Dual-stage hysteresis-based pressure control of constrained on/off pneumatic valves for McKibben actuators

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Abstract. *Pneumatic artificial muscles (PAMs) are very used in the field of biomimetics, where its good power/weight relationship makes them a good option to mimic animals. Seeking to better explore precise controllers on these actuators using on-off valves, in this work we use three different valves controlling a pneumatic muscle and prove that the proposed algorithm, a dual-stage hysteresis control in a 10ms loop, has a better performance than a traditional hysteresis method. Our method had a higher precision while keeping a similar airflow to the traditional method. This improves our capacity to build more precise, lightweight robots for faster locomotion.*

1. Introduction

Pneumatic systems are used in many robotic applications due to its good power-to-weight ratio and inherent compliant behavior. The compliance presented in this kind of system is an important feature when it comes to rehabilitation and safe interaction with humans [1]. Pneumatic artificial muscles (PAM's) can reproduce many characteristics from biological muscles, which makes them very useful in the biomimetics field [3], as well as humanoid robots [2]

Trying to achieve precise pressure control, faster response and a low weight system, Hamdan et al. [4] work with a PID controller for proportional valves achieved improvements for step response, command following and greater bandwidth, Jien et al. [6] improved the performance of a unconstrained on/off valve using multi-level PWM hysteresis control, Van Ham et al. [5] made a comparison between PWM and bang-bang control for pleated pneumatic artificial muscles. However, the algorithms presented in these works have a bigger set of parameters, needing more processing time

We use a feedback from a sensor to make a control decision of whether it is necessary to supply or exhaust the air in the muscle. Although the principle is simple, to reach the required pressure is a high-level challenge.

We show that the traditional algorithm has the best response time to fast movements but a worse response when we want precision. We modified this to have two decisions in the loop, which improves the performance while keeping the required precision. The Dual-Stage Hysteresis Based Pressure Control (DSHPC) is a modification in the Hysteresis Control method to achieve a high speed and precise pressure control for pneumatic artificial muscles using constrained pneumatic valves.

2. Experiments and Methods

The experiment consisted in the test of four algorithms using three different valves. The valves are the models VQZ1321-6L1-C6 6mm tube, VQZ1321-6L-C6 6mm tube, SYJ3320-6M-M3 4mm tube.

The components of the system are a 200mm pneumatic muscle, three pressure sensor. The valves previously mentioned and a microcontroller.

The algorithms used are based in a 10ms loop. A 5ms loop is tested to confirm our empiric knowledge of which one would get better results. Within the 10ms loop we will test three different algorithms.

The term decision is something that we must make clear. In every loop of the algorithm we have to read the pressure inside the actuator, compare with the desired pressure and decide if we will supply, exhaust the system or keep it still. Every time we say decision this is what we mean.

Most times, we do not get to the exact desired pressure. Expecting this error the HC use a value called hysteresis that is the accepted error in the system to make it stable. The biggest the hysteresis value the more stable the system is but the average error gets higher.

In the Hysteresis Control (HC, 10ms and 5ms), the decision is made after reading the systems pressure and compared if the desired pressure. This way keeping the decision for the whole loop.

In the Precise Hysteresis Control (PHC, 5ms/close) the decision is made the same way as the HC but is kept for 5ms and then the valve is closed.

In the Dual-Stage Hysteresis Based Pressure Control (DSHPC, 5ms/5ms), we have two hysteresis values set a low and a high value to track if the desired pressure is much far from the actuator pressure. This way, after the comparison between the desired pressure and the actuator pressure, we have the following stages: much lower, lower, inside, higher, much higher pressure. In this algorithm, if the module of the difference between the desired pressure and the actuator pressure is lower than the high hysteresis value, it will behave as the PHC method (will open for 5ms and close for the other 5ms, or it will be closed all the time). If this difference is higher we have the much lower or the much higher pressure the valve will be open for the 10ms in the loop, as the HC method.

The hysteresis values where set to 0.04MPa and to the DSHPC the high hysteresis value as 0.16MPa.

3. Experimental Results

The conducted tests show that our empiric knowledge was true. For precise movements the fig. 1 shows that the PHC is more precise than the other algorithms presented with the reference sign as show in Fig. 1 a. What is shown in Fig. 1 b, c and d is the difference between the desired pressure (reference value) and the pressure sensor reading, the values under the 0.04MPa value are irrelevant because they are within the hysteresis value.

The valve one has the best behavior within those valves for the hysteresis value used. In fig. 1 b, we can see clearly that the HC in 5ms and 10ms loop are unstable and often out of the hysteresis value while the PHC and DSHPC having a stable behavior and are most of the test inside the hysteresis. This proves that the DSHPC have the precision of the PHC algorithm for this valve.

For Fig. 1 c all the algorithms presented an unstable behavior and it is not easy to see in the graph which one is better. To make the understanding easier the average errors of the algorithms are as following: 0.029639MPa (5ms/closed), 0.033521MPa (10ms), 0.029844MPa (5ms/5ms) and 0.035798MPa (5ms). Therefore showing the PHC and DSHPC as the more precise ones.

Fig. 1 d shows the valve 1, the more precise of the tested in this work. Seeing the figure may mislead the reader to think that the algorithms are not precise but during the experiment all the algorithms were inside the hysteresis value, the 0.04MPa line. All the methods been precise.

We assured the precision of our algorithm but we are presenting the evaluation of the algorithm in two different features, the next one is to prove its speed when submitted to fast movements. Its results when going from a pressure of 0MPa to 0.6MPa.

Our result shows that for VQZ1321-6L1-C6 the slow algorithm is the PHC, entering the hysteresis zone after 60ms while the other algorithms in 50ms.

With the valve VQZ1321-6L-C6, the PHC is around 5% slower according to our

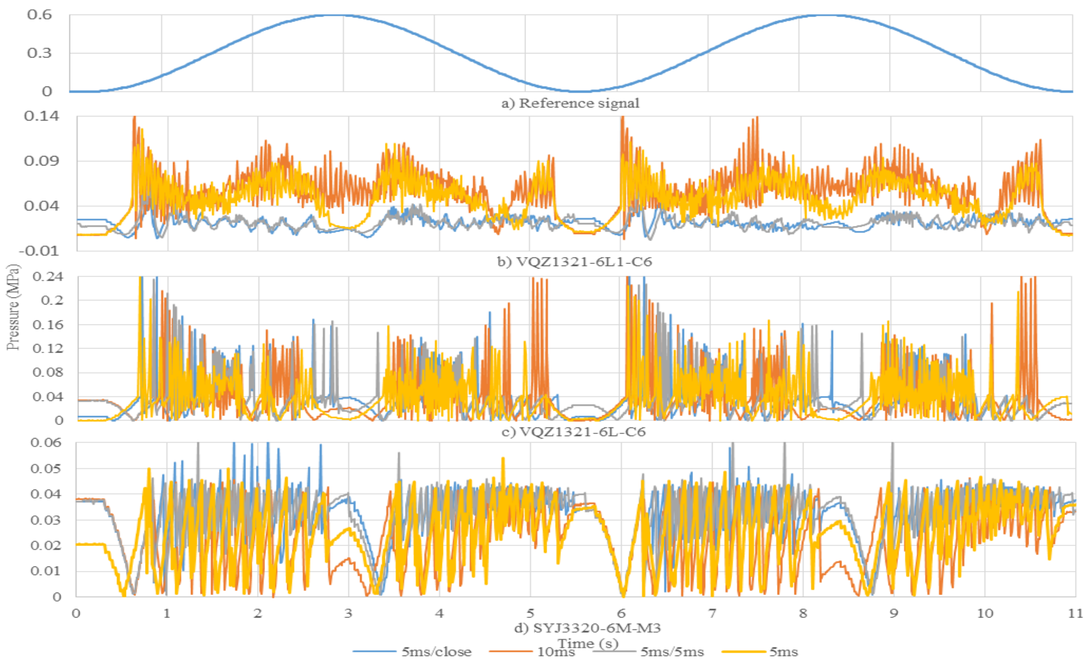

Fig. 1 Precision test of the four algorithms tested. It shows the difference between the desired pressure and the actuator pressure. The PHC and DSHPC algorithms have the best performance in this precision test for b and c and, as d has a better precision, the four algorithms keep the precision within or close to the hysteresis value.

analysis. The SYJ3320-6M-M3 valve shows that for the more precise valve we have the slowest changes in the pressures. Our algorithm keeps a high speed for fast movements achieving the hysteresis value in the 200ms while the PHC even after 300ms did not reach the 0.1MPa line.

4. Conclusion

Using constrained on/off valves with different airflows and the same control algorithm we get different behaviors in the methods tested. Even changing the valves, the DSPHC presents itself with a higher performance than the other algorithms.

The 10ms loop has been proved better than the 5ms one when controlling the presented valves. Seeking a precision improvement to the traditional hysteresis method the PHC was implemented. to improve the precision that the traditional hysteresis method has the PHC method was developed. It solved the precision problem but jeopardized the speed.

Seeking to achieve the precision of the PHC with the speed of the HC method the DSHPC algorithm was developed. This algorithm showed that it has the best of the two previously used methods when it comes to precision and speed**.**

5. References

[1] B. Tondu, S. Ippolito, J. Guiochet and A. Daidie, “A Seven-degrees-of-freedom Robot-arm Driven by Pneumatic Artificial Muscles for Humanoid Robots”, The Int. Journal of Robotics Research, vol. 24, No. 4, pp. 257-274, April 2005.

[2] R. W. Colbrunn, G. M. Nelson and R. D. Quinn, “Design and Control of a Robotic Leg with Braided Pneumatic Actuators”, Proc. IEEE/RSJ Int. Conf. on Intelligent Robots and Systems, 2001.

[3] Davis, S. T., and Caldwell, D. G. 2001. “The bio-mimetic design of a robot primate using pneumatic muscle actuators”, Proc. 4th Int. Conf. on Climbing and Walking Robots, K. Berns and R. Dillman, eds, Professional Engineering Publishing, London, pp. 197–204.

[4] Hamdan, M. (Marv) and Gao, Z., “A novel PID controller for pneumatic proportional valves with hysteresis”, IEEE Industrial Application Society 2000 Annual Meeting and World Conference on Industrial Applications of Electrical Energy, 8–12 October 2000.

[5] R. Van Ham, B. Verrelst, F. Daerden, and D. Lefeber. “Pressure control with on-off valves of pleated pneumatic artificial muscles in a modular one-dimensional rotational joint”, International Conference on Humanoid Robots, page 35, October 2003.

[6] Jien S, Hirai S, Ogawa Y, Ito M and Honda K, “Pressure control valve for Mckibben artificial muscle actuators with miniaturized unconstrained pneumatic on/off valves”, Proc. IEEE/ASME Int. Conf. on Advanced Intelligent Mechatronics (Singapore) pp 1383–8, 2009