Feedforward / Feedback Trajectory Control

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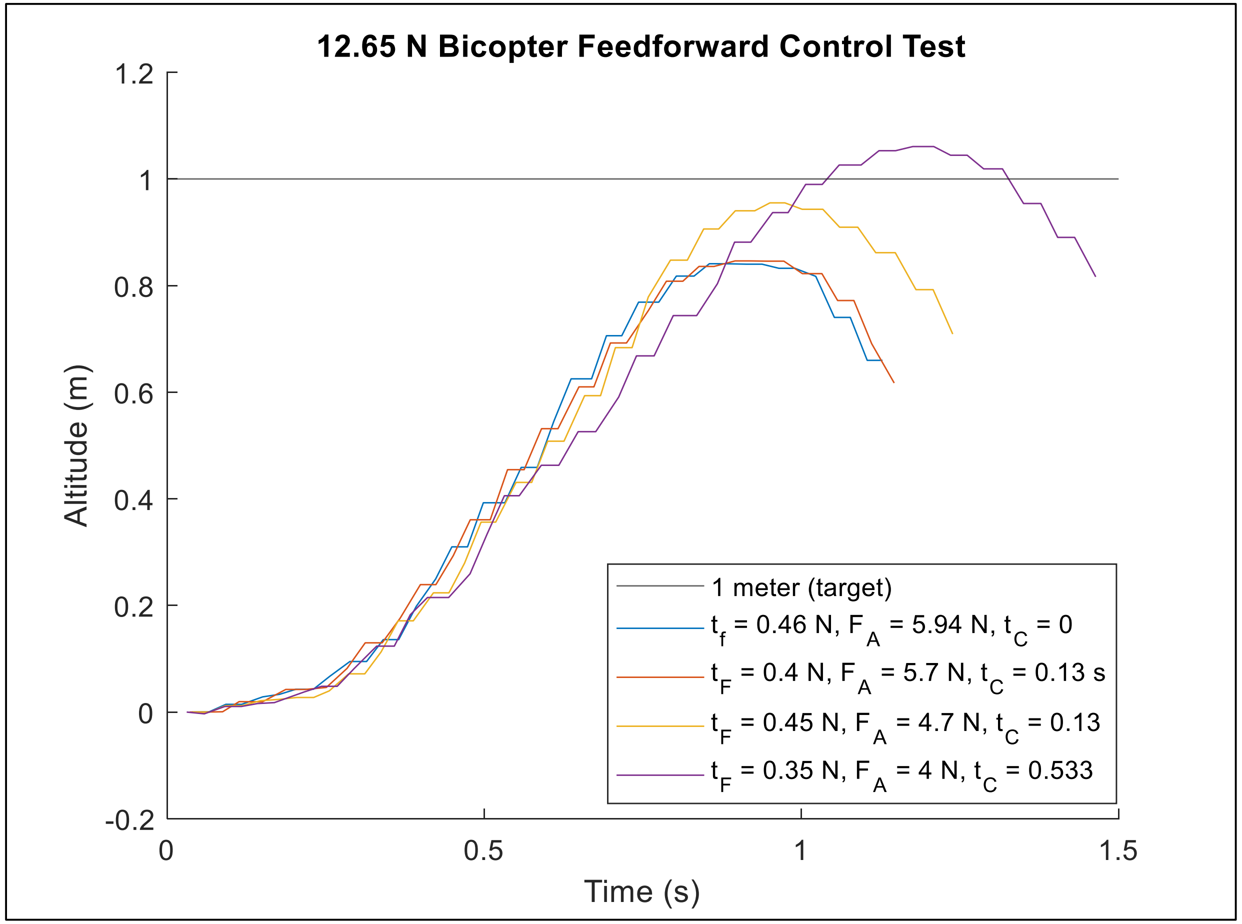
1. Control Scheme Test Plan

Run Name	Force time (sec)	Force Amplitude [N]	Coast time [s]	Copter weight[N]
FF_1.txt	0.46	5.94	0	12.65
FF_2.txt	0.4	5.7	0.133	12.65
FF_3.txt	0.45	4.7	0.133	12.65
FF_4.txt	0.35	4	0.533	12.65

Run Name	Kp	Ki	Kd
PID_1.txt	0.2	0.1	0.1
PID_2.txt	0.4	0.1	0.1
PID_3.txt	0.4	0.15	0.1
PID_4.txt	0.4	0.15	0.15
S-track_1.txt	0.2	0.1	0.1
S-track_2.txt	0.4	0.1	0.1
S-track_3.txt	0.4	0.15	0.1
S-track_4.txt	0.4	0.15	0.15
FF_FB_1.txt	0.2	0.1	0.1
FF_FB_2.txt	0.4	0.1	0.1
FF_FB_3.txt	0.4	0.15	0.1
FF_FB_4.txt	0.4	0.15	0.15

2. Feedforward Control (No Feedback)



This test was conducted with feedforward control without any feedback to the control system from sensors. As it can be seen, not all of the configuration make it to the 1 meter mark, and the longer the coast time the closer it is able to get to the 1 meter mark. But it can also be seen that the copter drifts away from its final position leading to it's altitude dropping.

This dropping can most likely be explained by the copter being slightly heavier than the entered weight, or the timing of the bang maneuvers being slightly mistimed, as the timing is fairly tight for them.

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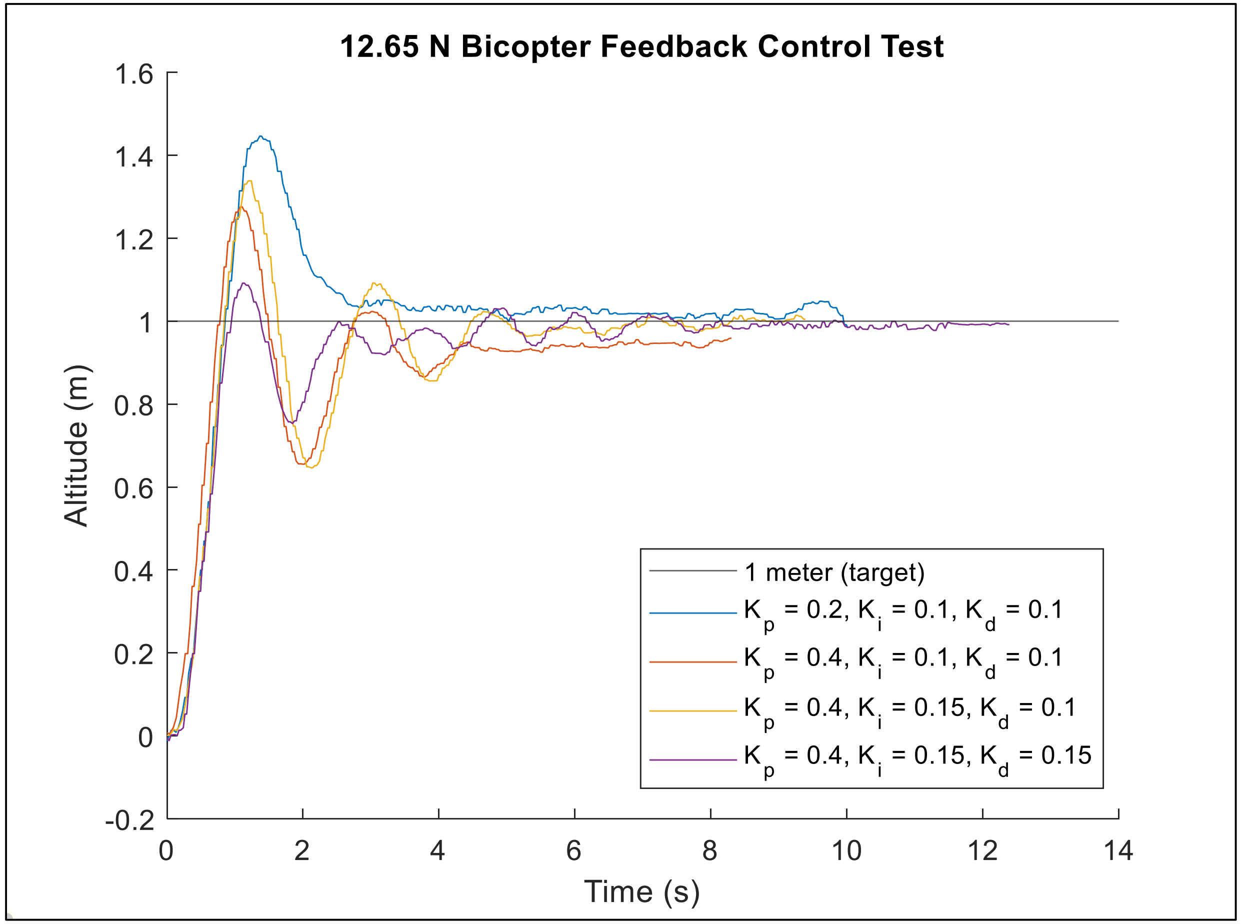
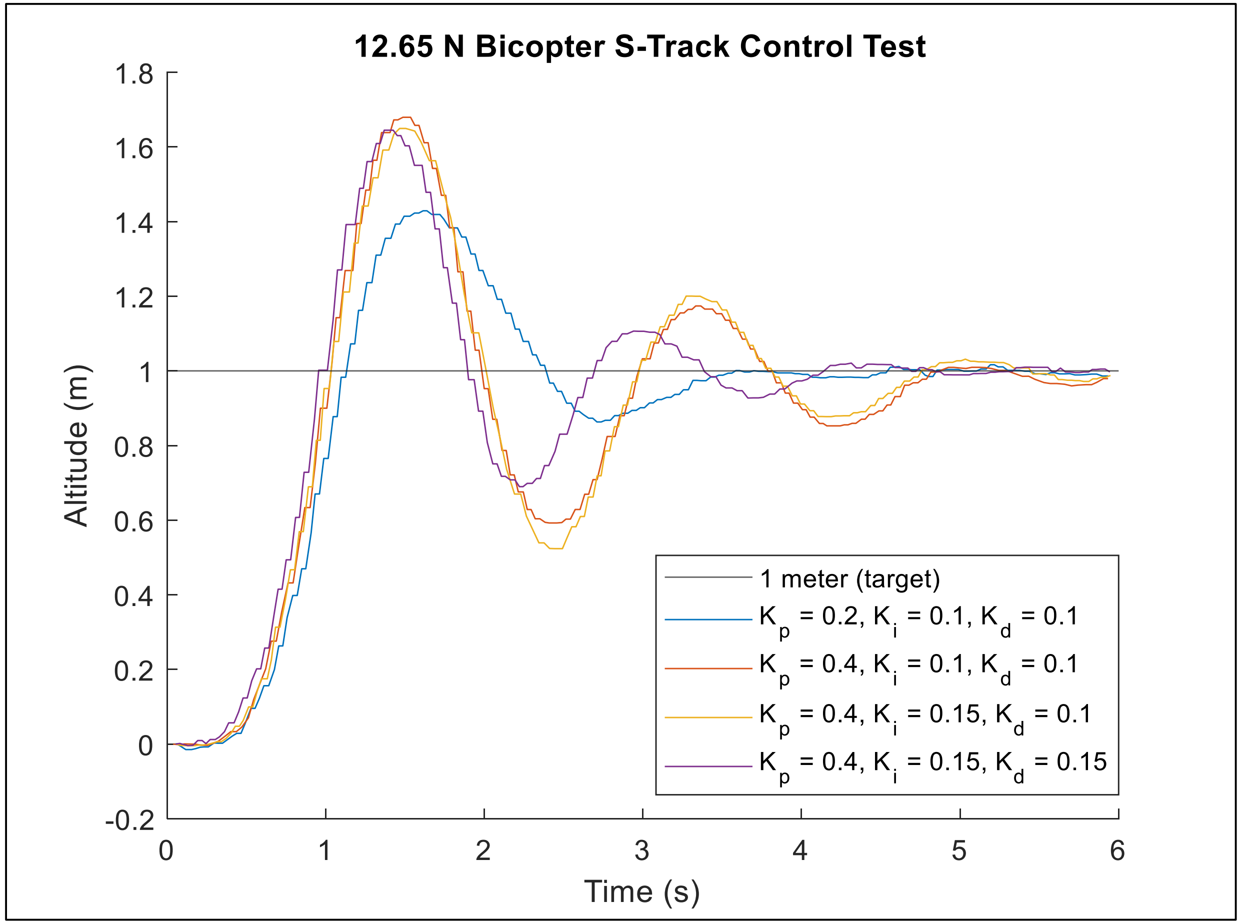
3. Feedback Control (No Feedforward)



This control scheme had a feedback control system instead of a feedforward control system, meaning that sensor data was used to then change the force being output by the copter to reach the target altitude. Four different control configuration were used with varying proportional, derivative and integral gains.

There are some trends that can be seen, such as the higher propotional gains settling in a shorter time, the larger integral gains oscillating more, and having higher derivative gains results in lower amplitude oscillations.

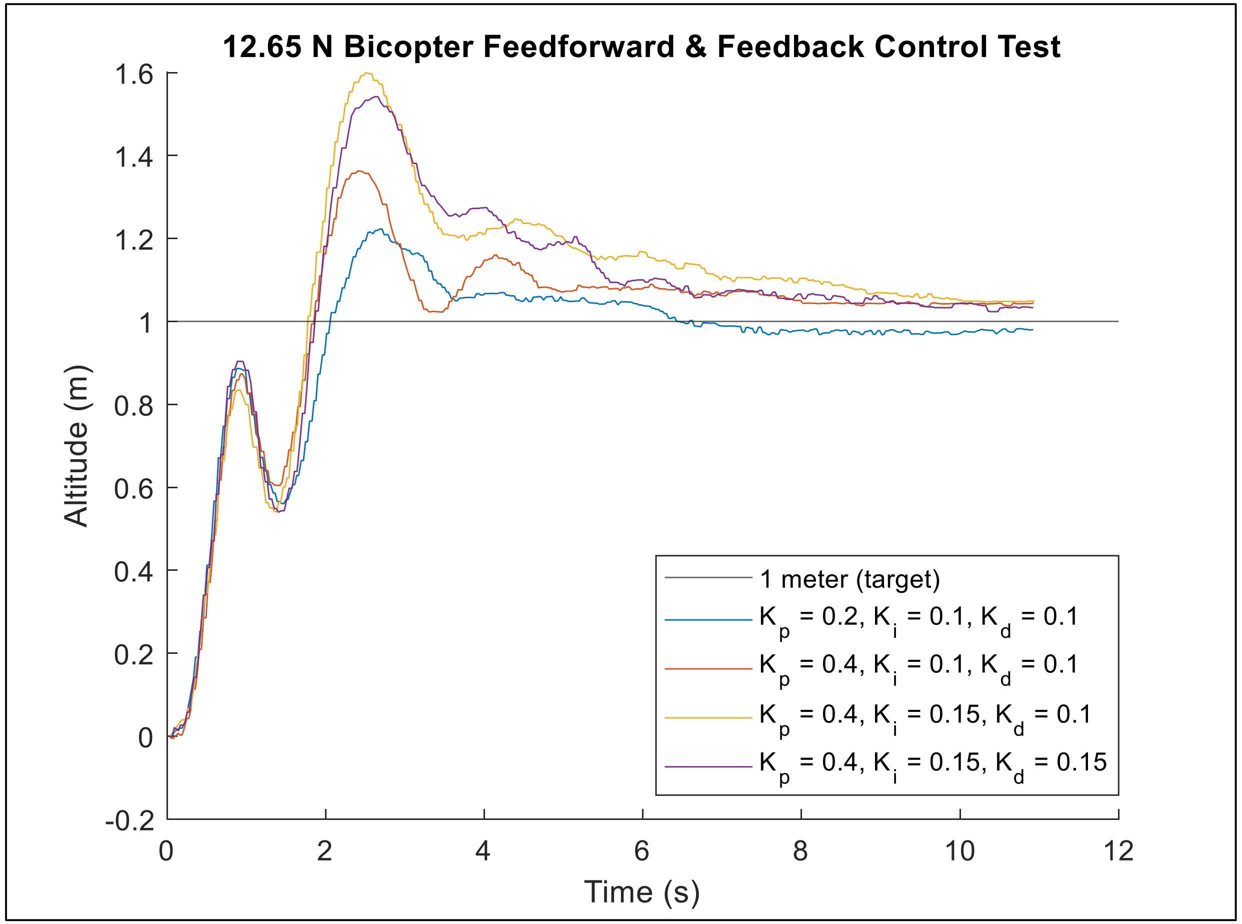
4. S-Track PID



The S-track test consisted of a feedback control system, and then the target altitude of the feedback control system is the theoretical altitude of the ideal (theoretical minimum energy) feedforward system with feedforward parameters of 0.46 seconds of force actuation, a 5.94 Newton force amplitude, and zero seconds of coast time.

These resulted in relatively slow rise times compared to some of the other schemes as the proportional gain, which generally helps boost the response at a step, is zero at the beginning and ramps up as time goes on. Another problem is that there are large oscillations throughout all the configurations.

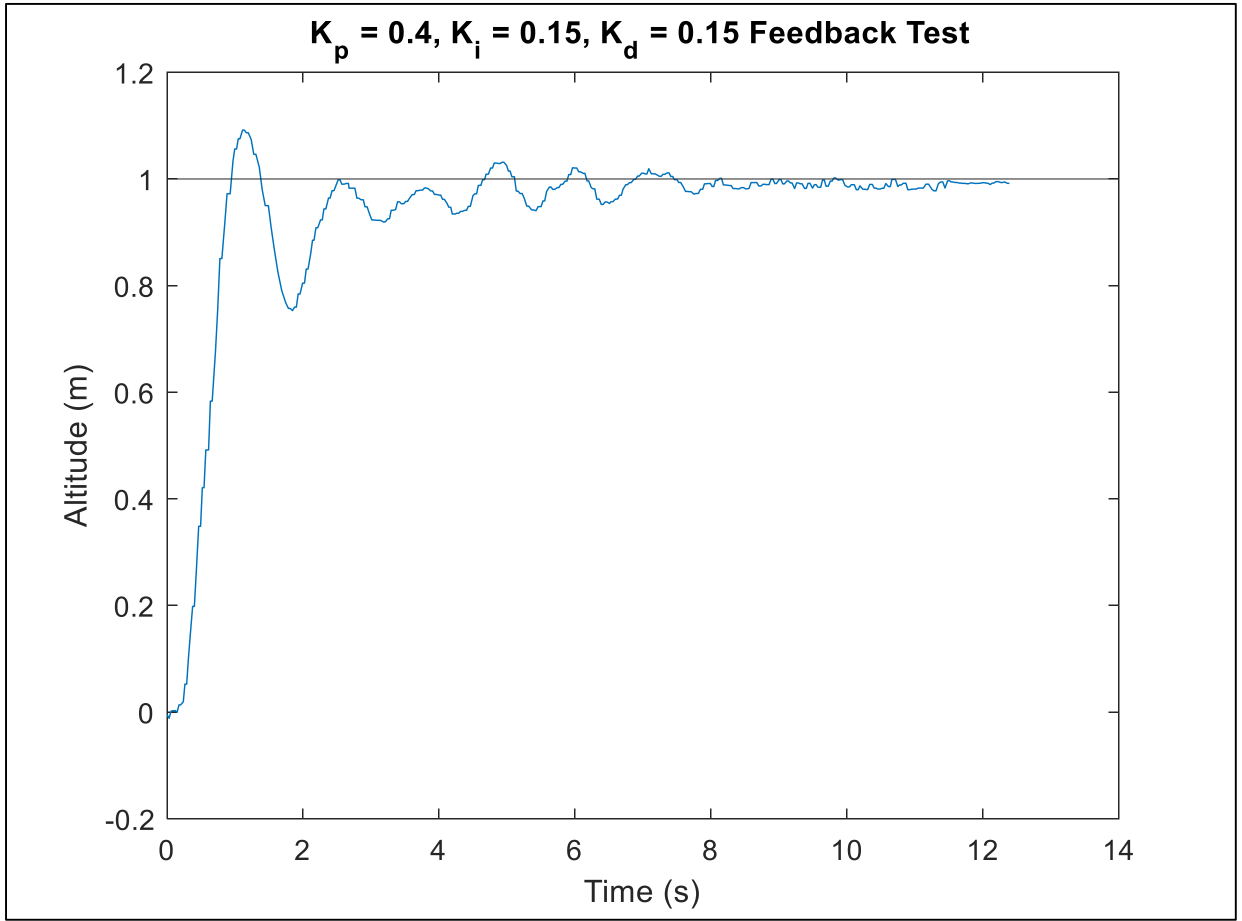
5. Feedback and Feedforward Control



The control system of this setup consisted of the feedforward control and feedback control together acting as the control system. This includes the feedforward control sending the precomputed force profile, then the feedback control adding or subtracting small adjustments based upon the sensor data. This is theoretically the most robust control method for the copter.

Looking at the data obtained from this, it has a large amount of overshoot and a relatively long time to settle after the initial peak, but there are not too many large oscillations while settling.

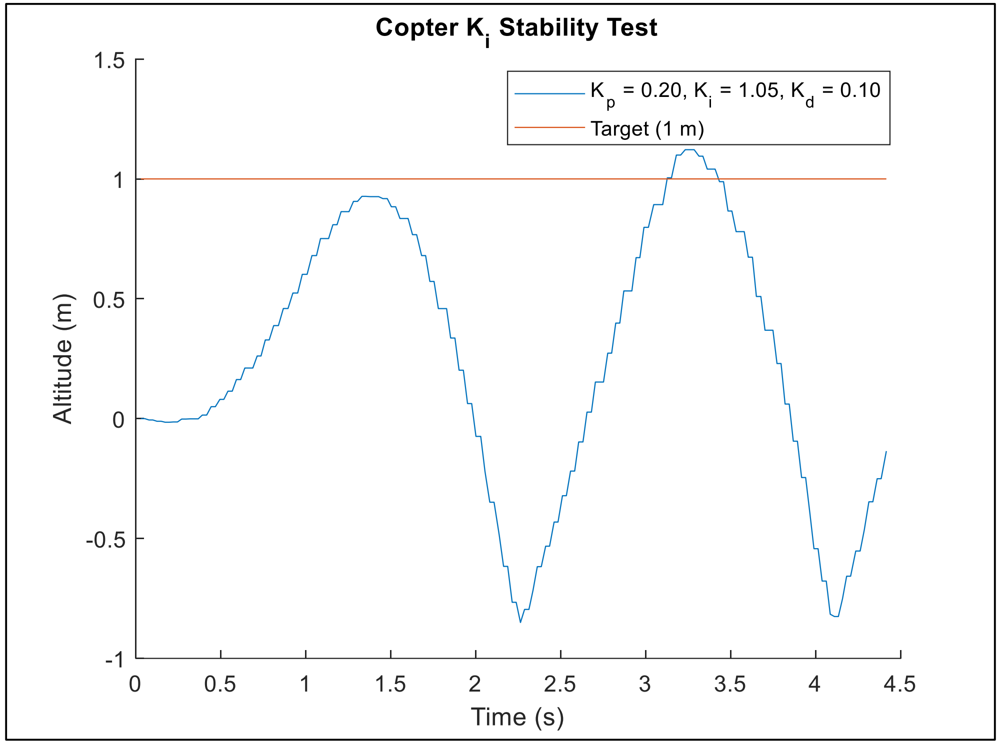
6. Best Control Scheme



The best control scheme selected is the fourth feedback control scheme. This used no feedforward or S-track, and the gains are list on the plot.

This test had the lowest overshoot of any of the schemes that actually made it to the 1 meter mark (i.e. not counting the feedforward only). The overshoot was about 9 centimeters, with the next lowest being around 20 centimeters. In addition to that, the oscillations are not that large in amplitude after, and it settles for the most part fairly quickly. This can be thanked for the larger deritivie gain compared to other, and it may benefit from higher derivative gain, but more testing would be needed.

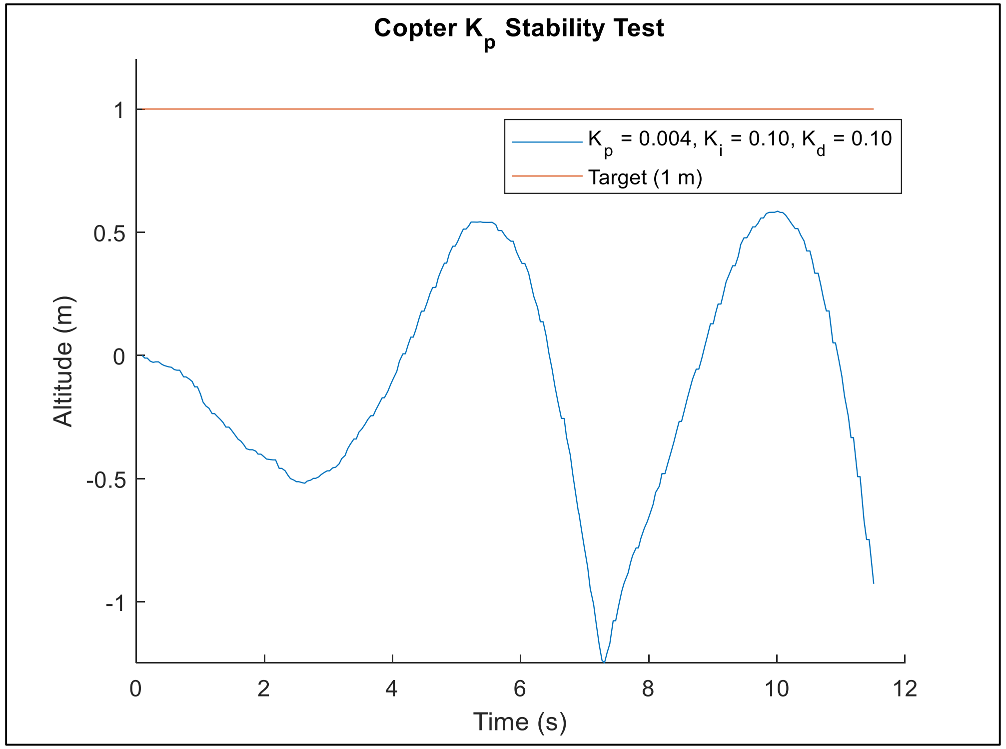
7. Control Stability Test



The system became unstable approximately when the K_i term was set to 1.05. The theoretical value calculated that the K_i term had to be less than, assuming the others remain equal, was 0.4 calculated by solving the following inequality:

$$24 \ * 0.1 \ * 0.2 > 1.23 * K_i$$

Once unstable, the system begin to experience major oscillations as the integral term of the controller try to use large adjustments for small amounts of error.

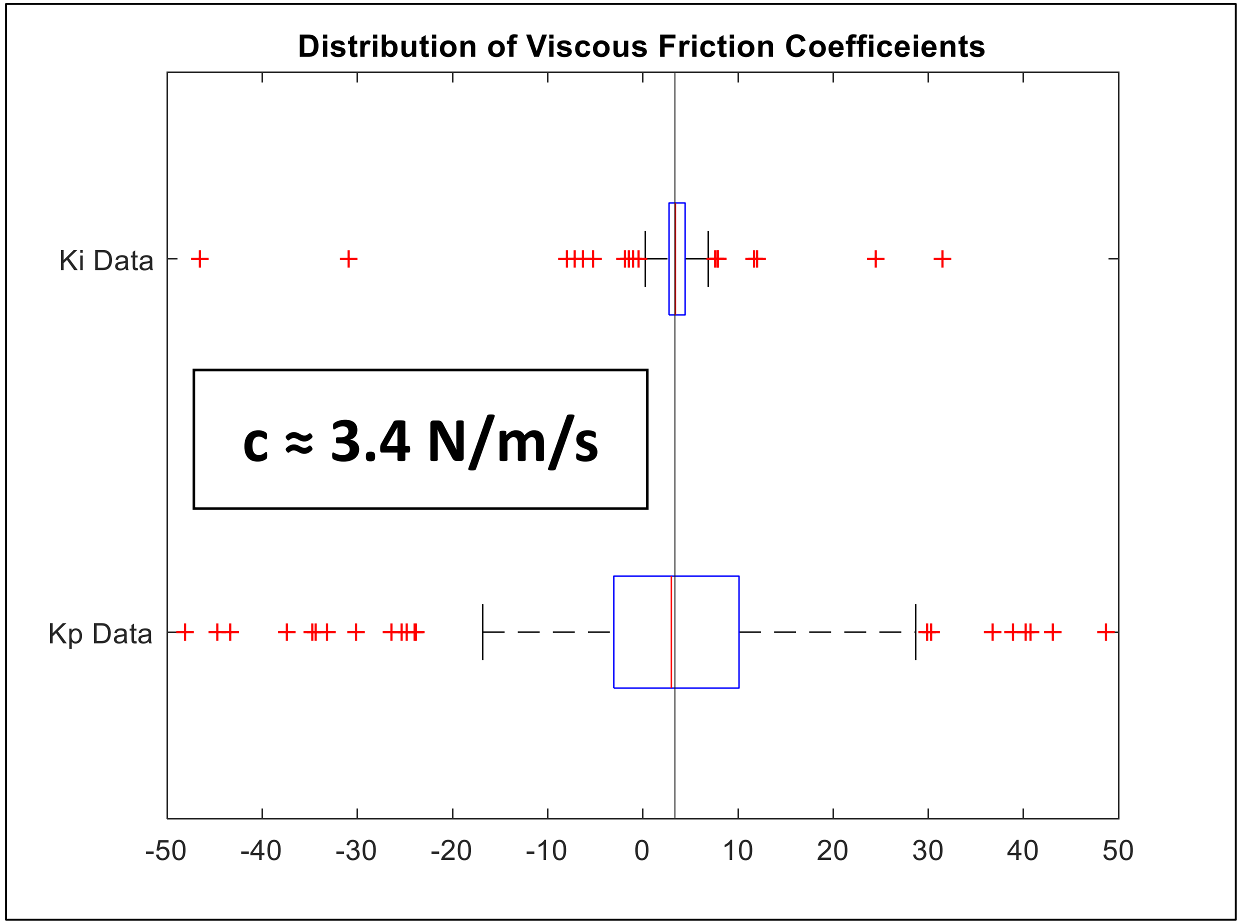


The system became unstable approximately when the Kp term was set to 0.004. The theoretical value calculated that the K_p term had to be less than, assuming the others remain equal, was 0.05 calculated by solving the following inequality:

$$24 \ * 0.1 \ * X > 1.23 * 0.1$$

Once unstable, the system begin to experience major oscillations as the proportional control would have to get extremely far away to do anything, then once close enough it would stop dong anything.

8. Viscous Damping Estimation



The coefficient of viscous friction was able to be estimated from the data shown in the previous slide. Using the equation of motion:

$$m\dddot{x} + (24\,K_d + c)\ddot{x} + 24\,K_p\dot{x} + 24\,K_I = 0$$

Then solving for c, and substituting the PID gains used in both scenarios, each data point gathered was able to provide an instantaneous estimation of the viscous friction coefficient by taking the derivative of the data and inputting it into the equation. This data was plot using two box plots on the left.

They both have their medians at a similar value, and the Ki data has a fairly tight distribution around it. The median from the Ki data is 3.4, while the median from the Kp data is 3. The median of the combined data sets is 3.4 as well, and so it is safe to say the c can be estimated to be 3.4 N/m/s.