2023 IEEE/ASME International Conference on
Advanced Intelligent Mechatronics (AIM)

Model-based impedance modulation of antagonistic pneumatic artificial muscles

Xinyao Wang, Tuo Liu, and Jonathan Realmuto

I. INTRODUCTION

SOFT wearable robots that leverage pneumatic-based actuators are envisioned as a comfortable, portable, and safe alternative to traditionally rigid designs.. However, control of such devices is still an outstanding challenge. Most tasks in daily life require adjustments of joint impedance in order to physically interact with dynamic environments [1]. In addition, under conditions of dynamic instability, increased impedance is often required to reduce the effects of neural motion noise [2]. This is especially important for individuals with significant motor variability, such as those with dystonia, who are an important target populations of wearable robots [3]. Therefore, it is critical to endow soft wearable robots with impedance modulation capabilities for successful deployment in assistive wearable robot scenarios aimed at augmenting user independence.

For rigid robots with high bandwidth motors, impedance control is the standard approach for facilitating physical interactions. The basic idea is to formulate the motor control law such that the robotic link behaves like a system with a specified dynamic force-velocity relationship, e.g., as a system with a desired equilibrium, stiffness, dampening, and inertia (e.g., desired impedance). However, such methods cannot be directly translated to soft robotic architectures due to bandwidth limitations, unidirectional actuation, and sensor feedback limitations.

Control of soft actuators has traditionally centered on achieving desired trajectories or providing specific forces and torques with less emphasis placed on controlling the impedance of the actuator. This can limit the versatility and adaptability of robotic systems, as they may not be able to respond effectively to changes in their environment or task demands. Most of the previous methods to achieve robot position or torque control are ad-hoc and based on specific robot hardware, and the impedance characteristics of the robot are often difficult to predict in advance. Compared to previous methods that focused on position or torque control, our research offers a significant improvement in controlling robot impedance characteristics. Our approach, inspired by biological motor systems, leverages antagonism to effectively modulate the joint equilibrium and stiffness. Our model-based approach leverages the force-deflection characteristics of a single actuator to develop an inverse model for joint impedance of the antagonistic setup. The inverse model takes as input the desired equilibrium and stiffness, and outputs the required pressures of each actuator to achieve the desired impedance.

II. METHODS

We first empirically evaluate a single pneumatic artificial muscle's properties by lengthening and shortening it with different nominal internal pressures. Using this data, we formulate a 3D surface (via interpolation), which includes hysteretic behavior, for force, and displacement. We then convert this surface to match the geometric constraints of the antagonistic setup, e.g., we convert the curves to torque-angle. The 3D surface provides a map from the nominal internal pressure to the associated torque-angle curve (a single slice in the pressure-torque plane of the 3D surface). We use this map (look up table), to predict the surfaces of stiffness and equilibrium of all possible combinations of nominal internal pressure. These surfaces can now be used as the inverse model for impedance modulation.

III. RESULTS

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. Our results show acceptable agreement with the model, with an average error of 3.60%.

IV. 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.

X. Wang, T. Liu, and J. Realmuto are with the department of Mechanical Engineering of University of California, Riverside, Riverside, CA, 92521 USA (e-mail: xwang442@ucr.edu, tliu189@ucr.edu, jrealmut@ucr.edu). This research was supported by NSF award CMMI 2221315.