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Sensors, Signals and Control

Part 3: PID Implementation, Validation and Retuning in Quanser

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1 Introduction

This report analyses the effectiveness of using a PID controller derived in Phase 2 on a Quanser-rig. Before testing the controller on a Quanser-rig, nonlinearities were added to the simulation. Through using a design process to improve the controller response, new control objectives were met, then implemented on the Quanser-rig. The following report discusses both the design process, testing results and any observations made through creating an effective controller for the Quanser-rig.

The following transfer function was used to design the controller, taken from Phase 1:

$$2^{nd} \text{ Order: } k \cdot \frac{1.109 \cdot \frac{180}{\pi}}{s^2 + 0.1313s + 1.109}$$

$$1^{st} \text{ Order: } k \cdot \frac{1}{15.24s + 1}$$

Where $k = 0.26$.

2 Nonlinearity Simulation Control Refinement

In Quanser Control Part 3, the improved PID controller successfully met the Phase 2 requirements but failed to meet the overshoot (OS) condition for the desired controller. The PID control architecture in Figure 1 from Part 2 was tested using both non-linear simulation and on the Quanser setup.

At this stage, the design process for the controller consisted of; extracting preliminary responses from the Quanser-rig, analysing the responses to obtain a simulated plant transfer function. The transfer function was designed to represent small changes in elevation angle, whereby selection of the controller architecture and gains, manifested a desirable response. The controller, therefore, was built to achieve a good response in the simulation, but is susceptible to errors when translating to the real Quanser-rig based the limitations in the assumption made.

To meet the overshoot requirement, the controller was further refined in the original simulation. Using understanding taken from Phase 2, shown in Table 1, gains were modified to improve the results further. The integrator gain (K_i) has the greatest effect on the steady-state error. K_i was first increased by an increment, until the transfer function response began to deteriorate. K_i had only a small range in which the response could be altered without degrading the results; suggesting that the original K_i value was a good fit. Maximising K_i first, meant that the effects of varying derivative gain (K_d) on the steady state would be minimised. A similar process was followed for then the proportional gain (K_p) and K_d , where K_p was maximised to reduce the rise time (T_R) and K_d was optimised to reduce the overshoot. Maximising these values, helped improve the performance characteristics without heavily deteriorating other properties.

To test the controller performance more vigorously, the PID was run in a new simulation, with non-linearities added; in the form of a rate limiter and saturation block. A rate limiter limits the speed of change of the signal, while the saturation block represents a limit in amplitude. This new simulation would improve the accuracy of the expected Quanser response emulation. A marginal change could be

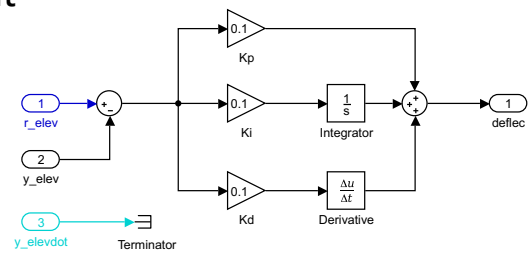


Figure 1: Showing original Controller Architecture

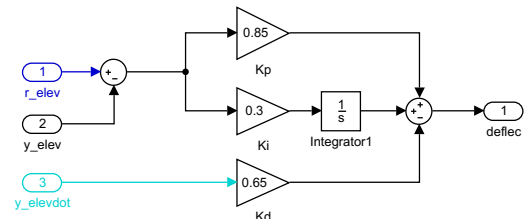


Figure 2: Showing Improved Controller Architecture

Table 1: Effect of Increasing PID Gains on Objectives

	Objectives			
	Tr	Ts	%OS	Ess
Kp	Decrease	Small Increase	Increase	Decrease
Kd	Small Change	Decrease	Decrease	Small Change
Ki	Decrease	Increase	Increase	Eliminate

seen when comparing the results of the non-linear simulation to the original, where overshoot would increase slightly. Further experimentation found that increasing gain values by an order of magnitude, destabilised the results revealing much greater non-linear effects. This observation confirmed that the PID gains selected fell within an acceptable region. With a small additional tweaking following the same design process, the final gain values shown in Table 2 met the requirements of the Phase 3 design characteristics.

Figure 2 shows the original controller configuration utilised the numerical Simulink derivative block within the PID controller. It was found that the control architecture could also be improved for the actual control rig. Using the derivative as output directly $y_{elev\dot{}}$ from the Quanser - it was expected that the numerical derivative block would not be as representative of the observed rate of change as the actual derivative output. This view was confirmed by the improved experimental results from provisional testing on the Quanser-Rig. The difference in architecture was unobservable in simulation, highlighting a noticeable difference between real and simulated output data.

Table 2: Showing Controller Gain Values Used

	Gains		
	Kp	Ki	Kd
Original	0.1	0.1	0.1
Improved	0.85	0.3	0.7

3 Quanser Controller Refinements

After satisfying the desired requirements in the non-linear simulation, the controller tests were conducted on the Quanser-rig. The controller performed well, meeting the desired requirements, where a small improvement in overshoot could be observed from the simulation. Due to sampling errors, small deviations from the steady state could be seen (see 3) of $\pm 0.4\%$ could be seen from elevation angle. As the sampling rate was limited by the sensors on the Quanser, results appeared jagged. This reducing the precision of the results but was small enough, for the results to represent the response of the Quanser to enough accuracy.

4 Results

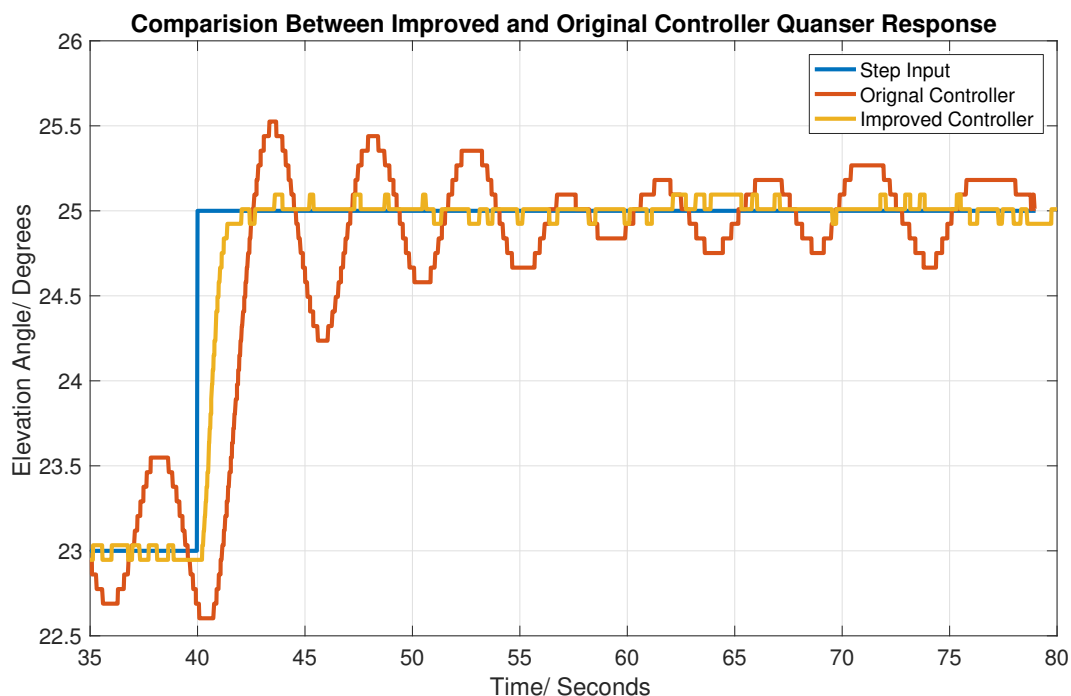


Figure 3: Showing Difference in Original and Improved Controller Performance on Quanser Response

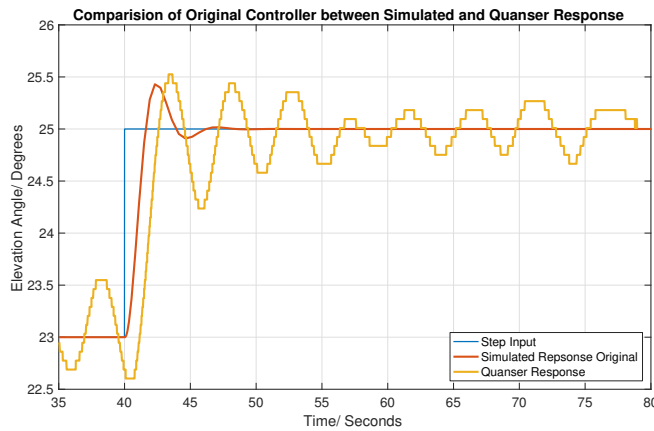


Figure 4: Showing Difference in Original Controller Performance Comparing Simulated and Quanser Responses

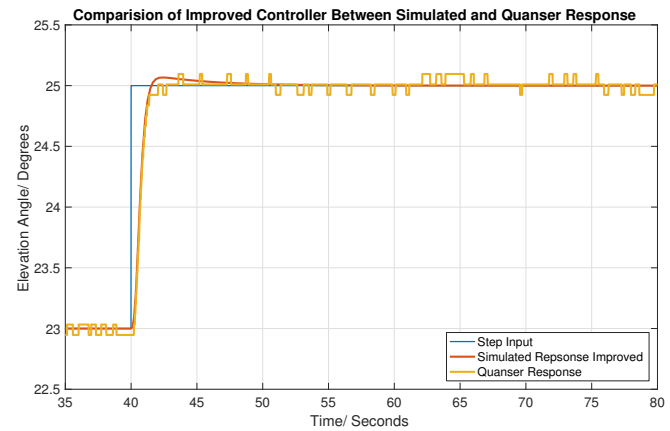


Figure 5: Showing Difference in Improved Controller Performance Comparing Simulated and Quanser Responses

Table 3: Showing Controller Response Results for Simulation and Quanser Tests

		Desired	Original Controller Simulated	Improved Controller Simulated	Original Controller Quanser	Improved Tuned Quanser
Objectives	Tr (s)	4	1.65	1.55	2.57	2.18
	Ts (4%) (s)	5	3.94	1.55	2.57	2.18
	OS(%)	10	21.48	3.35	26.26	0.48
	Ess (%)	0	0	0	0	0

5 Discussion

Figure 3 highlights the experimental difference between the original tuned PID controller (taken directly from Part 2) and the iteratively improved (with an alternative architecture) PID controller. The improved controller displayed a rise time of 2.18 seconds, settling time of 2.18 seconds (as the 4% error limits were satisfied at the same time as the rise time), an Overshoot of 0.48% and a negligible steady state error. The natural Quanser response to a step input (from Part 1) showed a sinusoidal response with large decaying amplitudes at high frequencies. The designed controller improved on this undesirable behaviour by increasing damping, and improving control of low amplitude oscillations. These values comfortably satisfied the required objectives, improving upon the desired objectives shown in Table 3. The improved controller showed a faster rise time, settling time and reduced overshoot percentage over the original controller design. In an engineering context, it is critical that the controller response is sharp and responsive, minimising delay times. Observing the step input time in Figure 3, it is evident that the choice of the controller effects the delay and error of the Step response.

The Quanser was allowed to settle after take-off to a reasonable level before the step input was tested. Using the same settling time-period, the original controller showed larger settling oscillations, this likely contributed towards the amplitude and phase error displayed in 4 between the simulated Quanser response and the experimental Quanser response. This observation is also reinforced by Figure 5 as the Simulink step input shows less delay. If the step was placed mid oscillations, this difference from the steady-state would add to the step response. This effect is likely to be present in real world rotatory wing aircraft. Design parameters were estimated conservatively to meet the requirements in any case.

Idealisation of the elevator actuation could also be observed when comparing the simulation to real world

response. It was assumed that no physical limitations are in place on the system. Realistically, this may be misrepresenting the physical actuator, likely introducing errors in the form of actuator delay.

The results presented above highlight the step response for the tuned PID controller for a step input of 2, chosen as the transfer function was derived from experimental results of elevator angle step changes between -2 and 2. It is expected that for step inputs out of this range, the tuned controller will perform sub-optimally; accurate near the 'fix-point' and showing deviations at higher step inputs.

Figure 6 shows the magnitude of rate of response for the Quanser-rig. It can be observed that the action (in terms of magnitude) and speed (showing thick solid band) are both adequate for the controller. This observation further confirms the correct magnitude of gains were selected for the controller as rate and magnitude are both within the limits of the Quanser performance.

The Quanser-rig tests were set in a reasonably controlled environment with few assumed non-linearities from these setup conditions. The PID, therefore, was designed assuming that all non-linearities were weak. The controlled environment meant the tuning process was simple allowing the specified requirements to be met. In more complex engineering applications, the system in question may display a larger number of non-linear effects. This may be accounted for using the method of gain scheduling. Gain Scheduling [1] achieves control of a non-linear system by linearising the problem at various operation states; resulting in a "family" of PID controllers which will each respectively activate when a certain operation state is achieved. Each of these PID controllers must be tuned independently to optimise for their respective linearisation. The design then switches between each of these models to achieve the "best response" for the current state. More conclusively, within limits of this study, the obtained tuned PID controller for the Quanser is effective and meets the desired time domain requirements. For further accuracy of either Quanser control or more complex systems; additional control structures should be considered, particularly if the controller should encompass less stable operations such as take-off and landing. In an aircraft control context, the control parameters may be altitude or Mach.

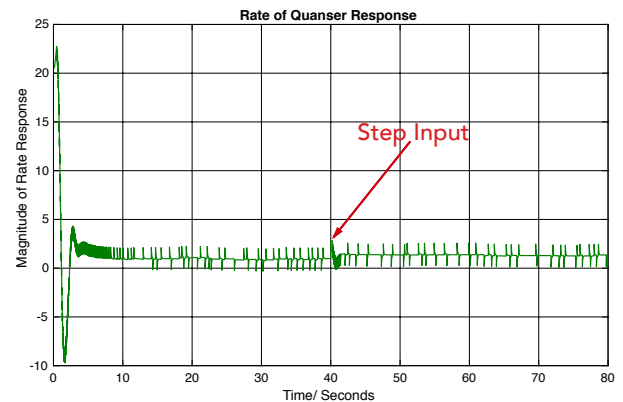


Figure 6: Showing Magnitude of Rate Response

6 Conclusions

This experiment has been a useful exercise in illustrating methods and common pitfalls when transferring a theoretically functioning PID controller to a real world system. Predicting the Quanser response using a non-linear simulation, allows for a good controller to be created but exact characteristics are difficult to predict without real-world experimentation. Further controller refinement is therefore required when transferring to the real system, using the simulation as a method of getting close to the answer. It was interesting to note that the real world response always varied from the expected simulations for every tested tuned PID controller and configuration - this difference is likely to be an artefact of the non-linearities present in the Quanser-rig.

References

- [1] (Nov. 2015). How to control a nonlinear system with a pid controller - mathematics stack exchange, [Online]. Available: <https://math.stackexchange.com/questions/1509148/how-to-control-a-nonlinear-system-with-a-pid-controller> (visited on 27/04/2017).