DESIGN, IMPLEMENTATION AND ANALYSIS OF A CONTROL SYSTEM

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Executive Summary

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1 Methodology

A test rig (see figure 1) controlled by two brushless DC motors is subjected to a 20° step input.

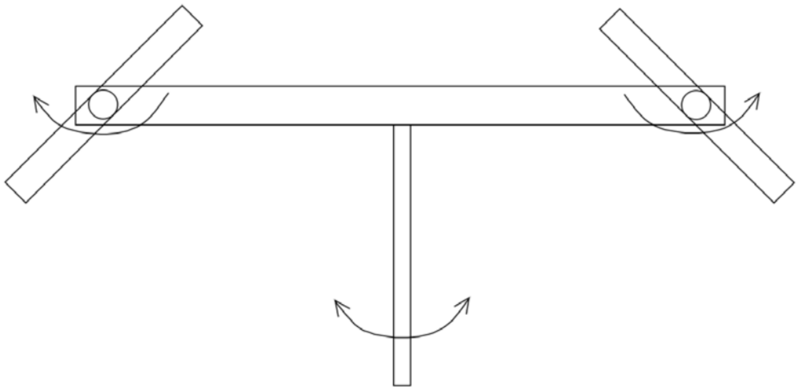


Figure 1: A front view of the test rig system (Hann, 2019).

A feedback control system was designed and implemented to meet the following design specifications:

$$\xi > 0.1 \qquad M_p\% < 15\%$$

$$e_{ss} < 1.5^\circ \qquad t_r < 0.8\text{s}$$

$$1 \leq K_p \leq 2.5 \qquad \frac{K_d}{K_p} < 0.7$$

The predetermined gain values were found using an iterative approach. The transfer function (see equation 1), with the suggested parameters $\alpha = 1.6$, $\beta = 2.9$, $\gamma = 1.3$ and $\tau = 0.34$, was used with MATLAB to predict how output would be affected by the gains and the step input.

$$\frac{X}{R} = \frac{\beta K_p s + \beta K_i}{s^3 + s^2(\alpha + \beta K_d - \beta K_p \tau) + s(\gamma + \beta K_p - \beta K_i \tau) + \beta K_i} \tag{1}$$

Three sets of predetermined gain values were ultimately decided on:

$$\text{P Controller}: \quad K_p = 1.20$$

$$\text{PD Controller}: \quad K_p = 1.20 \quad K_d = 1.20$$

$$\text{PID Controller}: \quad K_p = 1.20 \quad K_d = 0.72 \quad K_i = 0.84$$

By using three different types of controller, we were able to analyse the differences between them and to better understand the relationship between the step input, the gains, and the output.

The following expectations are visible in the MATLAB plot (figure 2) below. The P Controller would be expected to overshoot the target angle and then overshoot in the other direction, oscillating until it comes to a rest near the target angle. This would be an example of an underdamped system. The PD Controller would be expected to slowly converge upon the target angle with little or no overshoot (depending on the damping coefficient, ξ). A relatively large steady-state error (e_{ss}) would be expected. This would be an example of an overdamped system. The PID Controller is expected to overshoot but then quickly converge towards the target angle. This would be an example of a critically damped system.

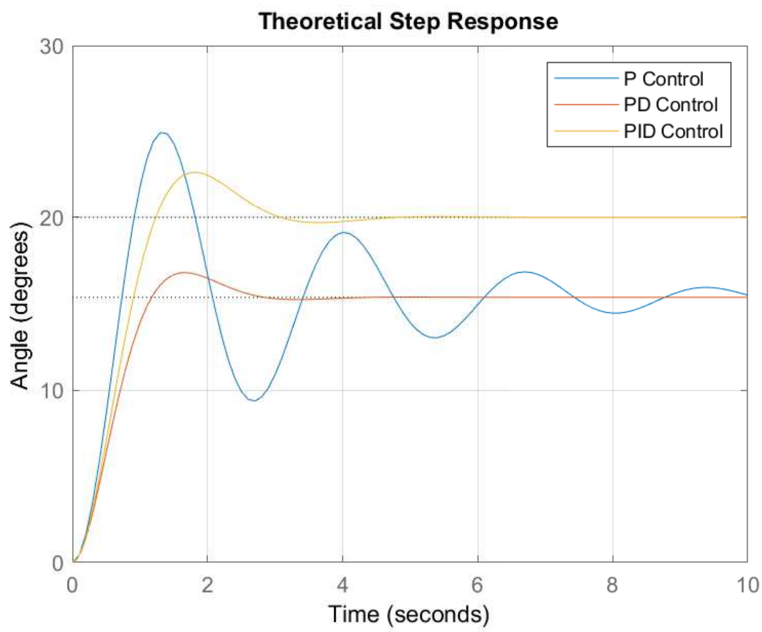
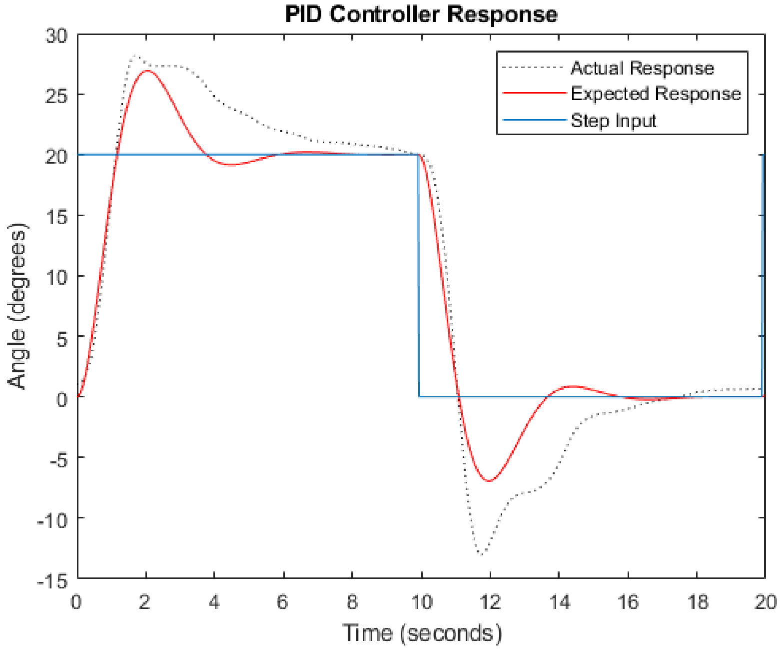


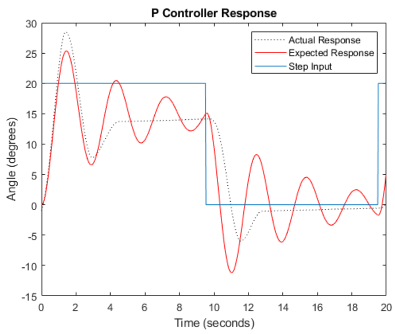
Figure 2: The graph showing the predicted responses of each controller.

2 Results & Discussion

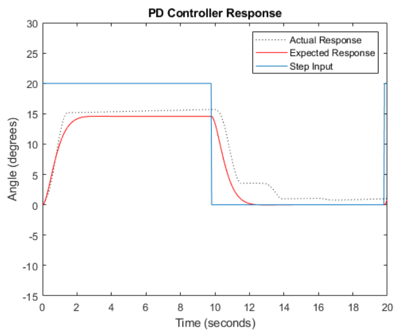
The following data (figures 3a to 3c) was captured during the lab:



(a) PID Controller response.



(b) P Controller response.



(c) PD Controller response.

System	K_p	K_i	K_d	M_p (%)	t_r (s)	e_{ss} (°)
PID Control	1.20	0.72	0.84	34.53	0.80	0.18
P Control	1.20	0.00	0.00	74.05	0.51	5.48
PD Control	1.20	1.20	0.00	0.21	1.30	5.44

Table 1: The analysed results from the experiment.

The experimental PID controller (figure 3a) response was similar to its model. The main differences were the time taken to recover from an overshoot, which were longer than the model. However, the results show that the steady state...

The P controller (figure 3b) was not particularly similar to the model, it was oscillatory and began to converge with some amount of steady-state error. The oscillations subsided very quickly, whereas the model predicted that the oscillations would continue for a longer time period. The oscillations occurred because of the lack of damping in the system.

The PD controller (figure 3c) increases the damping coeffecient of the step response. The experimental results almost exactly match the model with the exception of the fall time being less (and therefore slower). A small anomoly exists in the data after the input falls from 20° to 0°. This may have been from having too much damping in the system.

The damping of the oscillations in the P and PID controllers can be partially explained by the torque required to overcome static friction of the axle. Friction also existed from the USB cable that attached the microcontroller to the computer.

3 Conclusion

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