Model-based impedance modulation of antagonistic pneumatic artificial muscles

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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.

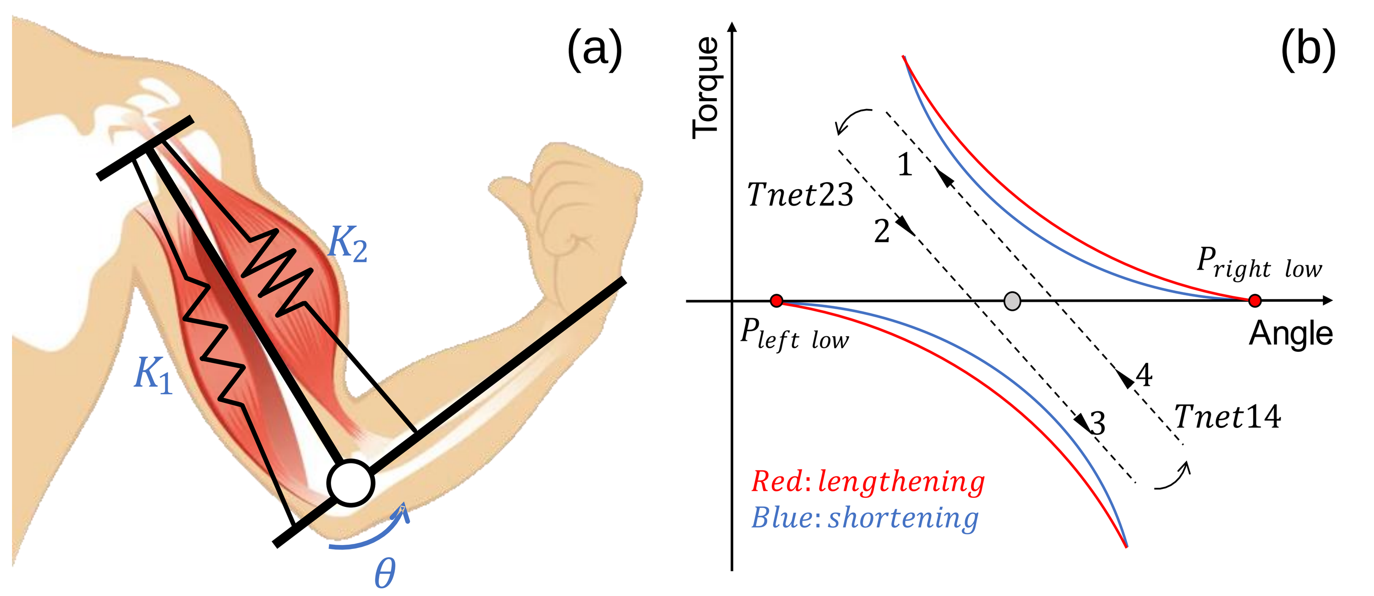

Figure 1. Human elbow can adapt to different daily tasks by adjusting the length and stiffness of the muscles. (a) Simplified diagram of human elbow anatomy. (b) Theoretical force-deflection curves.

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.

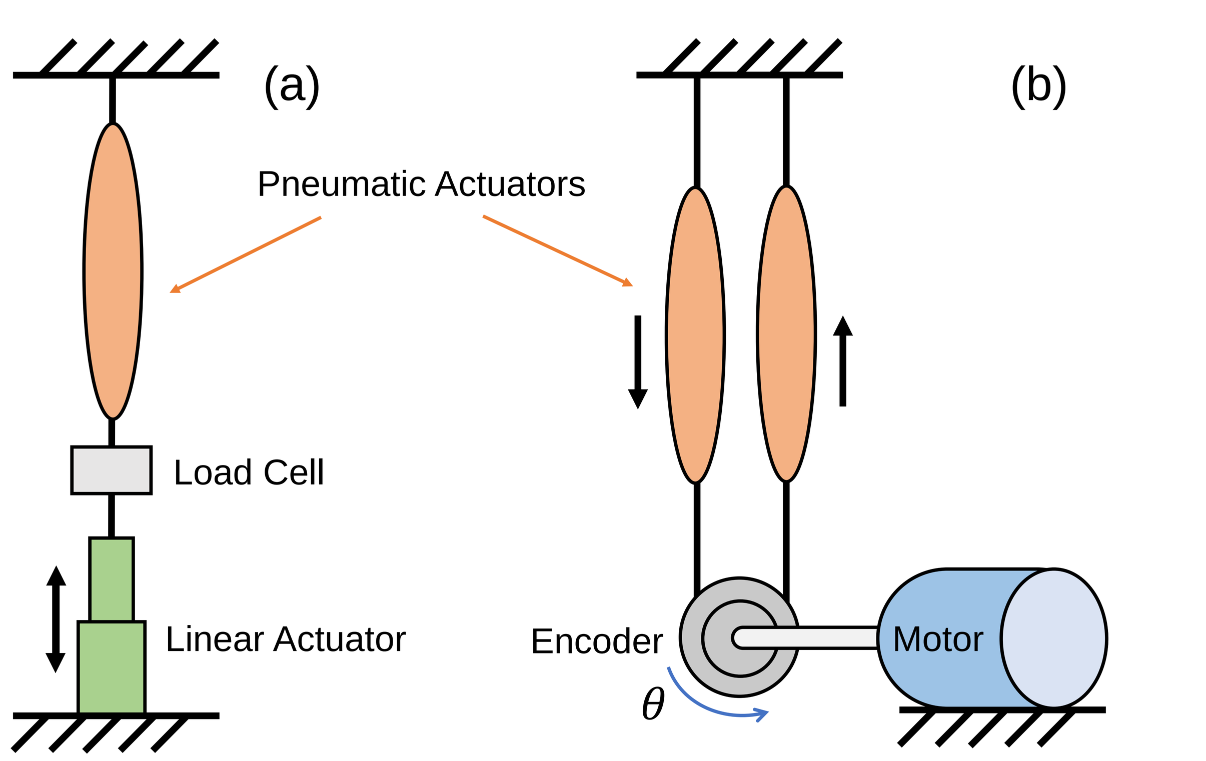

Figure 2. Experiment setups. (a) Single pneumatic muscle property test setup. (b) Antagonistic setup for system identification.

Methods

Evaluate pneumatic artificial muscle's properties and convert data to match the antagonistic setup features

Lengthening and shortening muscle (Figure 2 (a))

↓

Collecting muscle property data

↓

3D surfaces (Figure 3)

↓

Force-deflection curves (Figure 1 (b))

$$Tnet14 = P_{left\_blue} + P_{right\_red}$$

$$Tnet23 = P_{left\_red} + P_{right\_blue}$$

↓

Theoretical surfaces (Figure 4)

Result

The 3D hysteresis behavior surfaces are shown in Figure 3, where P_{low} is initial internal pressure when the single pneumatic muscle is unloaded, force and displacement are transferred to joint torque and angle). 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%.

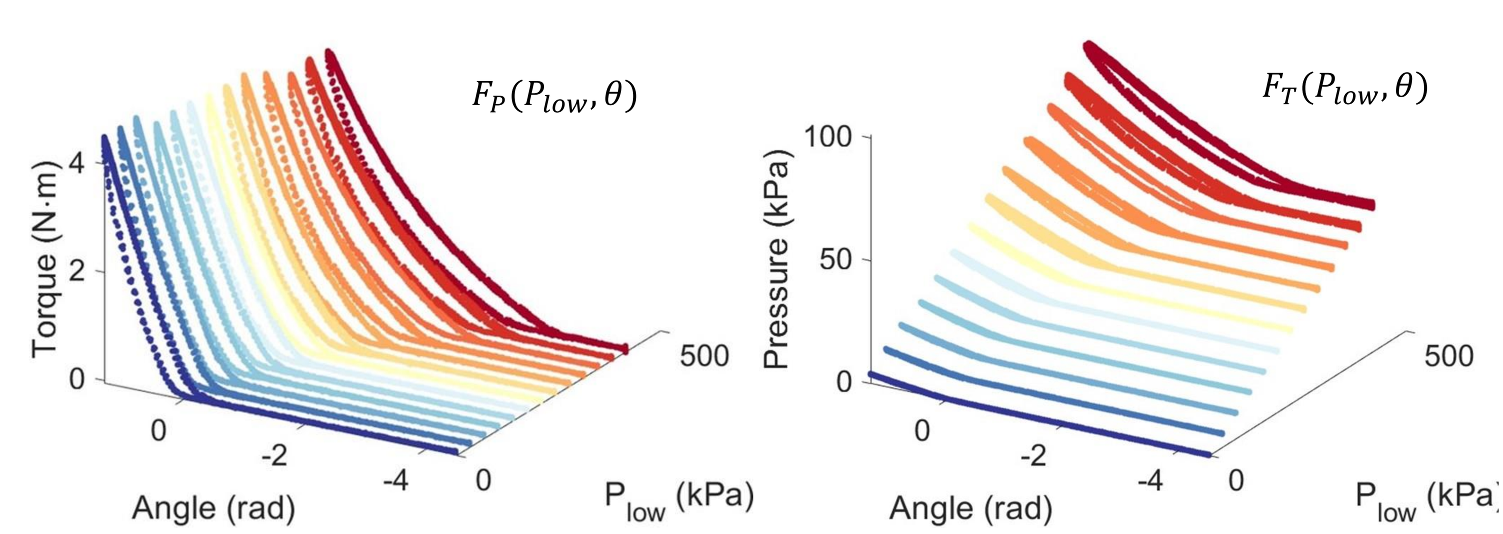

Figure 3. 3D surfaces include hysteresis behavior for force (joint torque), and displacement (joint angle) with different initial pressure.

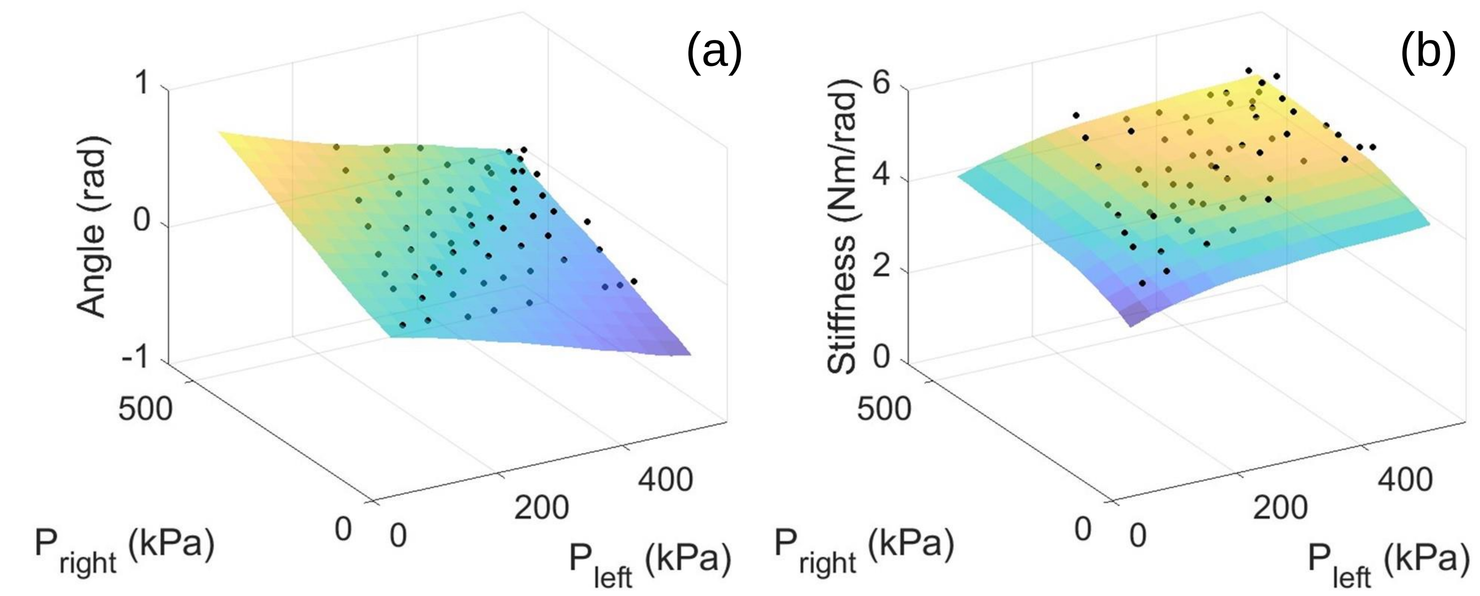

Figure 4. Comparison of theoretical surfaces and experimental data. (a) Joint angle comparison. (b) Joint stiffness comparison.

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

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