































By observation, P controller is sufficient and reliable to be implemented in the system controlling as well as steady state error compensation. Figure 12 summarizes the performances of simulated outputs in Figure 9, 10 and 11 with the respect of settling time, rising time, steady state error, and the percentage of overshoot. P controller is taken as a reference for both continuous and discrete time models.

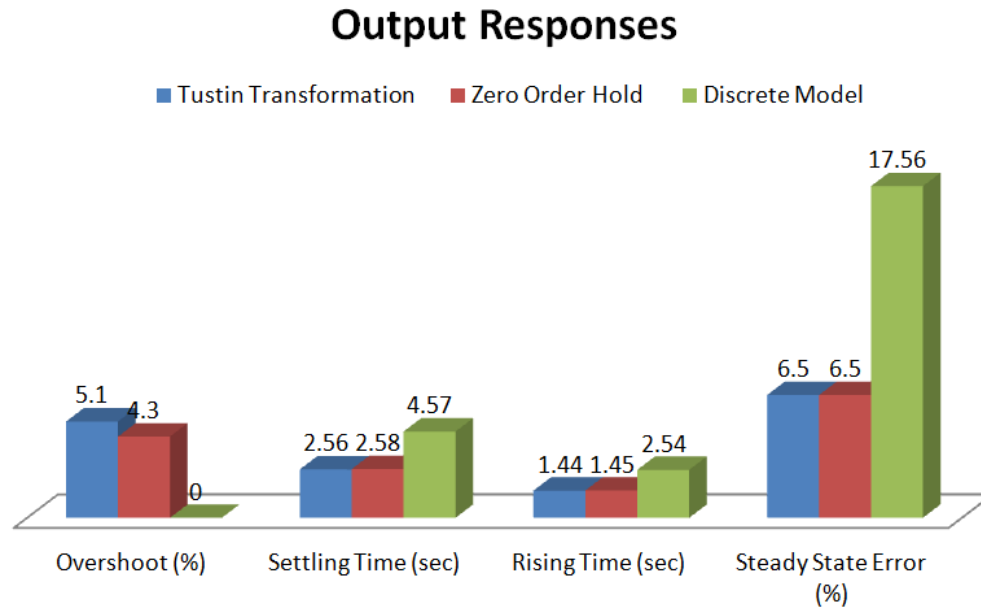


Figure 12. Output responses between continuous and discrete time models

Bilinear transfer function is chosen for the system modeling even though its percentage of overshoot is slightly higher than zero order hold. Figure 11 as a reference, it shows that the output responses of Bilinear transformation are not affected by machining vibration or distortion compare to zero order hold in Figure 10. Bilinear transformation method rounds any time delay to the nearest multiple of the sampling time. Therefore, P controller with the Bilinear transfer function is used for online testing with the connection to the pneumatic actuator as shown in Figure 13 and 14.

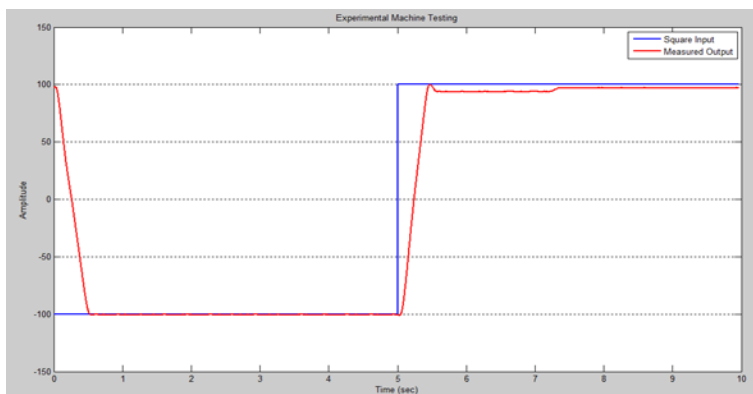


Figure 13 P controller online testing (Square wave input)

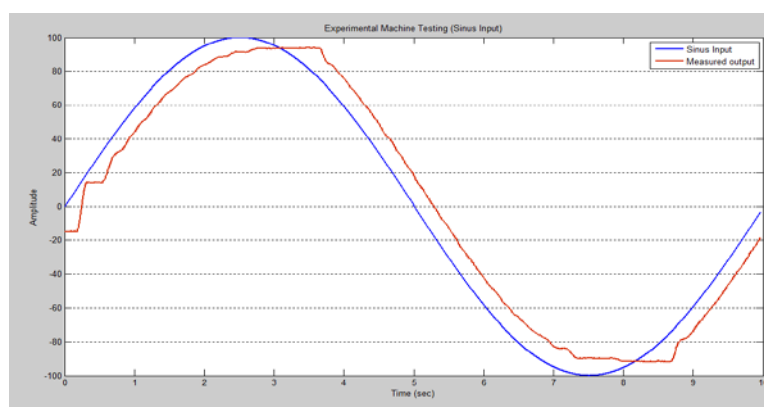


Figure 14. P controller online testing (Sine wave input)

From the Figure 4.13, it is observed that:

- i. Settling time,  $t_s = 0.81$ seconds
- ii. Rise time,  $t_r = 0.6$  seconds
- iii. Percentage overshoot = 4.25%
- iv. Steady state error = 2.3%

Meanwhile for the Figure 14, sine wave signal is imported to the system with the purpose to determine the measured output for the machine testing. Clearly, output response is 50.4 degrees out of phase compared to the reference input. In order to test the capability of the P controller in positioning control, additional loads with different weights are added to the system. Square wave signal is taken as the reference input to check the accuracy of output response as illustrated in Figure 15.



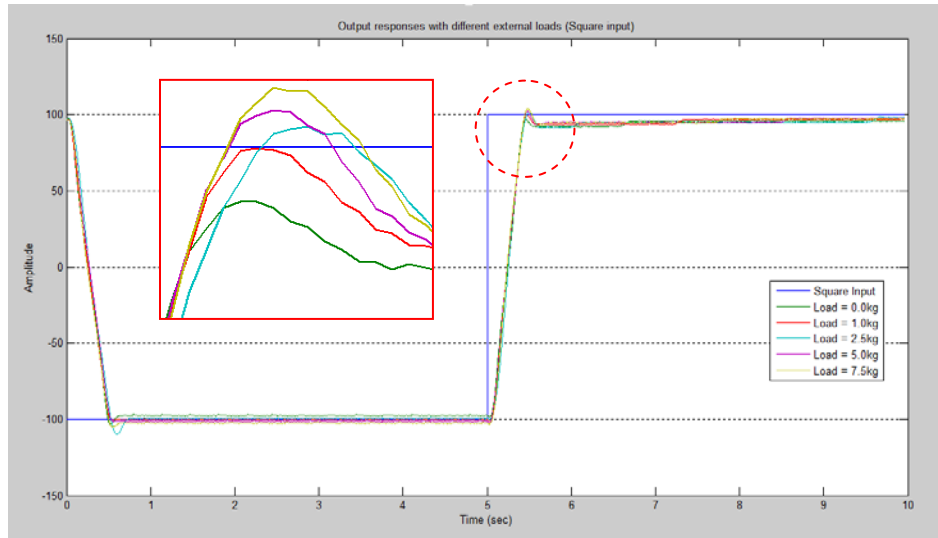


Figure 15 Output responses with different external loads

Apparently by observing the output responses in Figure 15, it shows that the external load with the highest weight has the most significant overshoot in the system. External loads with 7.5kg results the largest percentage of overshoot compare to the others. Nonetheless, P controller is applicable in the system even though the external loads are varied due to the steady state error is still within the range of 5 percent. In order to test the performance of PID controller, LQR controller is implemented in position control. Feedback vectors,  $K$  and the value of  $Nbar$  are stated as follows. In Figure 16, it compares the performance in between PID and LQR controller for positioning control.

$$\text{Feedback vector, } K = [2.6017 \quad 0.8530 \quad 0.4174 \quad 2.4979]$$

$$Nbar = 1.0695$$

LQR controller provides zero steady state error and percentage of overshoot in positioning control compare to PID controller. However, LQR controller is distorted by machining vibration or noise initially. Besides, PID controller response time is significantly fast yet it cannot fully compensate the steady state error back to the system. Regardless of that, both controllers are applicable in positioning control for the pneumatic actuator system. Table 4 summarizes the performance of PID and LQR controllers for positioning control.

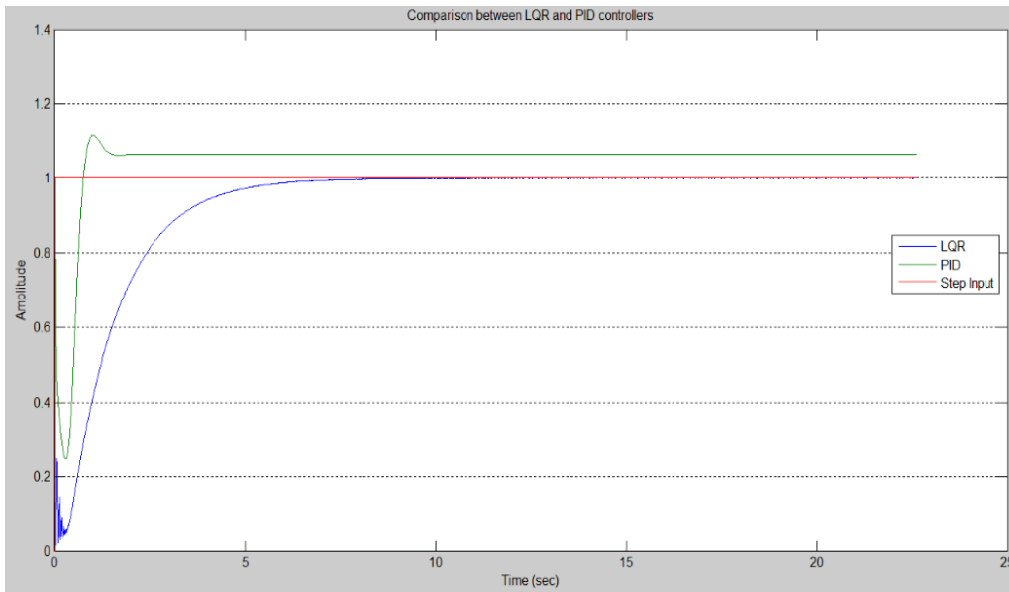


Figure 16. Comparison between LQR and PID controller

Table 4. Difference between LQR and PID controllers

	<b>LQR Controller</b>	<b>PID Controller</b>
<b>Rise time, <math>t_r</math> (s)</b>	6.25	1.34
<b>Settling time, <math>t_s</math> (s)</b>	6.97	1.56
<b>Steady state error (%)</b>	0.00	6.21
<b>Overshoot (%)</b>	0.00	4.72

## VI. CONCLUSIONS

As a conclusion, identification system provides a convenient method to control a nonlinear system by using linear controllers. It has been successfully applied to pneumatic actuator system to establish the best linear discrete model to the system. ARX model structure is selected for system modeling and controller design. PID controller is designed to the system with the reference of Ziegler Nichols tuning method. P controller with the Bilinear transfer function is applied for online testing. Step and sine inputs are injected with the purpose to determine the system response according to the tracking performance of input and output. PID controller is capable to improve the system robustness against the slight change in loads. External load with the highest weight has the most significant overshoot in the system. Both PID and LQR controllers are applicable to enhance the system performance. On real time control, output response is almost similar to the reference input for the system positioning control.

## REFERENCES

- [1] Hazem I. Ali, Samsul Bahari B Mohd Noor, S.M Bashi, M.H Marhaban, *A review of Pneumatic Actuators (Modeling and Control)*, Australian Journal of Basic and Applied Sciences, 3(2): 440-454,
- [2] Amin Mohammadbagheri, Narges Zaeri and Mahdi Yaghoobi, *Comparison Performance Between PID and LQR Controllers for 4-leg Voltage-Source Inverters*, International Conference Circuit, System and Simulation, 2011
- [3] Igor L Krivts, German V Krejnin, *Pneumatic Actuating Systems for Automatic Equipment Structure and Design*, Taylor & Francis Group, 2006.
- [4] Jian-Bo He, Qing-Guo Wang and Tong-Heng Lee, *PI/ PID Controller Tuning via LQR Approach*, IEEE Conference on Decision & Control, 1998.
- [5] Joachim Schroder, Duygun Erol, Kazuhiko Kawamura, Riidiger Dillman, *Dynamic Pneumatic Actuator Model for a Model-Based Torque Controller*, IEEE International Symposium on Computational Intelligence in Robotics and Automation, 2003.
- [6] Mark Karpenko, Nariman Sepeshri, *Design and Experimental Evaluation of a Nonlinear Position Controller for a Pneumatic Actuator with Friction*, American Control Conference, 2004

- [7] Nikolay A. Markov, Ilya A. Shipitko, Taras V. Benzrushko, *Synthesis of the Position Controller for the Pneumatic Actuator*, Siberian Conference on Control and Communications SIBCON, 2009
- [8] T. Kosaki, M. Sano, *A Compliance Controller for a Pneumatic Actuator with Observer-Based Friction Compensation*, IMACS Multiconferences (CESA), 2006.
- [9] R. Ghazali, Y.M. Sam, M.F. Rahmat and Zulfatman, *Recursive parameter estimation for discrete-time model of an electro-hydraulic servor system with varying forgetting factor*. International Journal of the Physical Sciences Vol 6(30), page 6829-6842, 23 November 2011
- [10] M.F. Rahmat, Sy Najib Sy Salim, N.H Sunar, Ahmad' Athif Mohd Faudzi, Zool Hilmi, Ismail K. Huda, *Identification and non-linear control strategy for industrial pneumatic actuator*, International Journal of Physical Sciences Vol. 7(17), pp. 2565 - 2579, 23 April, 2012.
- [11] S. Md. Rozali, M.F. Rahmat, N Abdul Wahab, R. Ghazali and Zulfatman, *PID Controller Design for an Industrial Hydraulic Actuator with Servo System*, IEEE Student Conference on Research and Development (SCOREd 2010), 2010.
- [12] R. Ghazali, Y.M. Sam. M.F Rahmat, K. Jusoff, Zulfatman, A.W.I.M. Hashim, *Self-Tuning Control of an Electro-Hydraulic Actuator System*, International Journal on Smart Sensing and Intelligent Systems Vol 4, No 2, June 2011.
- [13] M. Tham, *Discretised PID Controllers*, Chemical Engineering and Advanced Materials, University of Newcastle Upon Tyne, 1996-1998.
- [14] Jim McLellan, *Using Matlab and the System Identification Toolbox to Estimate Time Series Models*, February 2004
- [15] A.N.K. Nasir, M.A. Ahmad and M.F. Rahmat, *Performance Comparison between LQR and PID Controller for an Inverted Pendulum System*, International Conference on Power Control and Optimization, July 2008.
- [16] Mei Li, Chen Chen and Wenlin Liu, *Identification based on MATLAB*, International Workshop on Information Security and Application (IWISA 2009), 2009.
- [17] Jacques F Smuts, *Process Control for Practitioners*, OptiControls Inc., October 14, 2011.
- [18] Wodek Gawronski, *Modeling and Control of Antennas and Telescopes*, Springer Inc, ISBN 978-0-387-78792-3, 2008.

[19] Xue, Dingyu, YangQuan Chen, Derek P.Atherton, *Linear Feedback Control Analysis and Design with MATLAB*, Society for Industrial and Applied Mathematics Philadelphia, 183-218, 2007.