Force and Pressure Control of Soft Robotic Actuators

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ABSTRACT

Soft Robotic Actuators (SRAs) have piqued the interest of researchers in recent years. SRAs are generally constructed of soft elastomers and use air or water as a mean of actuation. Due to the inherent properties of these actuators, they are ideal for Human-Robot Interactions (HRI), exoskeletons for rehabilitation and for grasping delicate objects. Since SRA's are actuated using a fluid, being able to effectively control the rate of actuation, pressure and the force applied is necessary so that the actuator and the object being grasped does not get damaged. This paper aims to evaluate three types of controllers, an open-loop controller, pressure-feedback controller, and a force-feedback controller, all used to control an SRA. A custom test stand was built to hold the SRA and test it with all three controllers. The pressure-feedback controller was set to limit the pressure to 8.9 kPa and the force was limited to 0.147 N in the force-feedback controller. Since the open-loop controller had no feedback, the SRA was actuated at a specified frequency while force and pressure measurements were taken. The force-feedback and the pressure-feedback controllers accurately controlled the actuators and the open loop-controller was able to actuate the SRA reliably.

Keywords

Soft robotic actuator, controller, force feedback, pressure feedback

1. INTRODUCTION

Soft Robotic Actuators are at the center of robotic innovation for their dexterity and low-cost manufacturability, since molds for SRAs can easily be made using 3D printers. SRAs are made from extremely elastic material such as Eco-Flex 30 [Smooth-On Inc] and other types of elastomers. Since there are no rigid links in SRAs, they are ideal for tasks involving HRI and for grasping delicate objects such as eggs or coral [1], [2]. Methods of actuation for these actuators vary depending on design and use, ranging from compressed fluids, chemical reactions and Shape Memory Alloys (SMA) [3], [4]. SRAs take on many bio-inspired designs with many stemming from octopus, fish and caterpillars; and can produce life-like motion [2], [4]–[6].

In a previous study that used an open loop controller to actuate SRA's, it was concluded that the frequency of actuation and the geometry of the actuator greatly effects the performance of a soft robotic actuator [7]. Furthermore, it was noted that a higher pressure built up inside the actuator and higher force exerted by the actuator were achieved at lower frequencies. With further testing it was determined that better control of SRAs was needed to reach peak performance.

The purpose of this study is to evaluate the performance of three different control methods for controlling a SRA. An open loop controller was used to control the frequency of actuation of the SRA. The closed loop pressure-feedback controller and the force-feedback controller were built off the open loop controller with the aim of accurately controlling the actuation of the SRA by limiting the force applied and the pressure inside the SRA.

The same actuator was used throughout this paper and the only parameter that changed was the method of control.

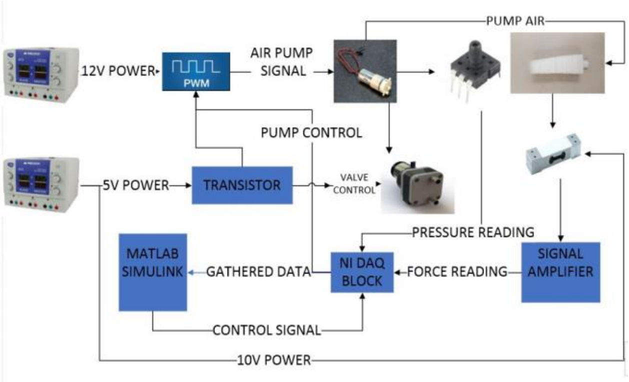

Figure 1: Test Station Setup

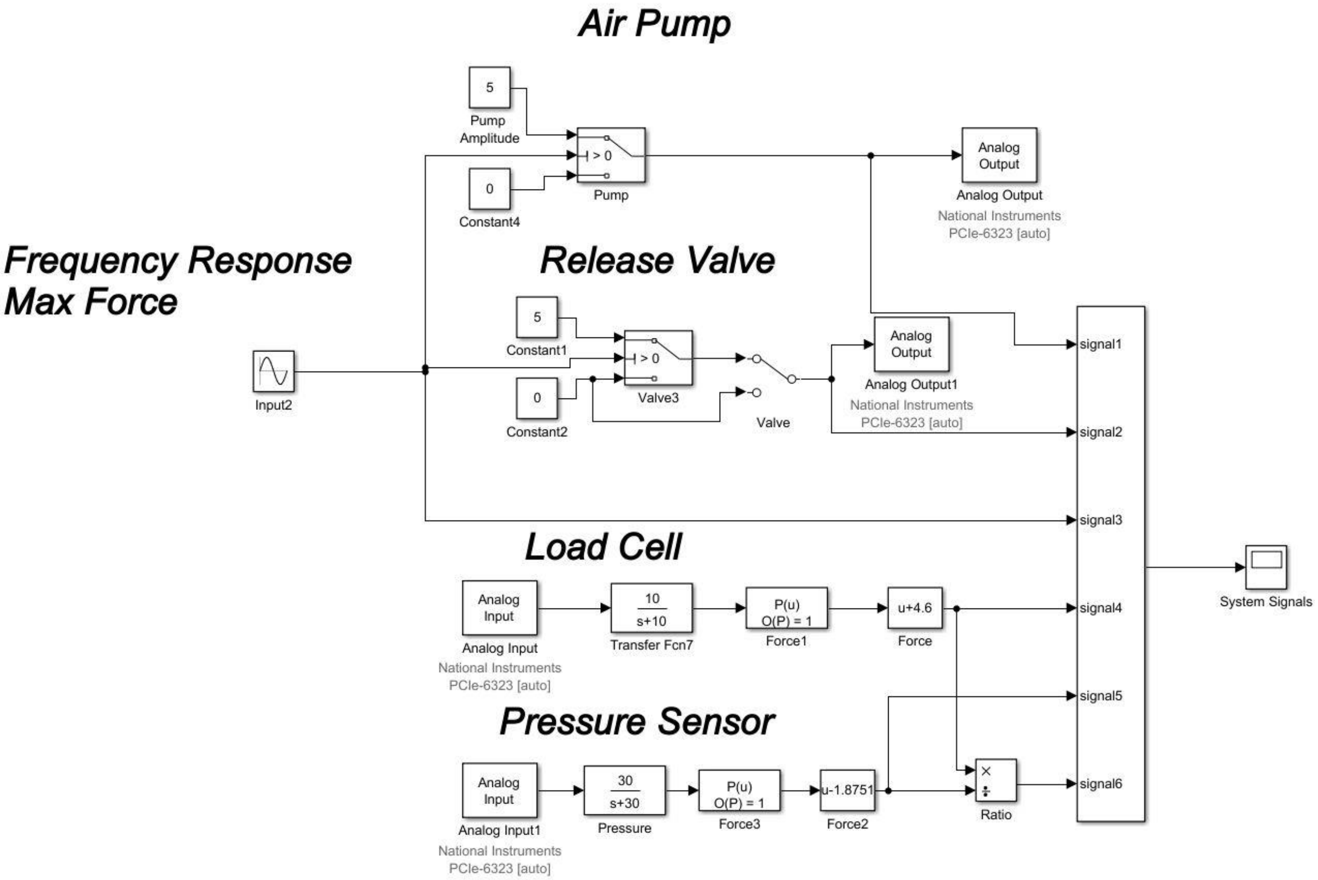

Figure 2: Open Loop Controller Layout

2. Experimental Setup

The test stand, shown in Figure 1, was comprised of a vertical aluminum plate that held the 3-D printed actuator mount and the 1kg load cell (LSP-1 by Transducer Techniques), which was used to monitor the force applied from the actuator. Off to the side of the stand was the SyRen 50 motor driver was used to send power to a generic 6V air pump. A 12V 2way solenoid valve was used to deflate the actuators. A Honeywell 0-15 psi pressure sensor was used to monitor the pressure of the actuator. Finally, a National Instruments DAQ block was used to allow the hardware to communicate back and forth with MATLAB/SIMULINK.

The actuator was fabricated using the same procedures as in [7]. A photo sequence of the actuator inflating is shown in Fig.3.

3. Controllers

3.1 Open Loop Controller

The open loop controller, shown in Fig. 2 used a sine wave as the input to the system. The frequency of the sine wave determined the rate of actuation for the SRA. For this controller the amplitude was set to 1. In this experiment, a frequency of 1 rad/sec was kept constant in all three controllers. The sine wave acts as a switch by activating the air pump and closing the valve when the amplitude is positive and opening the valve and turning off the pump when the value is negative. The force, pressure, error signal, and the input signal were recorded and saved to the MATLAB work space.

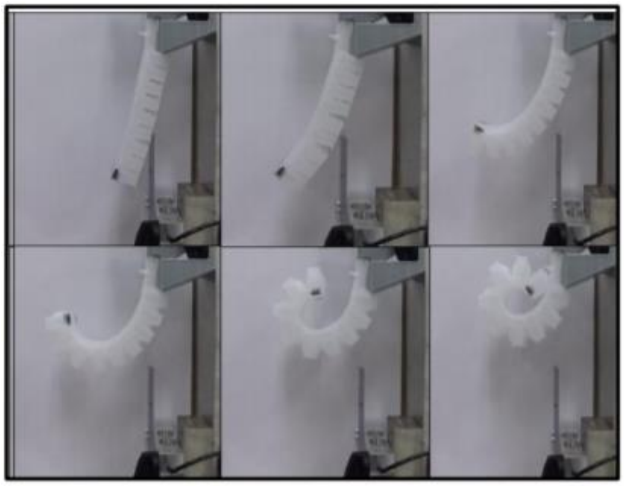

Figure 3: Photo Sequence of Actuator Inflating [7]

3.2 Force Feedback Controller

The force-feedback controller's sine input feeds into a gain block that is used to specify the force desire ($\boldsymbol{F_D}$) (Fig. 4). For this experiment this gain was set to 15, which equates to .147 N (15 g) as the input force (F).

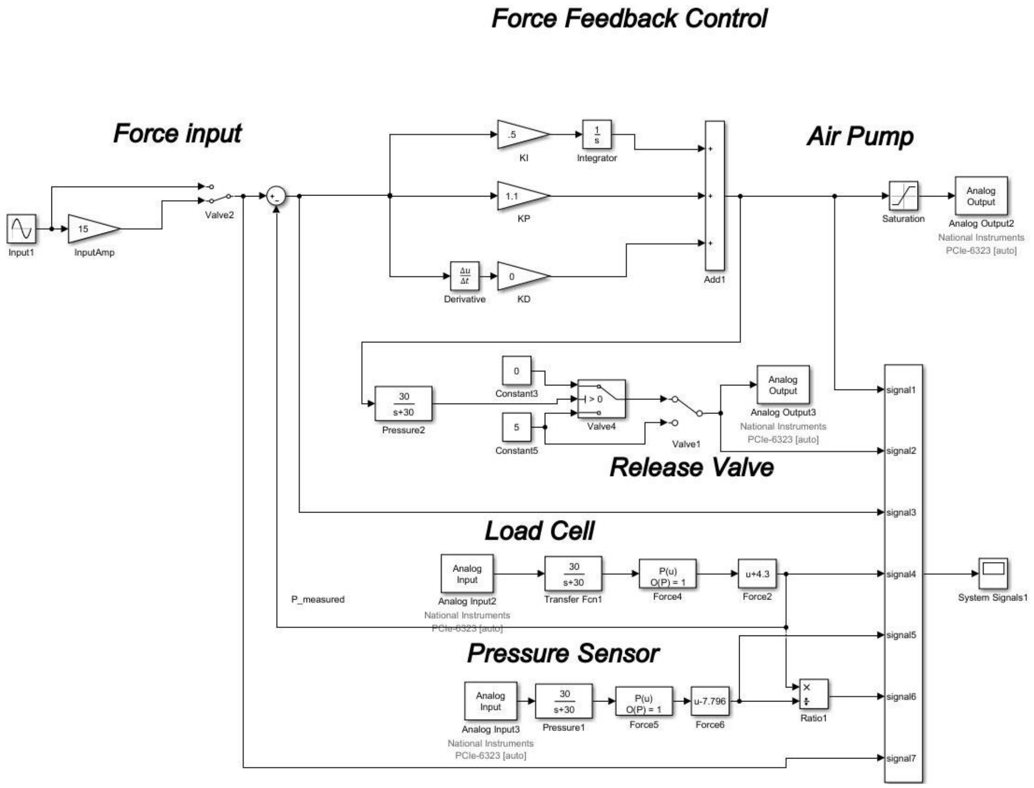

Figure 4: Force Feedback Controller Layout

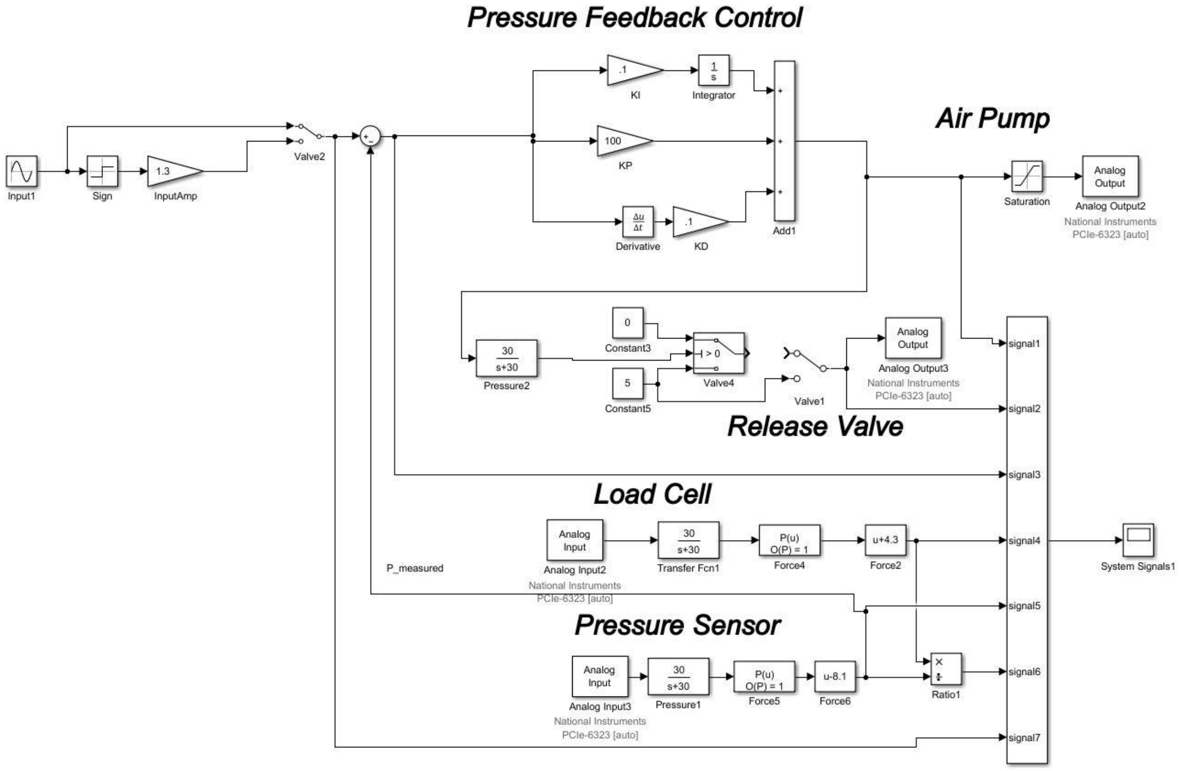

Figure 5: Pressure Feedback Controller Layout

The force tracked ($\boldsymbol{F_T}$) was the force measured at the end effector of the actuator. As the SRA inflated, the end effector pushed on the plexiglass attached to the load cell which recorded the force applied by the actuator.

To optimize this control scheme was used. The value for the proportional and integral gain are:

$$K_P = 1.1 \text{ and } K_I = 0.5$$

3.3 Pressure Feedback Controller

The pressure-feedback controller (Fig. 5) has a sine wave that fed into a gain block set to 1.3, which limited the pressure desired ($\boldsymbol{P_D}$) to 8.9 KPa (1.3 psi). The pressure tracked ($\boldsymbol{P_T}$) was the recorded pressure inside the actuator during inflation and deflation. This controller used a PID control scheme with the following gains:

$$K_P = 100, K_I = 0.1 \text{ and } K_D = 100$$

4. Results and Discussion

Figure 6 shows a comparison of the force measured for the same actuator, at a frequency of 1rad/s, using the open loop and force feedback controllers.

As shown the force achieved using the closed loop controller with force feedback was consistent throughout the experiment and had a value of 0.15N. This value is greater than that achieved with an open loop controller that was consistent at a value of 0.12 N.

Moreover, the force controller achieved much better tracking of the input signal as shown in Figure 6, where the error is consistently less than 0.01 N. As shown in the figure the tracking is accurate and consistent with minimal amplitude noise. The noise did not noticeably affect the performance of the actuator.

An additional metric of performance of the controller is the mean and standard deviation of the error signal. The mean had a value of 0.00179 N and standard deviation equal to 0.0024 N. The value of the standard deviation is almost double that of the mean due to the noise in the signal being comparable to the amount of error. Though the variation in the amplitude of the noise is minimal, it was frequent, which resulted in a higher standard deviation.

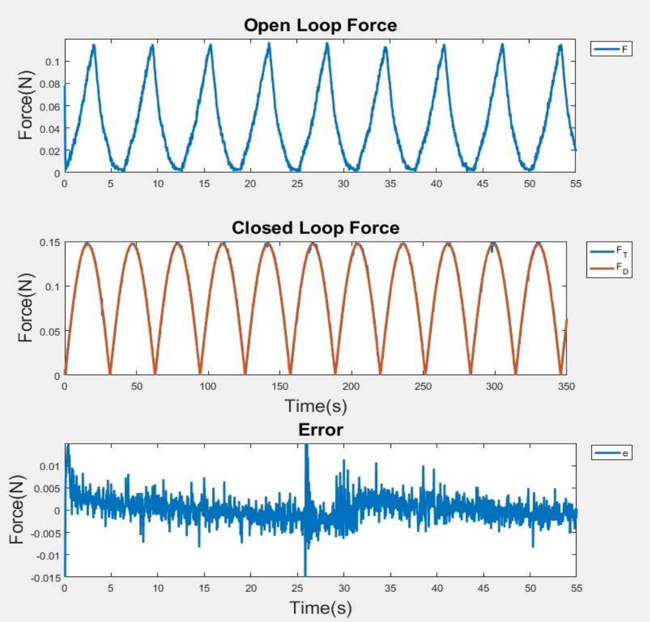

Figure 6: Open Loop Vs Force Feedback

Figure 7 shows a comparison of pressure measured inside the SRA at a frequency of 1rad/sec using the open loop and pressure feedback controller. The pressure is displayed in units of kPa and as shown the closed loop controller has a better performance in terms of pressure as it allowed pressure to build up to 8.5kPa while the open loop controller allowed pressure to build up to 5.5kPa.

The tracking of the pressure controller during the inflation of the actuator is very precise, however, the tracking lags in deflating the actuator. The reason for that is the valve that has an open/close control mechanism. Once the valve opens and the pressure is released, the pressure inside the actuator does not instantly release; rather, the elasticity of the SRA material constricts the air out of the actuator in a characteristic way based on inherent material properties.

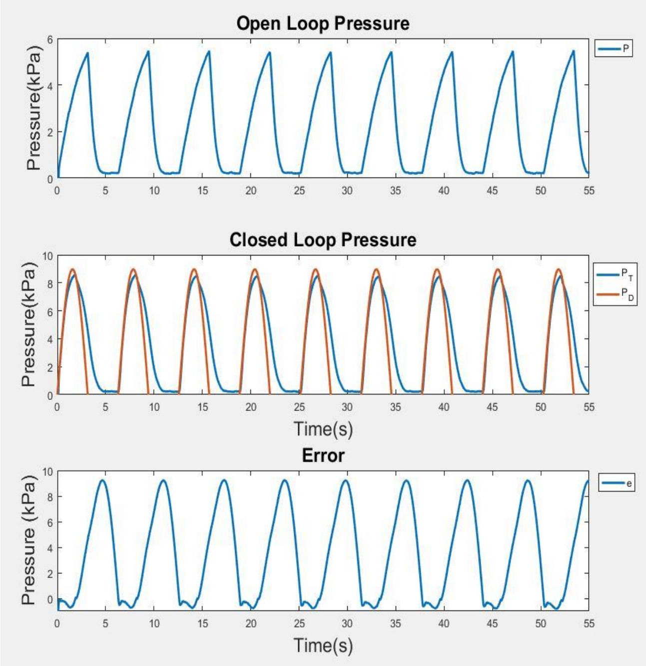

Figure 7: Open Loop Vs Pressure Feedback

Moreover, Figure 7 shows the P_T and P_D and the error signal. The error is almost zero for inflating the actuator and starts increasing for deflating the actuator. Even though the error signal looks cyclic with high amplitude, overall it does not substantially affect the performance of the actuator at low frequencies of operation. This impact would become significant at high frequencies.

Similarly to the analysis done on the force controller, the mean and standard deviation of the error signal were calculated for the pressure controller as well. The mean had a value of 5.045kPa and the standard deviation had a value of 5.21kPa. The high values of the mean and standard deviation are a result of the error achieved while deflating the actuator.

5. Conclusion

In conclusion the same actuator was tested at the same frequency by different controllers. The results between an open loop controller and a closed loop controller varied substantially and proved that a closed loop controller, either force or pressure feedback, could extract a higher performance from the SRA. Due to the nature of the actuator and its behavior while inflating and deflating, the force feedback achieved better tracking for the signal and substantially less error. Finally, the type of controller to be used will depend on the application of the actuator. If it is handling of delicate objects perhaps a force feedback is more appreciated and a pressure feedback could be more sensible for the case of haptic feedback.

For future research into SRAs, studies on how long-term cyclical loading affects the performance of the actuator and the life cycle of the material use to create these actuators. SRAs are widely used in cases of HRI and with the handling of delicate objects, so benchmark studies can be performed to determine the appropriate force need to grasp the object as well as an acceptable error in the force applied. Since the amount of force needed to safely grasp a delicate object and the acceptable deviations in the applied force can vary depending on the object, a wide variety of objects should be tested.

Acknowledgment

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6. REFERENCES

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