UNIVERSITY OF CAPE TOWN
Department of Electrical Engineering

EEE3094S 2021
CONTROL ENGINEERING

Laboratory 2: Feedback control of helicopter height

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1. Introduction.

This report investigates the design of a helicopter altitude controller. The helicopter is given an input voltage V which when is increased will increase the speed of the helicopter. The helicopter is set to have an input voltage of 2.5V as initial. The step is made possible using a potentiometer which when done instantaneously, the voltage will jump from 2.5 to 5V, which is the maximum input voltage. This report outlines the second part in the design process for a basic helicopter altitude controller. A controller transfer function model is developed and tested using various simulation tools. This model is the used to design and build a circuit in the real world.

Model Development

The helicopter model can be characterized by the following feedback loop:

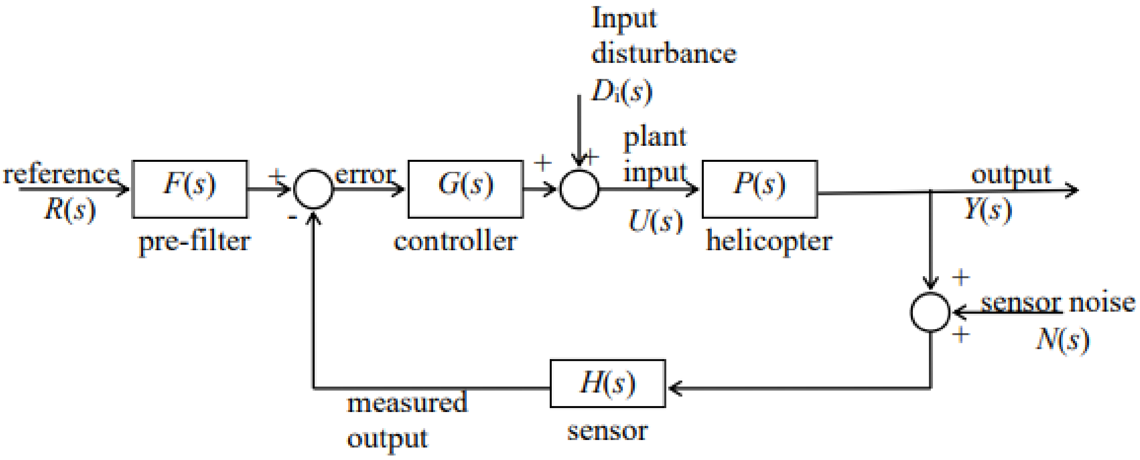


Figure 1: Helicopter feedback system

From the feedback loop above, it is clear that the helicopter will have some disturbances. The input disturbances in the flight of the helicopter are wind gusts which are considered as force disturbances.

Aim

The aim of the lab is to design a suitable controller to control the altitude of the helicopter according to client requirements from Mr Dominic de Maar.

The aim for this part in the helicopter controller design is to:

- Develop a transfer function model of the controller (G(s)) in simulation
- Test the controller response in simulation and refine
- Design and build a circuit of the controller

2. Specifications and Design Constraints

The specifications for the controller design are outlined as follows:

Table 1: Specifications for controller design

	Specification
Set point tracking	Within 0.4m of final value
Over/Undershoot	Must be less than 20%
Settling time	4 seconds
Output disturbance rejection	Within $t_{2\%}$
High amplitude oscillations	Must be smaller than 0.4v

Design Constraints

The following design constraints were in place for the controller design:

- No more than 4 op amps may be used in the circuit design of the controller
- The controller must not be a bang-bang (on-off) type controller

3. Simulation and Circuit design

Simulation was used to obtain a suitable transfer function model for the controller to meet all the specifications as set out in section 2.

Software

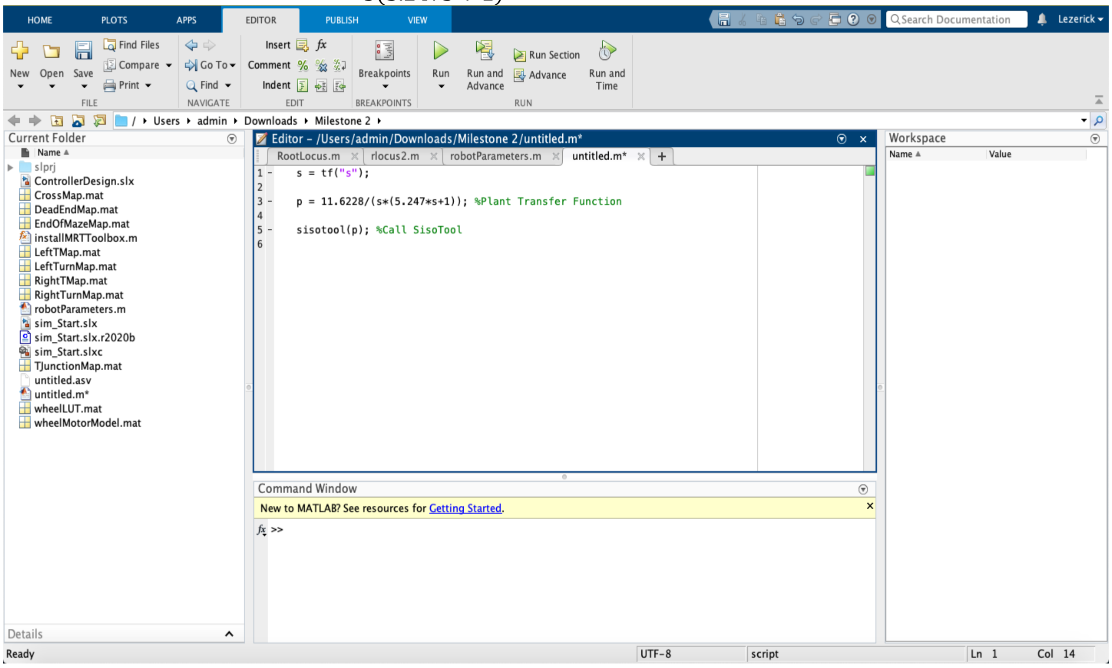
All simulations were executed using the Matlab and Simulink software along with Sisotool which is an add on within Matlab

Methodology

The following steps outline the process of obtaining the controller transfer function using Sisotool and Matlab:

i. Open a new matlab workspace and create transfer function object (tf) of the plant (P(s)) transfer function obtained in the first part of the lab.

ii. Run Sisotool with the P(s) as the input. Figure 1 shows how to execute steps 1 and 2 in Matlab. Our P(s) = $\frac{11.6228}{s(5.247s+1)}$



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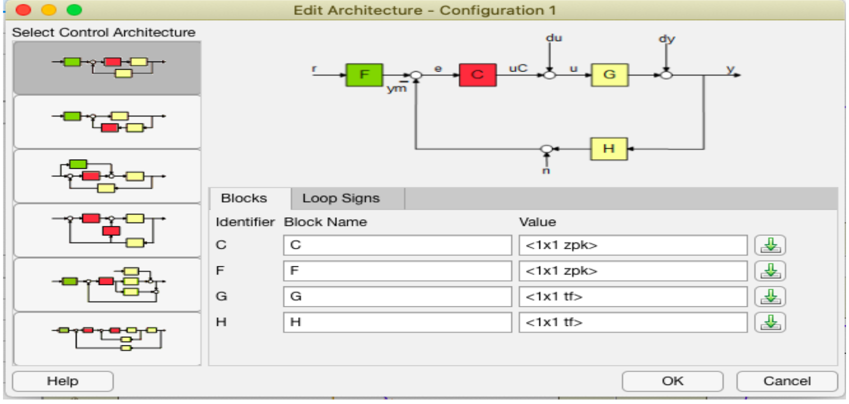
```
s = tf("s");

p = 11.6228/(s*(5.247*s+1)); %Plant Transfer Function

sisotool(p); %Call SisoTool
```

New to MATLAB? See resources for Getting Started.

Figure 2: Matlab code used for step 1 and 2

iii. Select the architecture you need for the design. We selected a basic negative feedback loop with the sensor(H(s)) value equal to 1 as shown in figure 2.



Edit Architecture - Configuration 1

Identifier	Block Name	Value
C	C	<1x1 zpk>
F	F	<1x1 zpk>
G	G	<1x1 tf>
H	H	<1x1 tf>

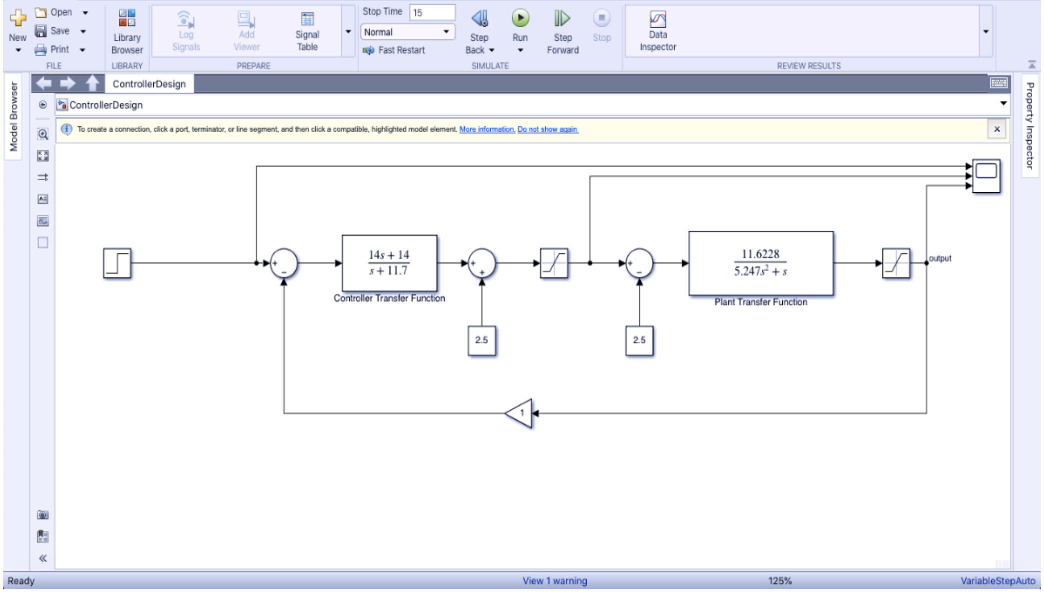
Figure 3: Architecture used in the controller design

iv. Select the type of controller you want to design. We chose to design a lead controller.

v. In Sisotool open a figure containing the rootlocus and the output response.

vi. On the rootlocus move the poles and zeros around to different positions on the locus by changing the gain while inspecting your output response. Do this until you see that the output response satisfies all the specifications and then save your transfer function as G(s).

vii. Finally use the transfer function from Sisotool to form a negative feedback loop in Simulink as shown in figure 3. Run this to make sure that the response satisfies all the specifications.



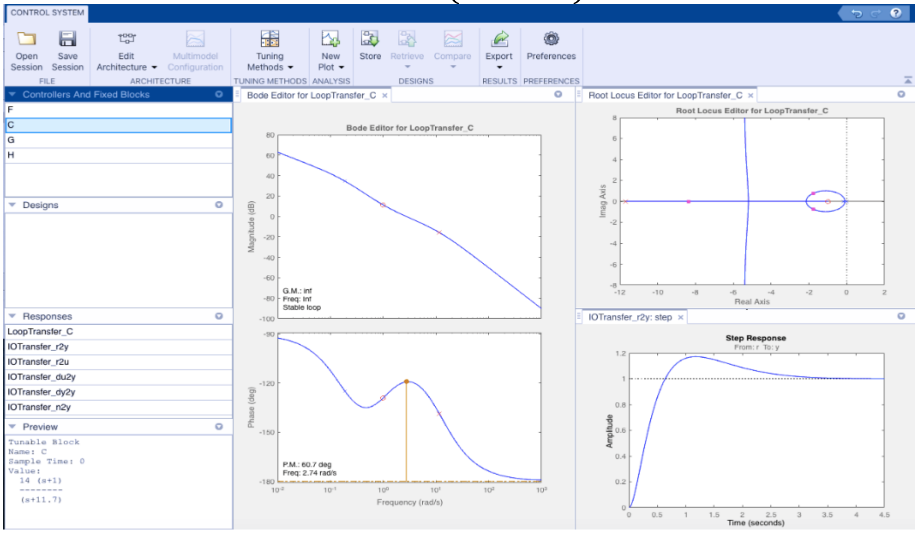
To create a connection, click a port, terminator, or line segment, and then click a compatible, highlighted model element. More information. Do not show again.

Figure 4: Negative Feedback implemented in Simulink

Results:

Using Sisotool the following transfer function model was obtained for the controller:

$$G(s) = \frac{14(s\ +\ 1)}{(s + 11.7)}$$



```
Tunable Block
Name: C
Sample Time: 0
Value:
  14 (s+1)
  --------
  (s+11.7)
```

Figure 5: Sisotool results

Using Simulink simulate the system in negative feedback as shown in figure 3 the following results were obtained.

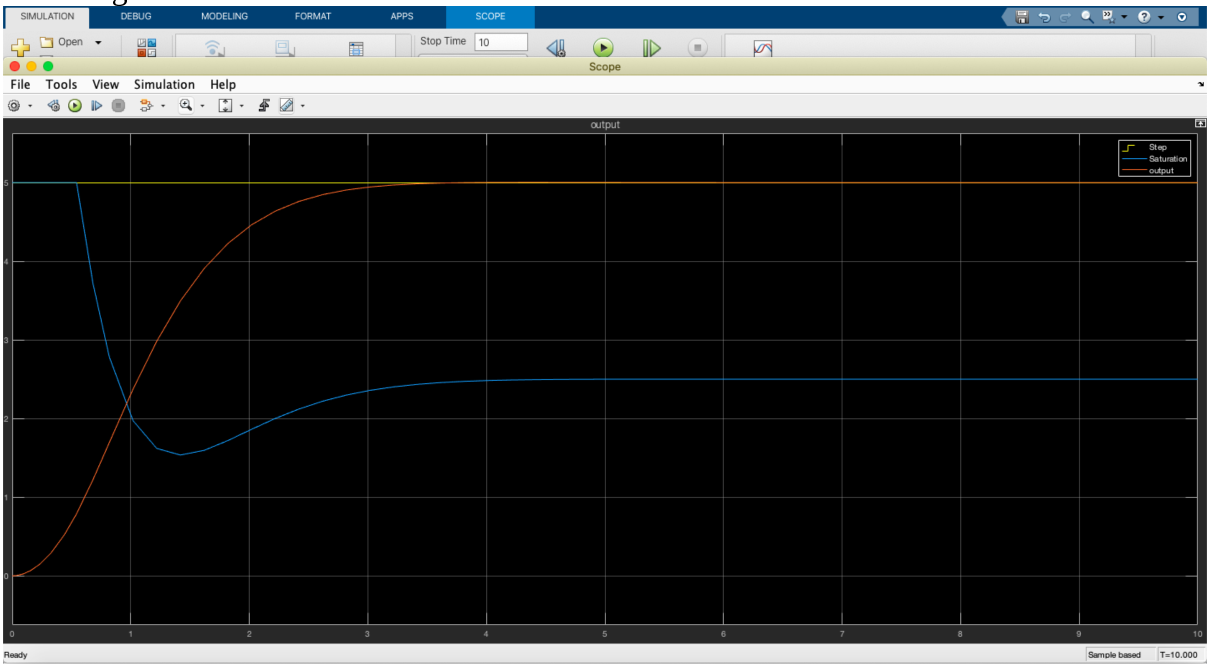


Figure 6: Output step response of the system with controller.

From figure 5 it is evident that the controller meets all the set specifications in simulation with the settling time, overshoot/undershoot and set point tracking all being within the specified range.

Table 2: Simulation results vs Specifications

	Simulation	**Specification**
Set point tracking	0m within final value	Within 0.4m of final value
Settling Time	3.5s	4.0s
Under/Overshoot	Less than 1% overshoot	Less than 20%

Continuous time circuit design

The type of controller we used for this laboratory is a lead controller. We chose a lead controller due to its simple circuit design which only uses one op amp (See figure 6 for the circuit diagram used in the design).

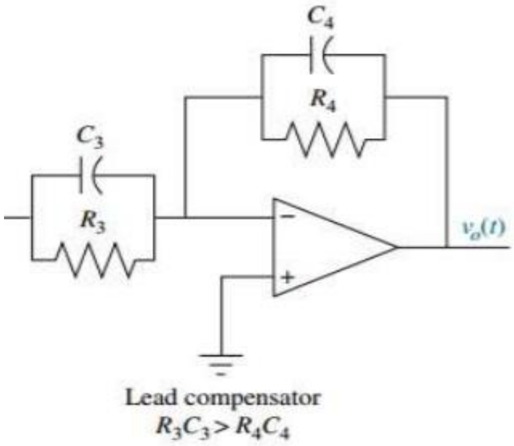


Figure 7: Lead controller circuit schematic

The formula for the lead controller in figure 6 is as follows:

$$V_{out} = V_{in}\left(-\frac{c_3}{c_4}\cdot\frac{\left(s+\frac{1}{R_3C_3}\right)}{\left(s+\frac{1}{R_3C_3}\right)}\right) \tag{1}$$

In addition to the controller the circuit design also needed to account for the two summing amplifiers. These amplifiers were used to implement the 2.5V offset to the input due to the helicopter only starting to fly after 2.5V and to provide a summing junction to complete the negative feedback loop. The following schematic was used for the summing amplifiers:

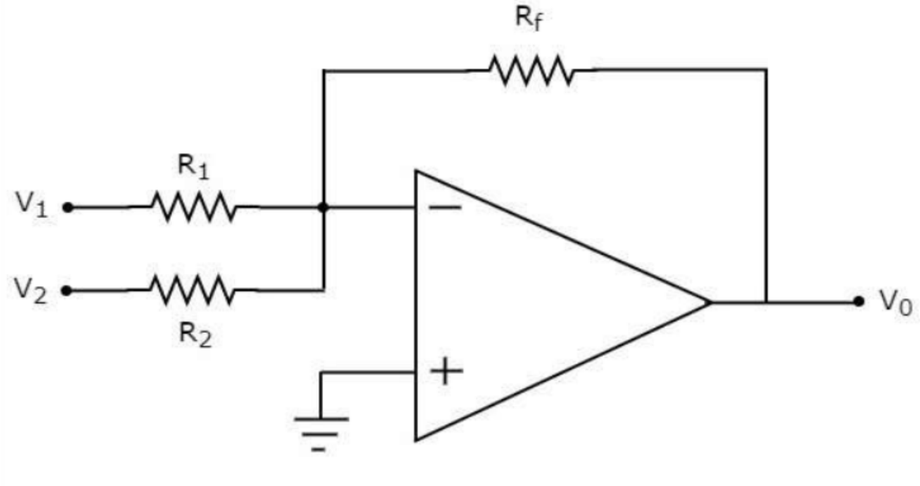


Figure 8: Circuit diagram of a summing amplifier

The formula for the summing amplifier in figure 7 is as follows:

$$V_{out} = -\frac{R_f}{R_1}(V_1 + V_2), where\ R1 = R2 \tag{2}$$

Combining these different sub-circuits we got the following complete circuit schematic:

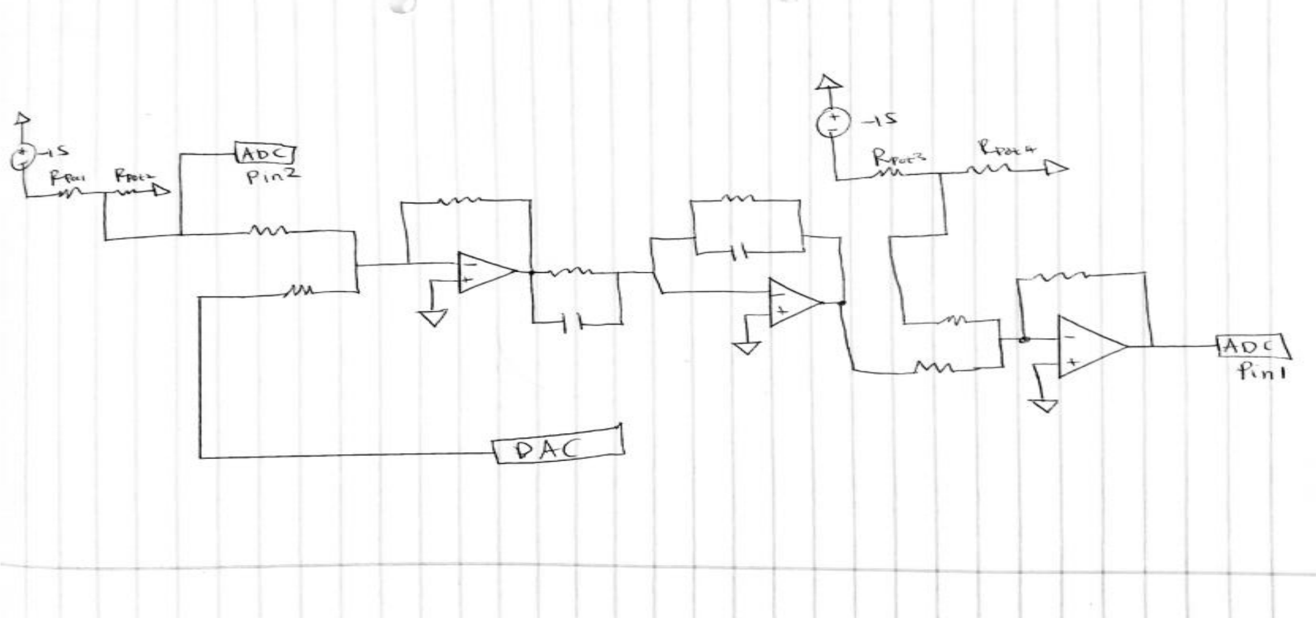


Figure 9: Complete circuit design without component values

Calculating Component Values:

Summing amplifier:

For both summing amplifiers we used 10kΩ resistors for all the resistors. This gave us a gain of 1 on both summing amplifiers as to not add extra gain in the overall circuit. The reason we chose to use 10kΩ resistors is due to their low noise and 5% tolerance.

Lead Controller:

For the controller we chose a value of 1mf for capacitor C3. This gave us the following values as a result:

- C3 = 1mf
- C4 = 71.143nf
- R3 = 1MΩ
- R4 ≈ 120MΩ

We chose C3 as 1mf to try and keep the resistor values as small as possible due to high resistors having a bigger tolerance range meaning they are less accurate and also, they are noisier than smaller resistors. Please see Appendix A for detailed calculation of controller component values.

Following the calculation of all component values we obtained the following complete circuit schematic:

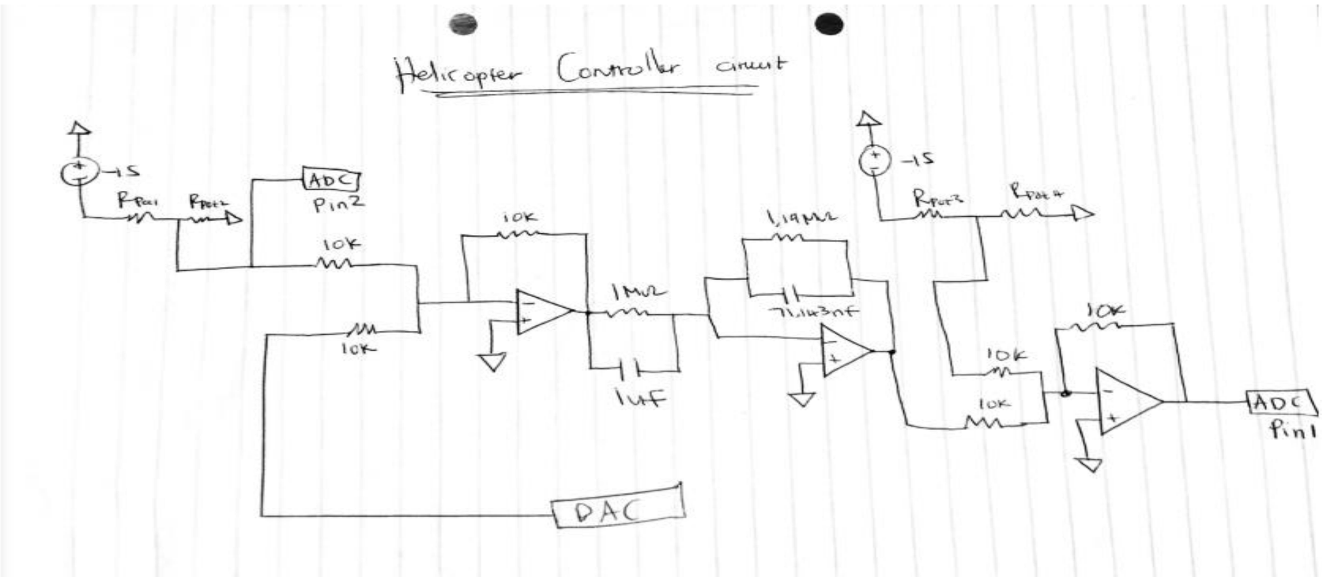


Figure 10: Complete circuit design with component values

Components list for building the circuit

- 1 Breadboard
- 2 Potentiometers('pot')
- 1 LM324 Op amp IC
- Jumper wires
- Standard Resistors

4. Simulation compared to lab results

The results obtained from the simulation can be seen in figure 6 and table 2. All the specifications are satisfied in simulation as seen from table 2. All the specifications were also satisfied in the laboratory using the circuit design in figure 10. However, we did have an overshoot with the controller in lab in contrast to the simulation which has no overshoot. This difference can be attributed due to the inaccuracies in the component values which affected the gain value of the controller transfer function. This can cause the poles of the overall design to be shifted on the rootlocus.

5. Conclusion and references

Conclusion

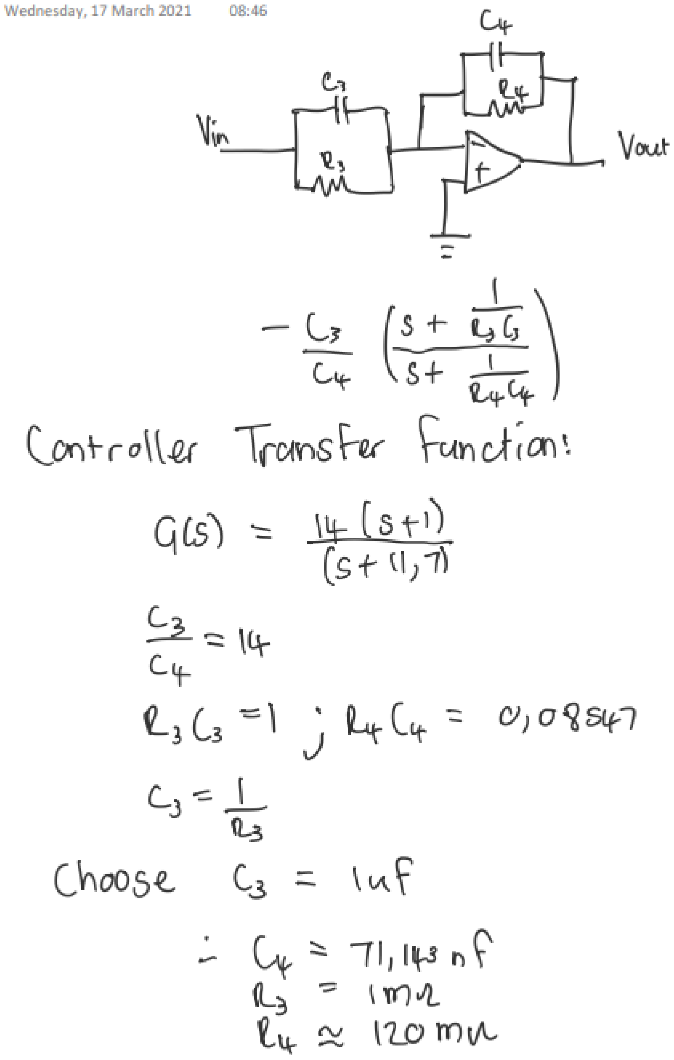
The controller controls the altitude of the helicopter according to the client's requirements. When disturbance such as wind gusts is introduced, the controller has the ability to reject the output disturbance and return the helicopter to its original position. The controller meets all the set specifications in simulation with the settling time, overshoot/undershoot and set point tracking all being within the specified range. The components used such as resistors created some noise which might have affected the results, however all requirements were satisfied.

References

1. Gareth D. Padfield, (2007), Helicopter Flight Dynamics: The Theory and Application of Flying Qualities and Simulation Modelling 2nd Edition Blackwell.
2. Department of Electrical Engineering EEE3094 Control Engineering HELICOPTER CONTROL LABORATORIES 1 & 2.pdf
3. "Arithmetic Circuits", Tutorialspoint.com, 2021. [Online]. Available: https://www.tutorialspoint.com/linear_integrated_circuits_applications/linear_integrated_circuits_applications_arithmetic_circuits.htm. [Accessed: 27- Oct- 2021].
4. Available: https://www.benardmakaa.com/wp-content/uploads/2018/09/LECTURE-3-Physical-Realization-of-Compensation.pdf. [Accessed: 27- Oct- 2021].

6. Appendices

Appendix A: Detailed calculation of controller component values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$$-\frac{C_3}{C_4}\left(\frac{s+\frac{1}{R_3C_3}}{s+\frac{1}{R_4C_4}}\right)$$

Controller Transfer function:

$$G(s) = \frac{14(s+1)}{(s+11,7)}$$

$$\frac{C_3}{C_4} = 14$$

$$R_3C_3 = 1 \;;\; R_4C_4 = 0,08547$$

$$C_3 = \frac{1}{R_3}$$

Choose $C_3 = 1uf$

$$\therefore C_4 = 71,143\,nf$$
$$R_3 = 1m\Omega$$
$$R_4 \approx 120\,m\Omega$$