Proceedings of Mechanical Engineering Research Day 2016, pp. 206-207, March 2016

PID control of vertical pneumatic artificial muscle system

M.H. Tan, S.H. Chong*, T.F. Tang, A.Z. Shukor

Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka,
Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

*Corresponding e-mail: horng@utem.edu.my

Keywords: Pneumatic artificial muscle; PID; vertical motion

ABSTRACT – Pneumatic Artificial Muscle (PAM) overcome the other common actuators as it has higher power-to-weight ratio. However, the air compressibility and lack of damping ability of PAM brings dynamic delay to the pressure response and causes oscillatory motion to occur. It is not easy to realize the motion with high accuracy and high speed due to all the non-linear characteristics of pneumatic system. A PID control using Ziegler Nichols method for a PAM system in vertical axis to control the tracking motion of the PAM is proposed in this paper. The effectiveness of the proposed control algorithm is demonstrated through experiments.

1. INTRODUCTION

PAM is a rubber tube clothed with a sleeve made of twisted fiber-code, and is fixed at both ends by fixtures. It is an actuator that is able to expand its muscle in radial direction when pressure is supplied and vice versa. PAM has a property like a spring, which enables it to change its own compliance by the inner pressure. The development of actuator system using PAM has been applied to some of the therapy robot and industrial machines. However, PAM has the characteristics such as hysteresis, non-linearity and low damping ability. The air compressibility and lack of damping ability of PAM system cause dynamic delay to the pressure response, which will result in oscillatory motion. Hence, it is not easy to realize the motion with high accuracy and high speed.

Many intelligent control algorithms have been proposed up to now. A simple PID control [1] is applied on a 7 degree of freedom PAM system to power up exoskeleton. Besides, a fuzzy PD+I learning control for a single PAM is done in previous study [2] with the limitation of low accuracy for tracking motion during the starting of operation. The PAM system is vulnerable to parameter changes over time when using fuzzy + PID control in [3]. Tetsuya Kimura applied a method of feedback linearization for a PAM system to handle the non-linear characteristics based on a non-linear model in [4]. Furthermore, a switching algorithm of control parameter using learning vector quantization neural network (LVQNN) was proposed by Kyoung Kwan in [5] on a PAM system.

2. EXPERIMENT SETUP

The experiment setup is shown in Figure 1. The hardware includes a personal computer (i7 4GHz), which calculates the control input and controls the 5/3 proportional directional valve (FESTO MPYE-5-1/8HF-710B) and two PAM (FESTO DMSP-10-150N-RM-CM) through a data acquisition unit. The pressures in both of the PAM are measured using the pressure sensors (FESTO SDE-10-10). A joint angle θ is detected by using a rotary encoder (3600 pulse/rev). All the signals are fed back to the computer through the data acquisition unit. Two ends of the PAM are connected to the fabricated base, while the other two ends are connected to each other through a timing belt. The timing belt is attached to a timing pulley attaching to a shaft to perform rotational motion. The experiments are conducted under a temperature of 20°C and supply pressure of 5bar.

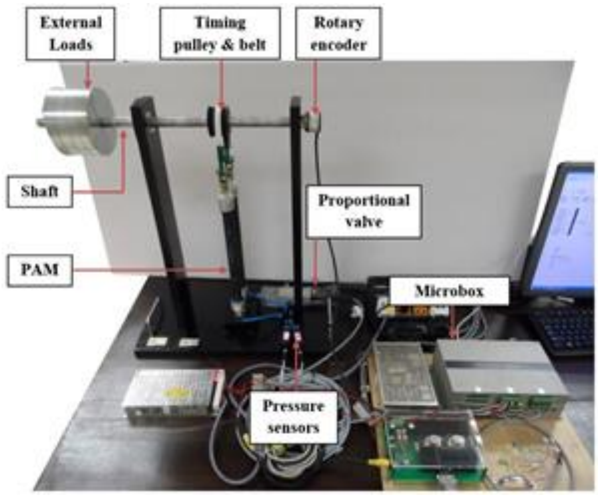

Figure 1 Photograph of the experiment setup.

3. CONTROLLER DESIGN

To design the PID controller for the system, Ziegler Nichols closed-loop tuning method is used to obtain the controller parameters. The ultimate gain value, K_u, and the ultimate period of oscillation, P_u, are obtained in order to calculate $K_c$by using this method. It is a simple method of tuning the PID controller and can be refined to give a better approximation of the controller parameters. The controller constants K_c, T_i and $T_d$in the system with feedback are obtained. The obtained gain value K_u is 40, and period of oscillation P_u is 0.6. These values are substituted into the Ziegler Nichols closed-loop equations and the approximated parameters are obtained as shown in Table 1.

Table 1 Ziegler Nichols closed-loop calculation.

Parameters	K_c	T_i	T_d
PID	24	0.3	0.075

For PID controller, we have the general equation of

$$C(s) = K_p(1 + \frac{1}{T_i s} + T_d s) \quad (1)$$

By substituting the PID parameters into Equation (1), yields

$$C(s) = 24 + \frac{80}{s} + 1.8s \quad (2)$$

Next, the parameters are fine-tuned to $K_p = 13$, $K_i = 15$ and $K_d = 0.1$ by using trial-and-error through experiments. These values are used as the parameters in the PID controller for sinusoidal input tracking motion as shown in Figure 2.

4. PERFORMANCE EVALUATION

Experiments are carried out using sinusoidal waveform as reference input for uncompensated system and system with PID controller. Figure 2 shows the comparison of the performances between the uncompensated system and PID controller with the sinusoidal input signal to the system at a low frequency of 0.1Hz. The experiments are carried out for 30s. It is shown that the uncompensated system does not reach the desired position angle, meanwhile the PID controller is able to overcome it and enables the system to track the desired input position with minor errors. The error of PID controller is approximately 1.3°, which is 91.7% better than that of uncompensated system. It is clear to show that PID controller is able to control the PAM actuated system in small velocity with minor error.

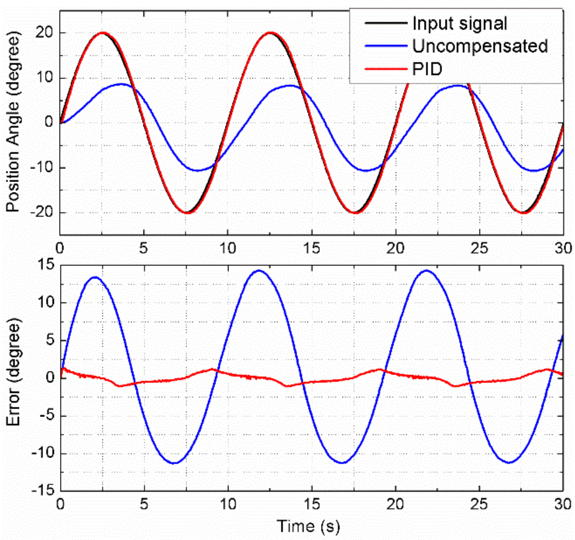

Figure 2 Closed-loop sinusoidal input experiment at f=0.1Hz.

5. CONCLUSIONS

A PID controller is proposed to control the tracking motion of PAM system in vertical axis. It has shown that the proposed method has a good control performance for the nonlinear system, such as PAM system. The PID parameters are designed using Ziegler Nichols tuning method. The controller design by this method does not need any training procedure in advance, but it only requires the input and output of the plant for the adaptation of control parameters. The parameters can be tuned iteratively. From the experiments of the position control of PAM system, the tracking performance is accurate at low frequency. The proposed method is simple and gives satisfactory trajectory tacking.

As future work, a proposed approach can be extended to examine the robust performance in the presence of load change to the PAM system.

ACKNOWLEDGEMENT

The authors would like to be obliged to Motion Control Research Laboratory, Universiti Teknikal Malaysia Melaka for providing the laboratory facilities and equipment support. The authors would like to thank UTeM Zamalah scheme scholarship for the financial support. The Fundamental Research Grant Project (FRGS/2/2014/TK03/FKE/02/F00240) from UTeM is gratefully acknowledged.

REFERENCES

[1] N. Tsagarakis, D.G. Caldwell, and G.A. Medrano-Cerda, "A 7 DOF Pneumatic Muscle Actuator (PMA) Powered Exoskeleton", in *IEEE International Workshop on Robot and Human Interaction*, Pisa, Italy, 1999, pp. 327-333.

[2] S.W. Chan, J.H. Lilly, D.W. Repperger, and J.E. Berlin, "Fuzzy PD+I Learning Control for a Pneumatic Muscle", in *IEEE Int. Conf. Fuzzy Systems*, 2003, pp. 278-283.

[3] K. Balasubramanian, and K.S. Rattan, "Fuzzy Logic Control of a Pneumatic Muscle System Using a Linearizing Control Scheme", in *Int. Conf. North American Fuzzy Information Processing Society*, 2003, pp. 432-436.

[4] T. Kimura, S. Hara, T. Fujita, and T. Kagawa, "Control for pneumatic actuator systems using feedback linearization with disturbance rejection," in *American Control Conference, Proceedings of the 1995*, 1995, vol. 1, pp. 825-829.

[5] K.K. Ahn, T.D.C. Thanh, and Y.K. Ahn, "Intelligent switching control of pneumatic artificial muscle manipulator," *JSME Int. J. Ser. C Mechanical Systems, Machine Elements and Manufacturing*, vol. 48, no. 4, pp. 657-667, 2005.