

Dynamic Tracking of Joint Motion with Antagonized Smart Braids

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Abstract

Our lab has developed a way to measure the contraction of Pneumatic Artificial Muscles (PAMs) using the reinforcing fibers themselves as sensing elements. We achieve this by using electrically-conductive wire to form the fiber braid. The inductance of this “Smart Braid” increases as the actuator contracts. We are interested in using these sensors for the feedback control of fluid systems that rely on PAM actuators. Toward that end, we have begun to explore highly portable inductance measurement techniques. Here, we demonstrate the force-compensated tracking of a rotary joint angle at 1 kHz. This is an important step towards the utilization of these sensors in feedback control systems.

Introduction

McKibben Muscles are a common and popular type of soft, fluid-powered actuator due to their force dense, lightweight, and compliant features [1]. When pressurized fluid enters these “muscles” they expand radially while contracting longitudinally. It would be nice to use these actuators without rigid joints. However, the absence of rigid joints becomes a challenge for feedback control. Traditional sensors rely on a fixed datum point to perform tracking accurately. Some systems, like the trunk-like OctArm robot, use string potentiometers to determine the trunk tip position [2]. While these sensors provided sufficient shape sensing, the strings become a liability in harsh or high friction environments.

We have developed a way to characterize the contraction of McKibben artificial muscles by using the braid as a sensor [3,4]. The braid of the muscle is made with insulated wires that form a single circuit. The inductance of this circuit corresponds to different braid lengths. We will present on our work to use these self-sensing actuators to track the motion of a joint driven by antagonized McKibben muscles (Fig. 1). We compare the joint angles predicted by the inductance measurements to joint angles measured with a potentiometer.

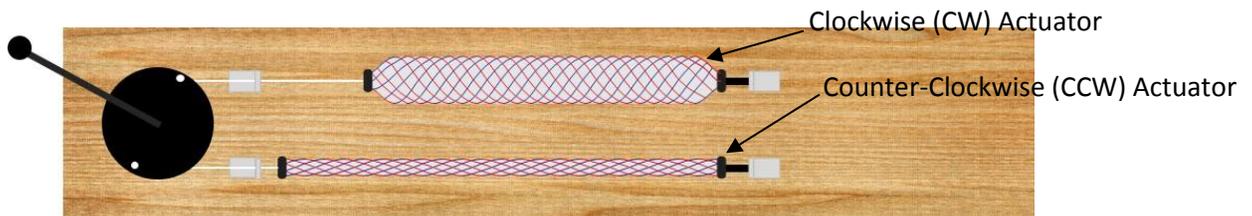


Figure 1: The Smart Braid actuators that drive the joint can also measure its motion through the inductance measurements of the braids.

Theory

Inductance: The long solenoid equation provides an intuitive understanding of the relationship of the inductance to the braid length and cross sectional area. In this approximation, the inductance L is proportional to the cross sectional area A and inversely proportional to the braid length l :

$$L = \mu_0 \frac{N^2 A}{l} \quad (1)$$

μ_o is the magnetic permeability of the core and N is the number of turns of the coil. As the Smart Braid decreases in length and increases in cross sectional area, the fibers start to align to each other. This causes an increase in inductance similar to a solenoid. Therefore, the inductance decreases when the muscle relaxes, while the inductance increases when the muscle contracts.

Methods

Inductance Sensing: The inductance measurements are taken with a TI-LDC1612 Inductance-to-Digital Converter, which is connected to a resonant circuit made up of the smart braid and a small capacitor in parallel [5]. By using a frequency counter, the TI-LDC1612 measures the circuit's frequency of oscillation, f_{sensor} . The sensor frequency is then used to determine the inductance of the smart braid, L , using the value of the capacitance, C :

$$L = \frac{1}{C \times (2\pi \times f_{sensor})^2} \quad (2)$$

Calibration: To calibrate the Smart Braid sensor, we increased the pressure of a single actuator from 15-45 psi, with increments of 5 psi after every 30 seconds, while the antagonized actuator would be pressurized to attain a specified desired tension in the system. We do that for both actuators and measured the inductance at 1 kHz. Only the final 15 seconds of each 30-second period were analyzed. The inductance measurements of each muscle were fit with a linear regression to the angle of the pulley as shown in Fig. 2.

We also tested the antagonized actuators with various levels of tension. This allowed us to characterize both the force-pressure relationship of each actuator and the stiffness of the actuator connections.

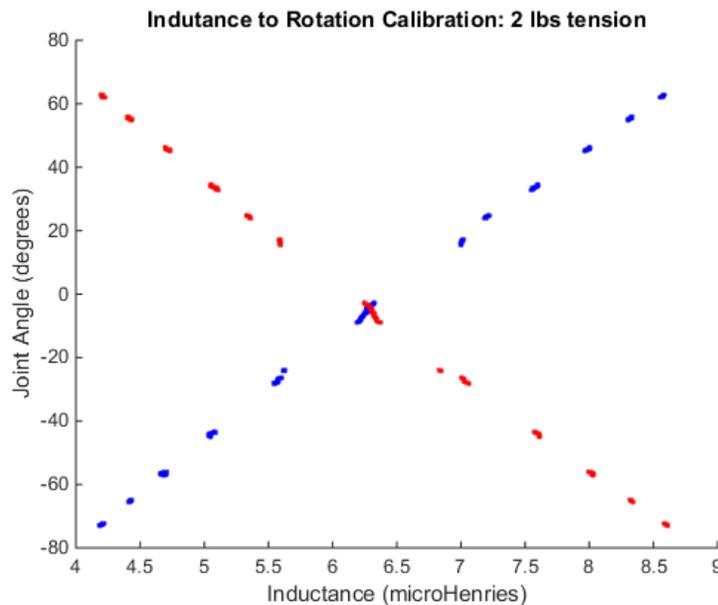


Figure 2: The calibration test was run with a specified tension of 2 lbs and the inductance measurement was collected at 1 kHz. The inductance had a linear relationship to the angle, which is proportional to the actuator length.

Dynamic Tracking: Once the Smart Braid sensor was calibrated, we introduced perturbations to the system by manually pushing the lever arm attached to the pulley shaft with the actuators pressurized to 20 psi. The inductance measured was then used to compute the angle outputs, which was compared to the results of the potentiometer. The length of the each actuator was computed using inductance measurements collected at 1 kHz. Using the pressure measurements and the characterized, force-pressure relationship, we were able to estimate the tension in each actuator connection. With the estimated tension, we applied our model of the connection stiffness to compensate for the stretching in the actuator connections. We can then calculate the “force compensated” joint angle.

Results and Discussion

The result of the dynamic tracking experiment was compared to the calibrated data. As shown in Fig. 3, the angle predictions provided by both the CCW actuator and the CW actuator are not too far from the angle measured by the potentiometer. The actuator that is “slack” always significantly under-predicts the magnitude of the angle. By compensating for the stretching in the connections, the joint angle predictions improve for the actuator under tension.

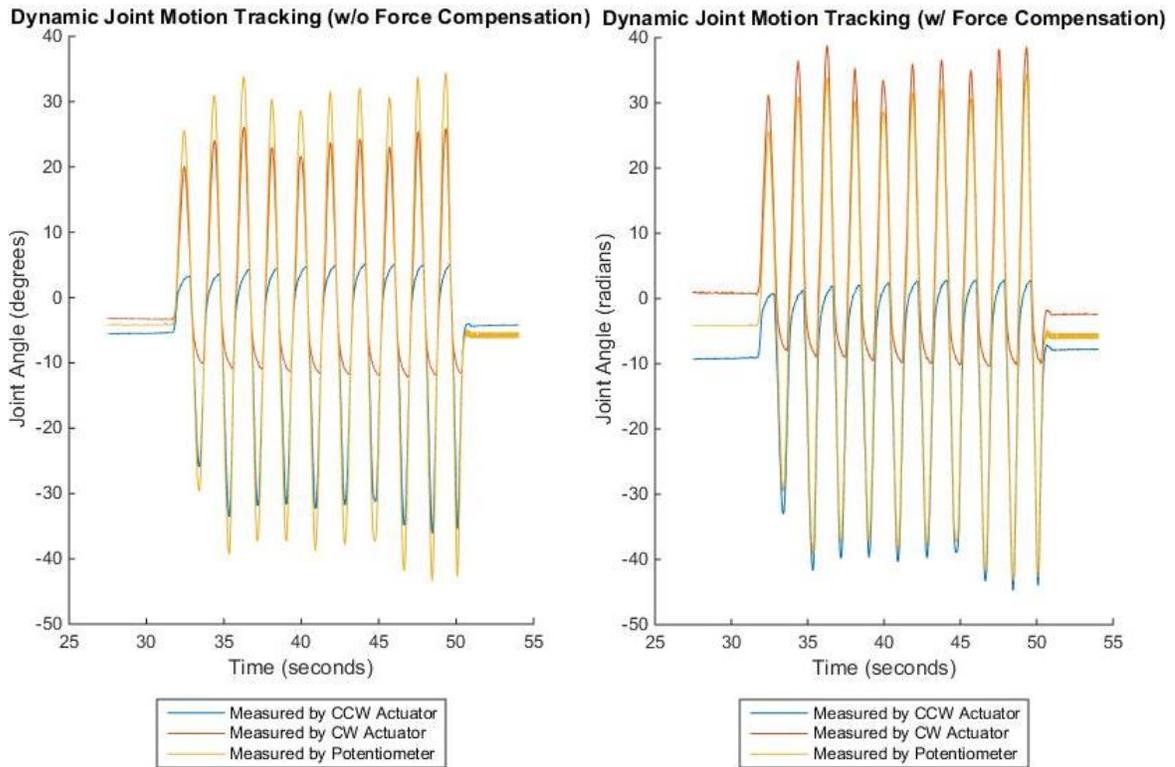


Figure 3: The force perturbation on the lever arm moved the pulley between -45 degrees and 30 degrees. The muscles were not inflated before 30 seconds, thus showing a difference in angle prediction between the actuators due to the slack in the rope connecting to the pulley.

References

- [1] Caldwell, Darwin G., N. Tsagarakis, and G. A. Medrano-Cerda. "Bio-mimetic actuators: polymeric pseudo muscular actuators and pneumatic muscle actuators for biological emulation." *Mechatronics* 10.4 (2000): 499-530.
- [2] Grissom, M. D., Chitrakaran, V., Dienno, D., Csencits, M., Pritts, M., Jones, B., McMahan, W., Dawson, D., Rahn, C., and Walker, I., 2006. "Design and experimental testing of the octarm soft robot manipulator". In Defense and Security Symposium, International Society for Optics and Photonics, pp. 62301F–62301F.
- [3] Felt, W., Remy, C. D., 2014, "Smart Braid: Air Muscles that Measure Force and Displacement," *International Conference on Intelligent Robots and Systems*, The Institute of Electrical and Electronics Engineers, Chicago, 2014.
- [4] Felt, W., Chin, K. Y., Remy, C. D., "Contraction Sensing with Smart Braid McKibben Muscles". Submitted: July 30, 2015
- [5] National Instruments, "LDC1000 Inductance-to-Digital Converter", <http://www.ti.com/lit/ds/symlink/ldc1000.pdf>