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Lab 2

MVMAMA001   STLTSE004

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1. Introduction

This lab aims to design a controller for the pitch of a helicopter, which controls the angle of attack of the main rotor to change the lift force on the aircraft. This, in response, changes the height of the helicopter which is the desired output. The controller will also enable the helicopter to closely track a preset height and reject vertical disturbances. Additionally, it is to have a prescribed settling time of 11 seconds and an overshoot of no more than 20% of the peak response.

2. Model Summary

The transfer function for the height of the helicopter was determined by aggregating the results from three different methods. These were the method of least squares, step response graphical derivation and finally, using the System Identification Tool in Matlab (in Lab 1). The height transfer function is as follows:

$$\boldsymbol{Y(s)} = \frac{\mathbf{21.556}}{\mathbf{s(14.429}\boldsymbol{s}\mathbf{+1)}}$$

To get desired response, a First Order Lead Compensator was chosen for the helicopter because it increases both the stability and response speed of the system. Theoretically, it achieves this by moving the root locus to the left as well as dominant (real) poles [1]. The continuous-time equation for the compensator takes the form:

$\boldsymbol{C(s)} = (\frac{\boldsymbol{s+z}}{\boldsymbol{s+p}})$ [2]

Where z is a zero and p a pole. After it is designed to meet all specifications, it is then cascaded with the plant to form a closed-loop system, as shown in the figure below.

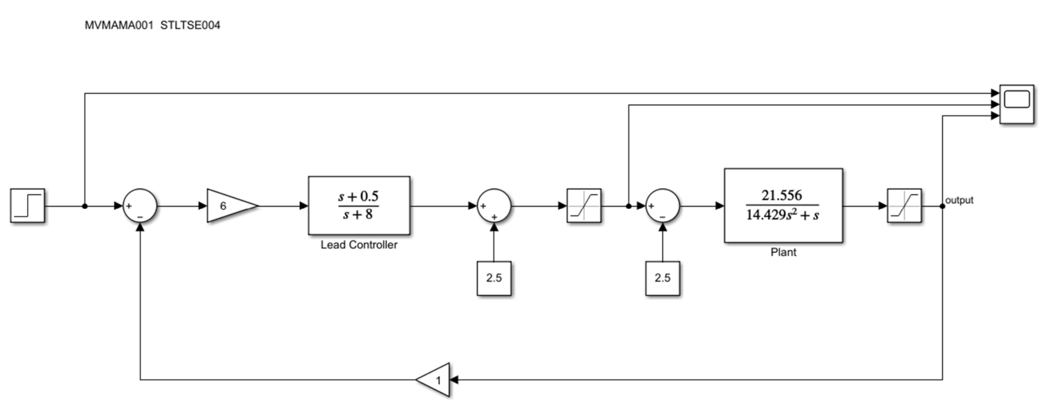

Figure 1: Compensated Closed Loop System

Specifications and Implementation

By manipulating the positions of the aforementioned poles and zero, a compensator that can closely track a preset height and reject disturbances is achieved. Furthermore, the required settling time of 11 seconds and an overshoot below 20% of the peak response are also realized.

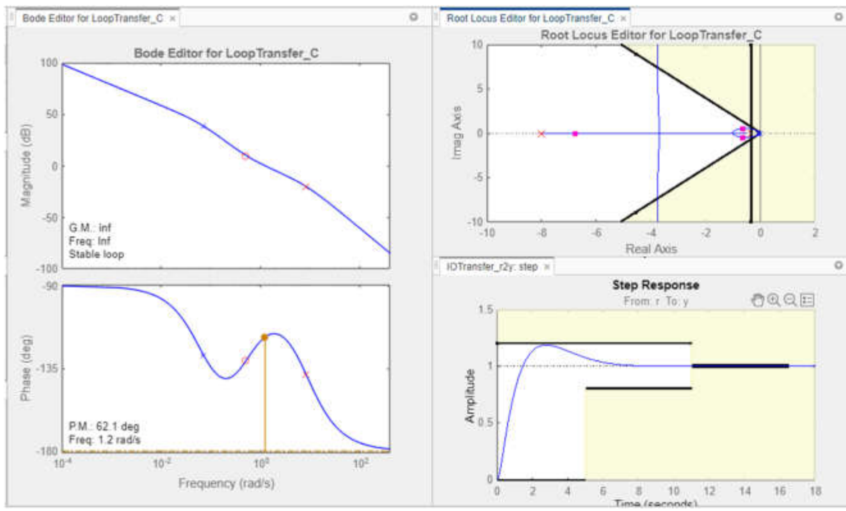

Figure 2: SISO Controller Design Interface

Figure 2 above shows the SISO tool interface which is used to manipulate the root locus properties of the controller in order to get the desired behaviour. In the root locus plot, the shaded areas serve as boundaries for the region where the controller pole may be placed to exhibit required response metrics. Similarly, the step response plot must not traverse the shaded area. There are multiple combinations of gain(k), pole(p) and zero(z) that result in a controller that meets these specifications, however, the values 6,0.5 and 8 were chosen for the gain, zero and pole respectively. These yield a controller that has an overshoot below 20%, a settling time of 11 seconds and a stable response as required. The step response plot on the bottom right of figure 1 does not cut through any shaded zone, which confirms that the design is suitable and can now be implemented. The controller is then defined by these parameters thus;

$$\boldsymbol{C(s)} \;= \boldsymbol{6(\frac{s+0.5}{s+8})}$$

To implement this design, three op-amps of the ST LM324N-octopot, 7 resistors and 2 capacitors and two potentiometers were used. The resistor values were computed in the manner below;

$$c(s) = K_c \frac{\left(s+\frac{1}{T}\right)}{\left(s+\frac{1}{\alpha T}\right)} \quad [1]$$

$$c(s) = 6\frac{(s+0.5)}{(s+8)}$$

$C_1 = C_2 = 4.8\mu F$

$$\frac{1}{T} = 0.5$$
$$T = 2$$
$$T = R_1 C_1$$
$$R_1 C_1 = 2$$

$R_1 = 416\ 667\Omega$

$$\frac{1}{\alpha T} = 8$$
$$\alpha T = \frac{1}{8}$$
$$\alpha T = R_2 C_2$$
$$R_2 C_2 = 0.125$$

$R_2 = 26\ 041\ \Omega$

$$K_c = \frac{R_4 C_1}{R_3 C_2}$$
$$\frac{R_4}{R_3} = 6$$

$R_4 = 100k\Omega$

$R_3 = 16\ 666\ \Omega$

With all the values calculated, a controller circuit was built following the schematic in figure 3 below;

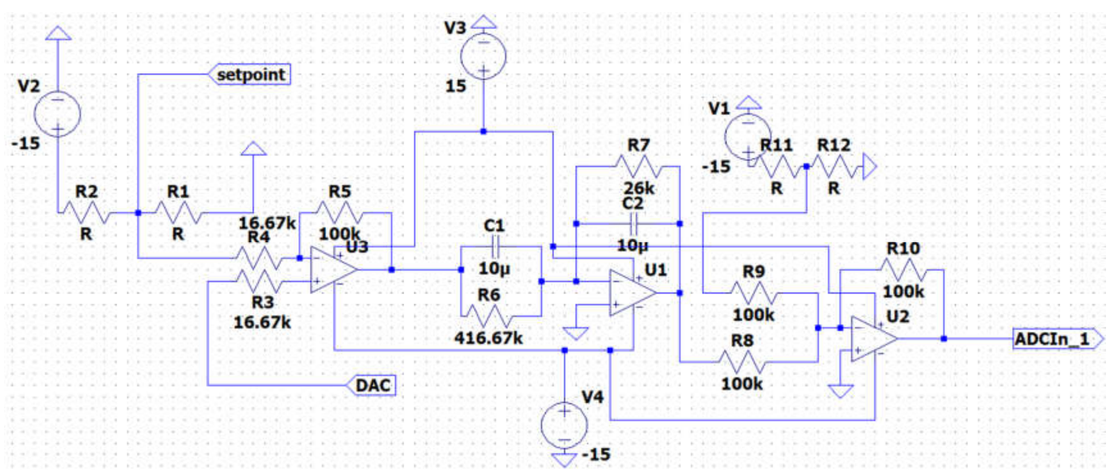

Figure 3: Controller Schematic

The output of the controller is at ADCin, this is where it interfaces with the plant. The setpoint is used to set a hovering height.

Results

After the circuit design was completed, it was simulated in Matlab using the state flow package to assess whether it behaves as expected. Figure 4 below is the plot of a simulated step response of the closed-loop system with the lead compensator. It shows that the helicopter's height (red), overshoots the setpoint (yellow) by less than 20% and quickly settles in 11 seconds. The plot also shows the controller action in blue, which is minimal at the steady-state operation as required. Furthermore, the aircraft closely tracks the set height.

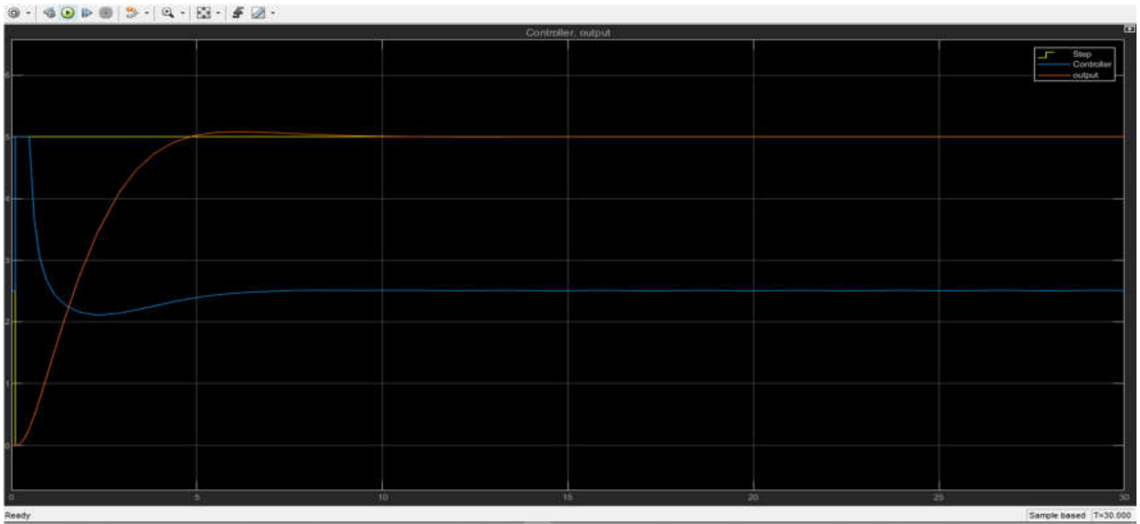

Figure 4: Simulation

The controller was also interfaced with a DAC in the lab to assess response to several real-life dynamics. These include tracking, the controller enabled the helicopter to track a set height very accurately, this is seen from the 50th second when the height is altered, the helicopter follows the input closely. Also, the system overshot the set height by less than 20% and also settled in no more than 11 seconds. Finally, one tested aspect was that of disturbance rejection. This is seen just before the 40th second where a downward disturbance is introduced, the controller action quickly counteracts that and stabilises the plane back at the set height.

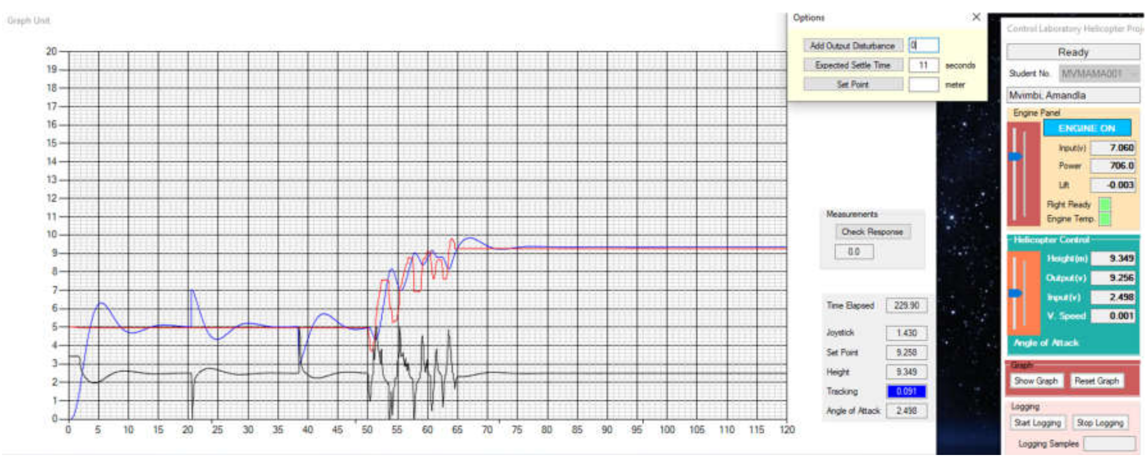

Figure 5: Lab Results

Conclusion

All in all, the lead compensator controller has successfully met all design requirements of the system. The system settles within the required 11 seconds, overshoots within the 20% boundary and track the height accurately. In addition, the controller is robust enough to handle disturbances and still operate stably as summarized by figure 5.

Bibliography

[1] K. Ogata, Modern Control Engineering, Prentice-Hall, 1970.

[2] N. S. Nise, Control Systems Engineering, California: Wiley, 2015.