

Figure 9. Simulated outputs for different controllers in discrete time model

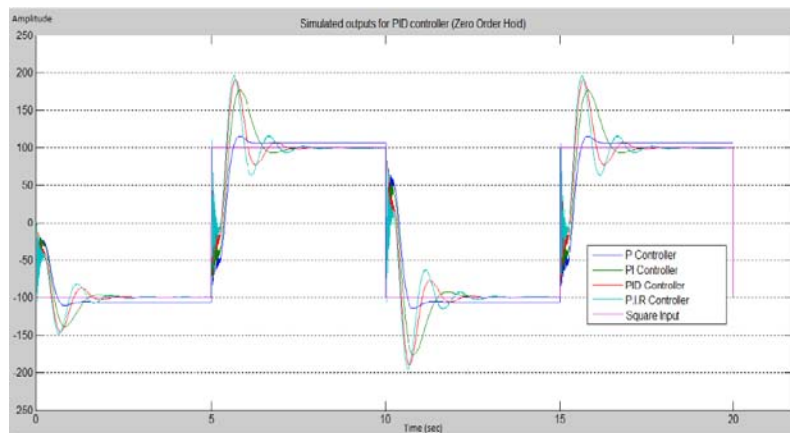


Figure 10. Simulated outputs for different controllers in continuous time model (Zero Order Hold)

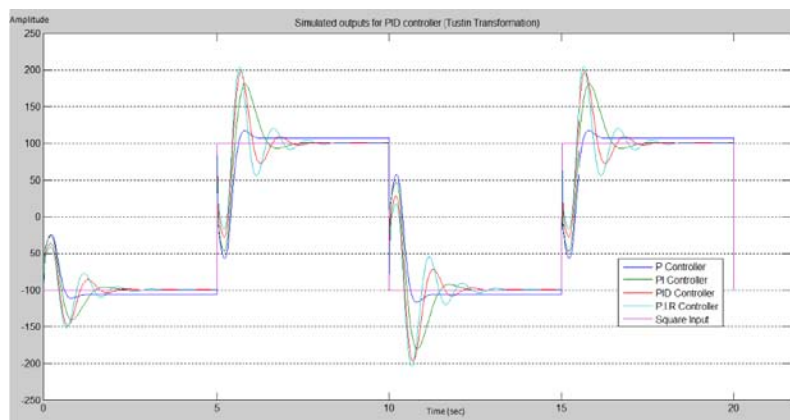


Figure 11. Simulated outputs for different controllers in continuous time model (Bilinear Transformation)

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.

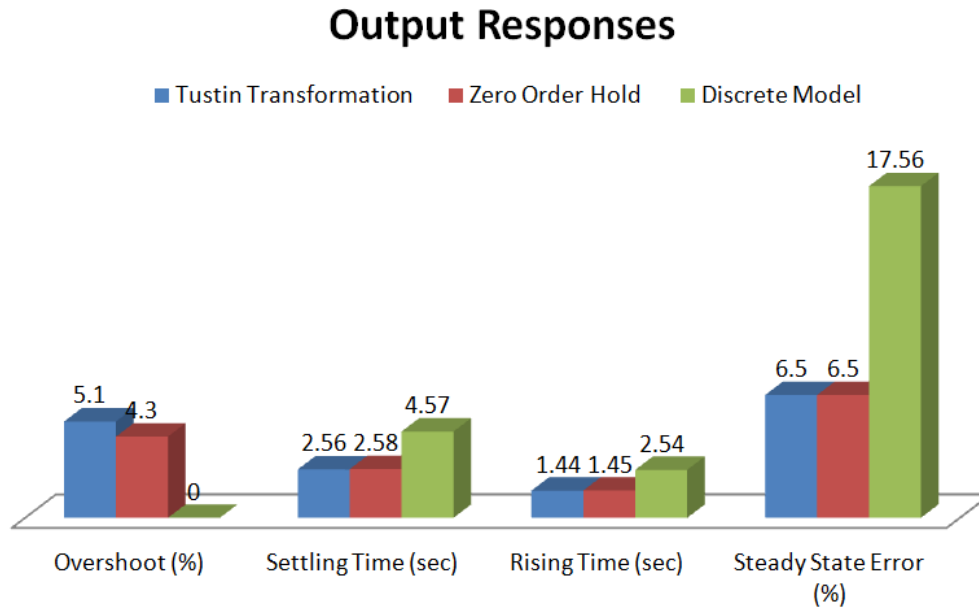


Figure 12. Output responses between continuous and discrete time models

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.

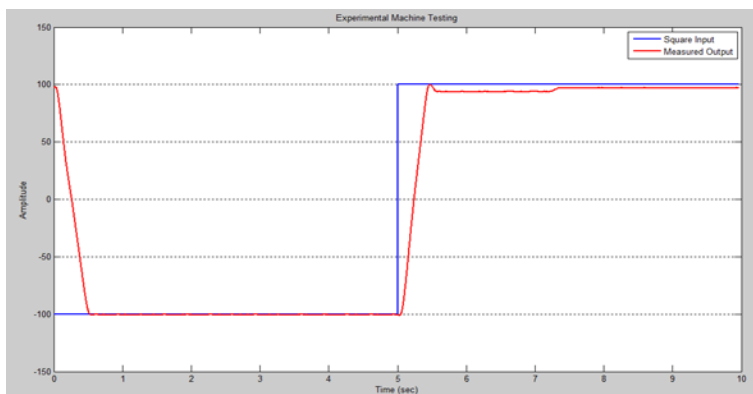


Figure 13 P controller online testing (Square wave input)

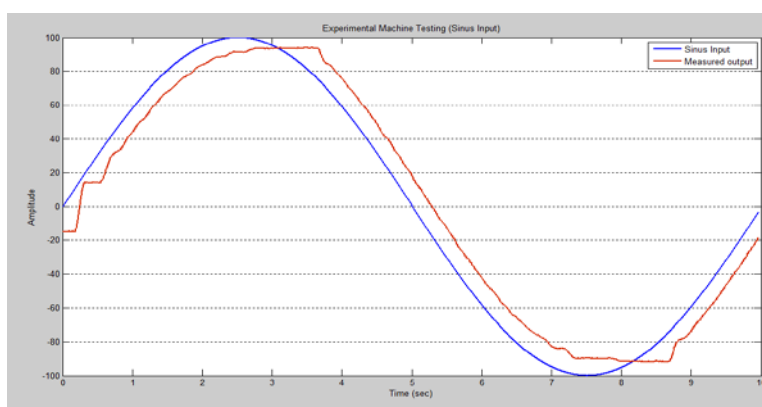


Figure 14. P controller online testing (Sine wave input)

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.



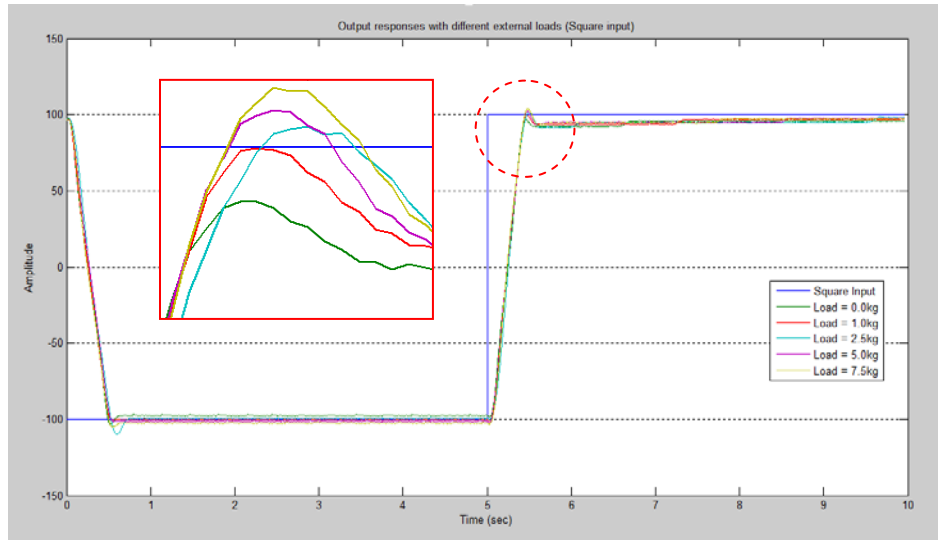


Figure 15 Output responses with different external loads

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.

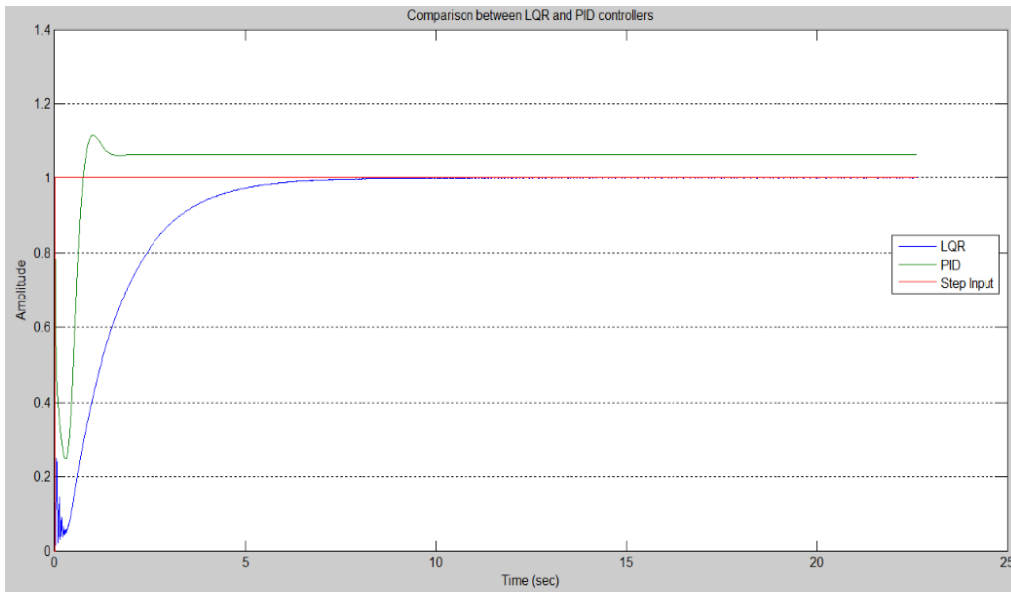


Figure 16. Comparison between LQR and PID controller

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.

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