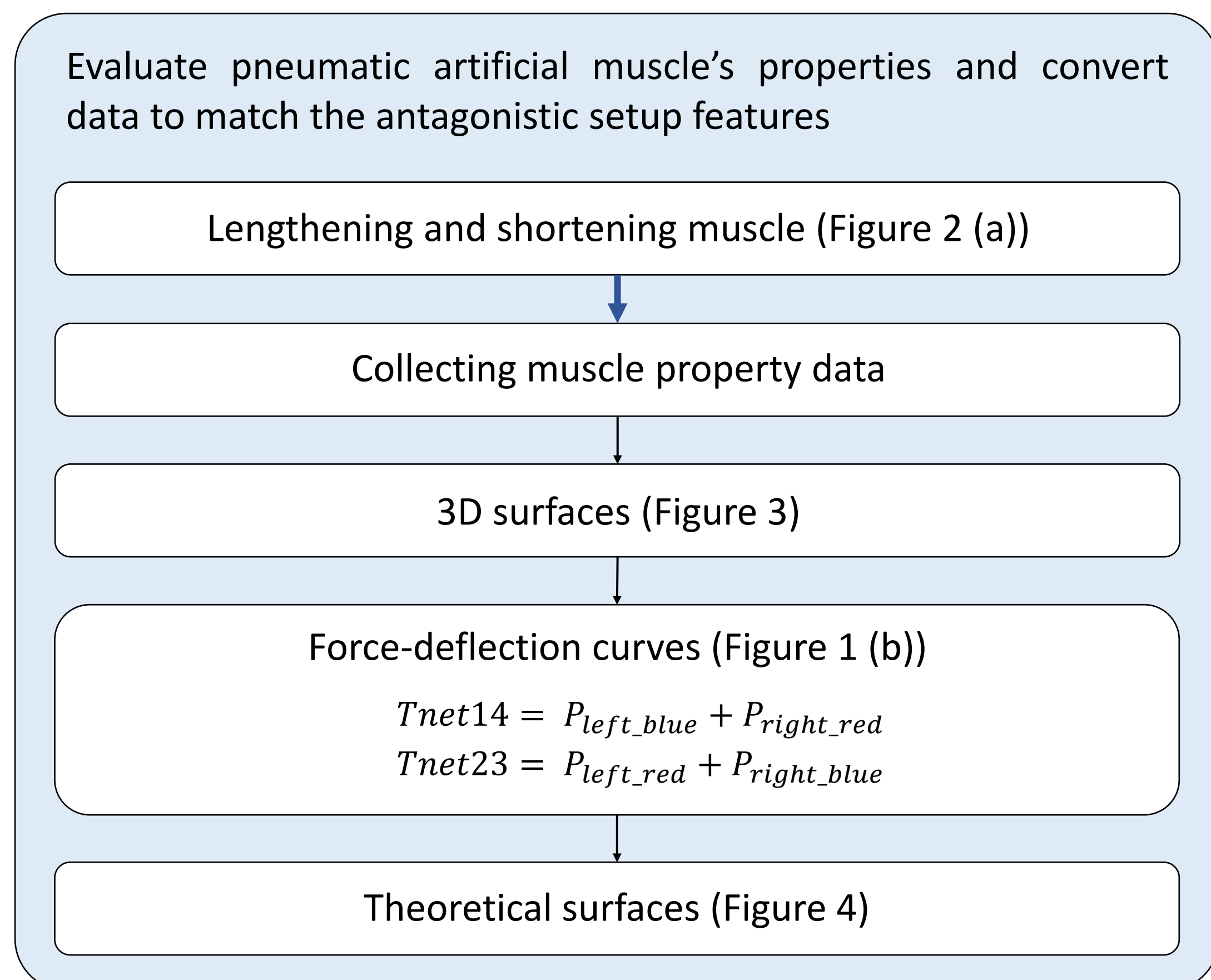


Figure 2. Experiment setups. (a) Single pneumatic muscle property test setup. (b) Antagonistic setup for system identification.

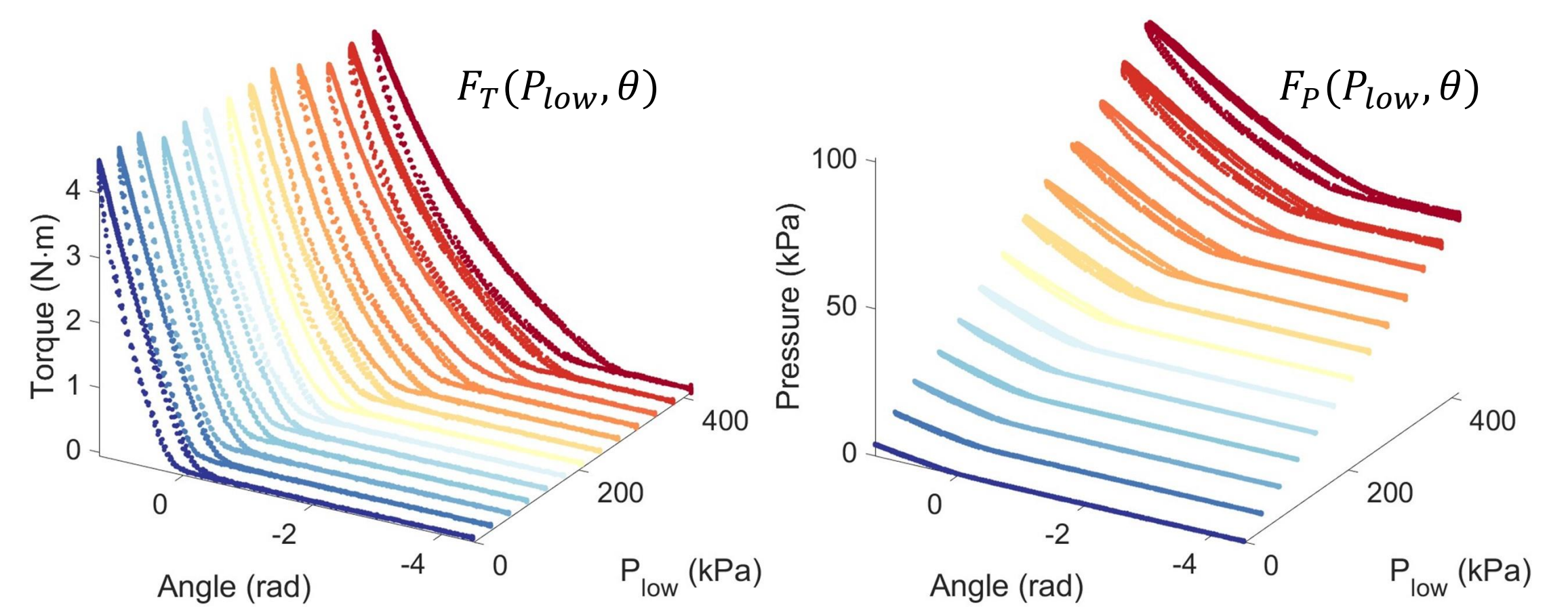


Figure 3. 3D surfaces include hysteresis behavior for force (joint torque), and displacement (joint angle) with different initial pressure.

Result

The 3D hysteresis behavior surfaces are shown in Figure 3, where P_{low} is initial internal pressure when the single pneumatic muscle is free of load, force and displacement are transferred to joint torque and angle based on antagonistic setup dimension.

To validate our technique, we evaluate the equilibrium and stiffness of the antagonistic setup using system identification for a variety of nominal pressures. The input loading was achieved using a high bandwidth DC motor attached to the joint with a sine sweep trajectory (Figure 2 (b)). Our results show acceptable agreement with the model, with an average error of 3.60%.

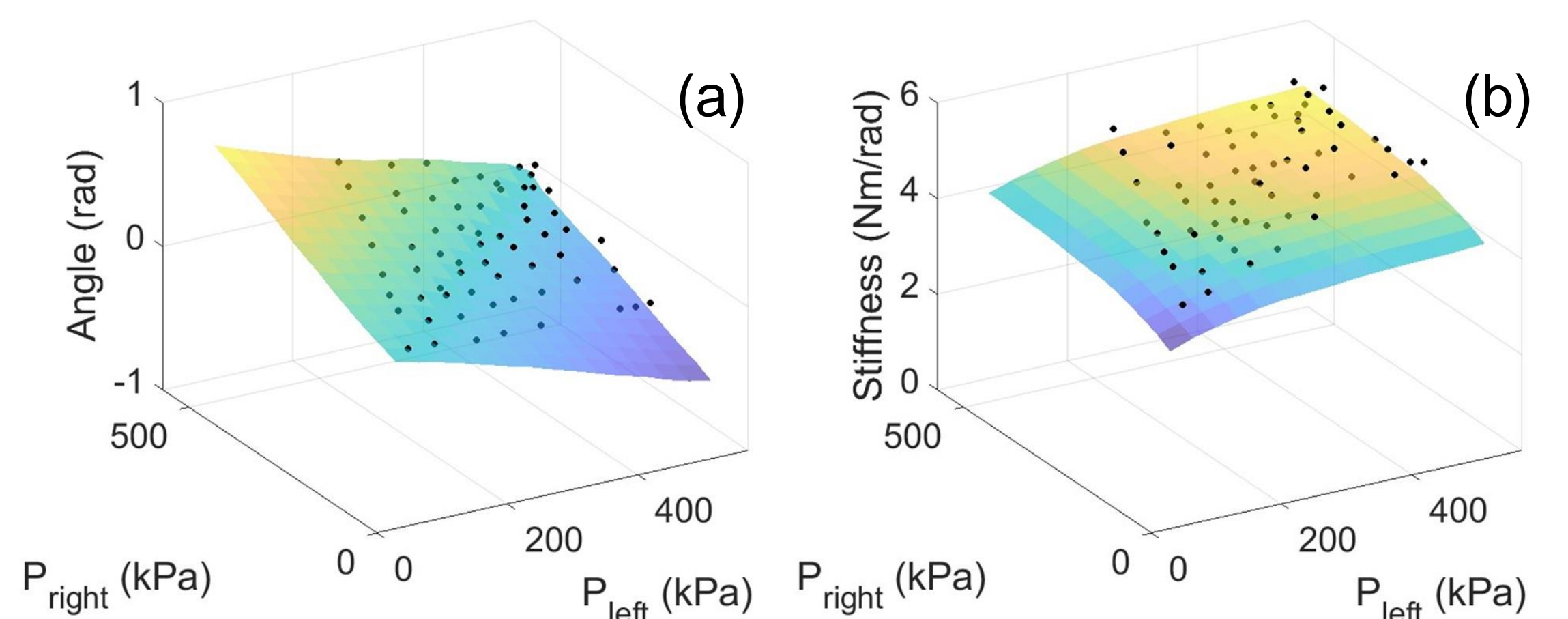


Figure 4. Comparison of theoretical surfaces and experimental results. (a) Joint angle comparison. (b) Joint stiffness comparison.

Conclusion

We successfully characterized the properties of a commercial pneumatic muscle and proposed a theoretical model for direct impedance control. The results have demonstrated that the model can accurately predict the joint impedance with acceptable error, and therefore can be used for model-based impedance modulation. Overall, this study demonstrates an effective and efficient method for generating model-based impedance modulation. In our future work, we aim to close the loop for real-time impedance modulation.

References

- [1] N. Hogan, "Adaptive control of mechanical impedance by coactivation of antagonist muscles," IEEE Transactions on automatic control, vol. 29, no. 8, pp. 681–690, 1984.
- [2] L. P. Selen, D. W. Franklin, and D. M. Wolpert, "Impedance control reduces instability that arises from motor noise," Journal of neuroscience, vol. 29, no. 40, pp. 12 606–12 616, 2009.
- [3] V. W. Chu, S.-W. Park, T. D. Sanger, and D. Sternad, "Children with dystonia can learn a novel motor skill: strategies that are tolerant to high variability," IEEE Transactions on Neural Systems and Rehabilitation Engineering, vol. 24, no. 8, pp. 847–858, 2016.

Acknowledgment

This research was supported by NSF award CMMI 2221315.