

Instrumentation and control assignment

by Jess Eardley

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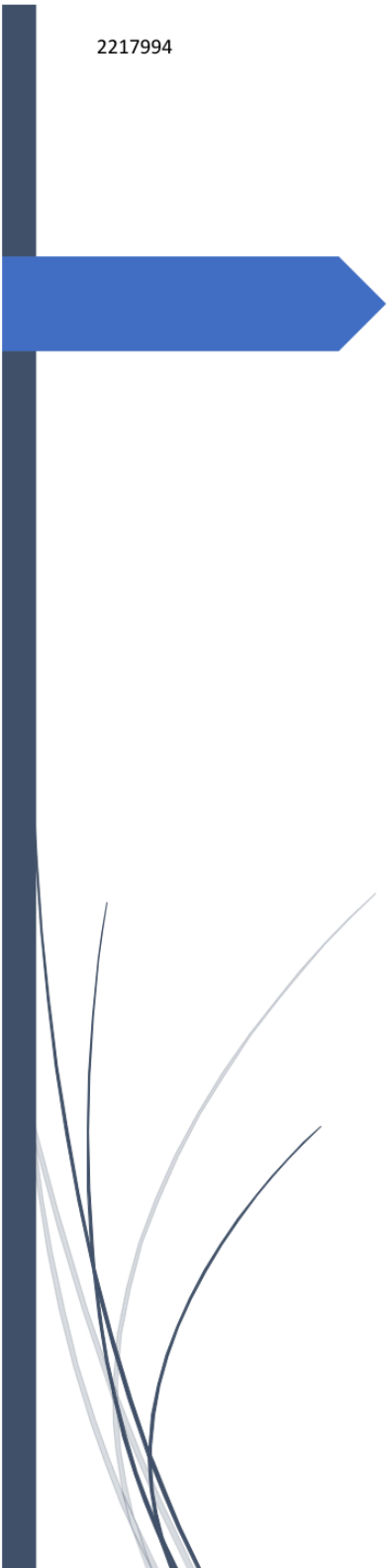
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Control System Design



Control System Design

ACDB5011

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Abstract

This report contains the design and analysis of a CIWS turret close loop control system simulation using MATLAB and Simulink. The design parameters and specification requirements were to have the control systems settling time under 2 seconds and the overshoot under 5%. The simulation met these requirements with a settling time of 3.88% and 1.02 seconds. The control system was validated using mathematical transfer function and Laplace transfer functions. The system was concluded stable by the analysis of pole zero plots and root locus graphs.

1 Introduction

1.1 Overview of Report

Contained in this report is the investigation into the performance of a simulation of a control system for an angular positioning system for an automated Close-In Weapon System (CIWS) turret. The aim contained in the brief was to create a closed loop control system for a CIWS turret using the software MATLAB and Simulink. The transfer function $G(s)$ was given:

$$G(s) = \frac{1}{10s^2 + 10s + 5} \quad \text{Eqn. No.}$$

The requirement of the system set out in the brief was to bring the positioning system response under 2 seconds and with an overshoot of less than 5%.

The brief required the closed loop transfer function of the system as a whole to be validated by comparing the results of simulations of the single transfer function and the simulation results.

Further on in this report are the details of the simulation set-up as well as the parameters used, results a discussion and a conclusion.

1.2 Control Systems

A control system is a system consisting of various components that are designed to control and regulate the behaviour of a larger system or process by adjusting the input to produce a desired output [1].

A control system is a component used widely for a number of processes. Such as industrial, domestic, and medical. A control system is used in traffic control process e.g. Traffic lights, to make decisions in real time for consistent and safe control of vehicles on the roads. Control systems are used to keep operations and processes, smooth, efficient, safe and abide by standards and regulations [1].

1.2.1 Types of control systems

- Closed Loop Control Systems- A closed loop control system is one that regulates a system using a feedback loop from the output to the input to maintain a desired state without the requirement of human interaction [2]. The control system is a more adaptive and therefore gives more accurate outputs. Such is required from a thermostat in a home to continually detect the room's temperature and turn the boiler to on when the temperature is read below threshold.

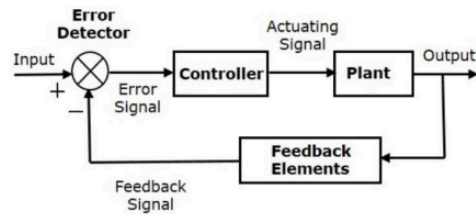


Figure 1 Closed Loop Control System [1]

- Open Loop Control Systems – An open loop control system is one that has no feedback [1]. An example is a traffic control system based on a timer.

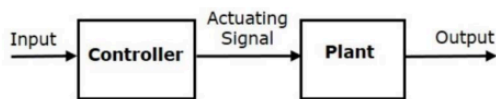


Figure 2 Open Loop Control System [1]

1.3 PID controllers

Proportional-Integral-Derivative (PID) Controllers are devices for fine control of a process to minimize errors in outputs to keep the system in question running smoothly [1]. The tuning process involves determining what controller parameters produce the desired output. This allows the process to have minimal errors between the variables of the process and its set point [3].

There are four types of PID controller:

- Proportional (P) controller
- Proportional plus integral (PI) controller
- Proportional plus derivative (PD) controller
- Proportional plus integral plus derivative (PID) controller [4]

PID controllers can reduce the overshoot response to a step reference change. This is the controller used in the Close loop control system discussed in the main body of this report. As feedback control can cause a closed loop system to become unstable, a PID controller is vital to the systems stability. The stability of the system is investigated in the discussion of this report using close loop poles on a root locus plot [4].

2 Simulation Setups

Using MATLAB Simulink function, the process controller for the CIWS turret was created using elements such as: a step generator, Comparator block (properties set to + and -), PID controller block, Forward transfer function block and Oscilloscope. See Figure 3.

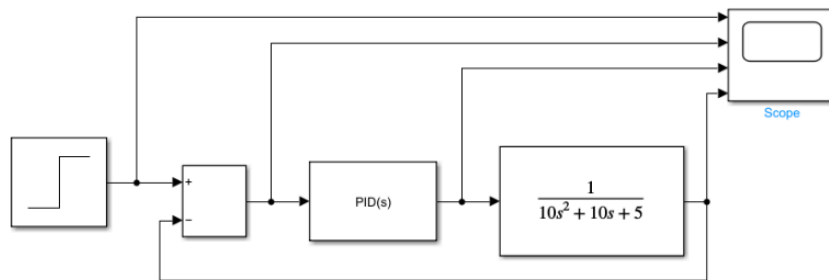


Figure 3 Control system simulation setup in MATLAB Simulink

The PID controller block was manually tuned until the threshold value of process control within 2 seconds with an overshoot of less than 5%. For the PID controller values see Figure 4 the values for Kp (P), Ki (I), Kd (D) and N can also be seen in this figure, this is then used for the mathematical calculations.

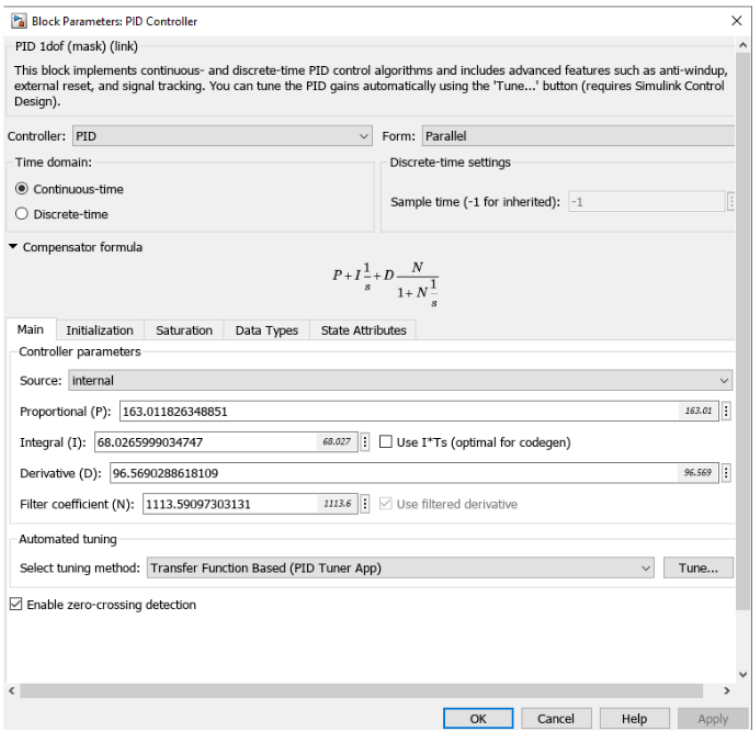


Figure 4 PID controller parameters

Figure 5 shows the control parameters for the PID controller. The PID controller produced a system with the settling time of 1.02 seconds and an overshoot value of 3.88%. The tuned response of the system is displayed in the step plot.

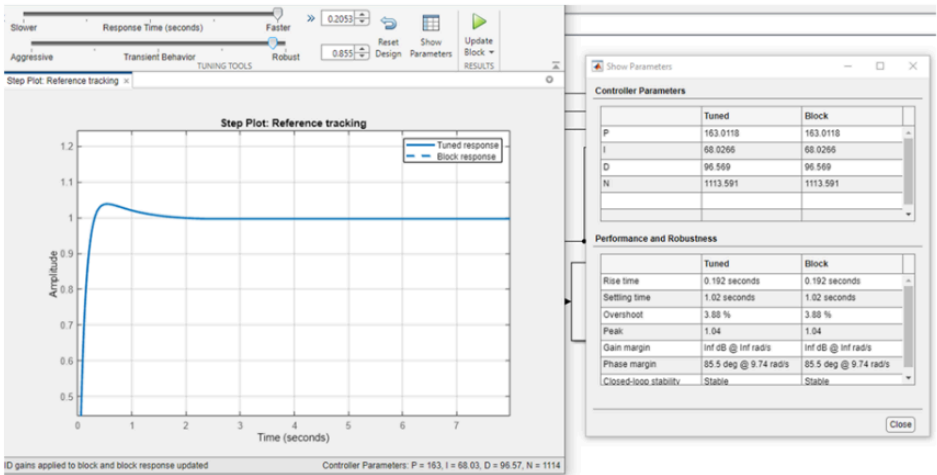


Figure 5 PID tuning and performance i.e. settling time and overshoot

The simulation parameters assigned in the brief for the forward transfer function block can be seen in Figure 6 and in Figure 3.

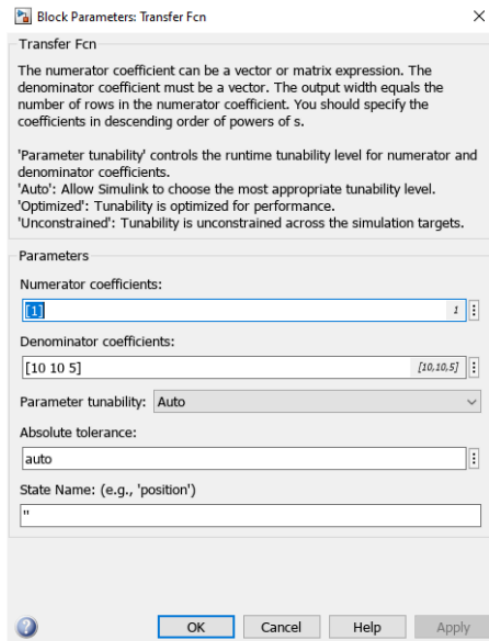


Figure 6 Transfer function parameters (plant)

Figure 7 shows the PID controller and transfer function, $G(s)$ multiplied together and added into the simulation as a validation of the simulation. The mathematical formulas and values from the simulation to undertake this validation are shown in Figure 5 and 6 and the following equations.

$$G(s) = \frac{1}{as^2 + bs + c} \quad [5]$$

$$a = 10, \quad b = 10, \quad c = 5$$

$$K_p + K_i \frac{1}{s} + K_d \frac{s}{\frac{1}{N}s + 1}$$

Using the PID tuner in MATLAB Figure 5, the following values were obtained:

$$K_p = 163.0118, \quad K_i = 68.0266, \quad K_d = 96.569, \quad N = 1113.591 \text{ s} = \text{Laplace variable}$$

Laplace transfer function of the PID controller:

$$163.0118 + \left(68.0266 \frac{1}{s}\right) + 96.569 \frac{s}{\frac{1}{1113.591} + 1}$$

To calculate the forward path transfer function of the system, the controller's transfer function must be multiplied by the transfer function of the process using Laplace transfer functions.

$$\begin{aligned} & \left(163.0118 + \frac{68.0266}{s} + 96.569 \frac{s}{\frac{1}{1113.591} + 1}\right) \times \left(\frac{1}{10s^2 + 10s + 5}\right) \\ & \left(163.0118 + \frac{68.0266}{s} + 96.569 \frac{s}{\frac{s+1113.591}{1113.591}}\right) \times \left(\frac{1}{10s^2 + 10s + 5}\right) \\ & \left(163.0118 + \frac{68.0266}{s} + 96.569 \left(s \div \frac{s+1113.591}{1113.591}\right)\right) \times \left(\frac{1}{10s^2 + 10s + 5}\right) \\ & \left(163.0118 + \frac{68.0266}{s} + 96.569 \left(s \left(\frac{1113.591}{s+1113.591}\right)\right)\right) \times \left(\frac{1}{10s^2 + 10s + 5}\right) \\ & \left(163.0118 + \frac{68.0266}{s} + 96.569 \left(\left(\frac{1113.591s}{s+1113.591}\right)\right)\right) \times \left(\frac{1}{10s^2 + 10s + 5}\right) \\ & \left(163.0118 + \frac{68.0266}{s} + \left(\frac{107538.3693s}{s+1113.591}\right)\right) \times \left(\frac{1}{10s^2 + 10s + 5}\right) \\ & \left(\frac{((s(s+1113.591)) \times 163.0118) + (s+1113.591)68.0266 + s(107538.3693s)}{s(s+1113.591)}\right) \times \left(\frac{1}{10s^2 + 10s + 5}\right) \\ & \left(\frac{163.0118s^2 + 181528.4734s + 68.0266s + 75753.80952 + 107538.3693s^2}{s^2 + 1113.591s}\right) \times \left(\frac{1}{10s^2 + 10s + 5}\right) \\ & \left(\frac{107701.3811s^2 + 181596.5s + 75753.80952}{s^2 + 1113.591s}\right) \times \left(\frac{1}{10s^2 + 10s + 5}\right) \\ & \frac{107701.3811s^2 + 181596.5s + 75753.80952}{(s^2 + 1113.591s)(10s^2 + 10s + 5)} \\ & \frac{107701.3811s^2 + 181596.5s + 75753.80952}{10s^4 + 10s^3 + 5s^2 + 11135.91s^3 + 11135.91s^2 + 5567.955s} \\ & \frac{107701.3811s^2 + 181596.5s + 75753.80952}{10s^4 + 11145.91s^3 + 11140.91s^2 + 5567.955s} \end{aligned}$$

The block diagram is redrawn as, see Figure 7.

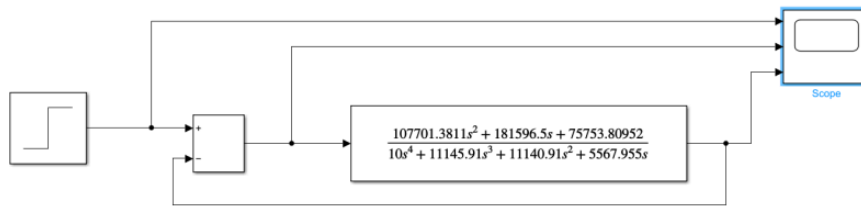


Figure 7 Control system validation controller and process multiplied together

The feedback loop was removed and the transfer function of the system as a whole is calculated in the using the following equation:

$$TF = \frac{G}{1+GH} [6]$$

Where TF is the transfer function of the whole system, G is the forward path transfer function, and H is the transfer function of the feedback loop, in this case $H = 1$.

$$TF = \frac{107701.3811s^2 + 181596.5s + 75753.80952}{10s^4 + 11145.91s^3 + 11140.91s^2 + 5567.955s} \times 1 + \left(\frac{107701.3811s^2 + 181596.5s + 75753.80952}{10s^4 + 11145.91s^3 + 11140.91s^2 + 5567.955s} \right) \times 1$$

$$TF = \frac{107701.3811s^2 + 181596.5s + 75753.80952}{10s^4 + 11145.91s^3 + 11140.91s^2 + 5567.955s} \times \left(\frac{10s^4 + 11145.91s^3 + 11140.91s^2 + 5567.955s}{10s^4 + 11145.91s^3 + 11140.91s^2 + 5567.955s} \right) + \left(\frac{107701.3811s^2 + 181596.5s + 75753.80952}{10s^4 + 11145.91s^3 + 11140.91s^2 + 5567.955s} \right) \times 1$$

$$TF = \frac{107701.3811s^2 + 181596.5s + 75753.80952}{10s^4 + 11145.91s^3 + 11140.91s^2 + 5567.955s} \times \left(\frac{10s^4 + 11145.91s^3 + 11140.91s^2 + 5567.955s}{10s^4 + 11145.91s^3 + 11140.91s^2 + 5567.955s} \right) + \left(\frac{107701.3811s^2 + 181596.5s + 75753.80952}{10s^4 + 11145.91s^3 + 11140.91s^2 + 5567.955s} \right) \times 1$$

$$TF = \frac{107701.3811s^2 + 181596.5s + 75753.80952}{10s^4 + 11145.91s^3 + 11140.91s^2 + 5567.955s} \times \left(\frac{10s^4 + 11145.91s^3 + 11140.91s^2 + 5567.955s}{10s^4 + 11145.91s^3 + 11140.91s^2 + 5567.955s} \right) + \left(\frac{107701.3811s^2 + 181596.5s + 75753.80952}{10s^4 + 11145.91s^3 + 11140.91s^2 + 5567.955s} \right) \times 1$$

$$TF = \frac{107701.3811s^2 + 181596.5s + 75753.80952}{10s^4 + 11145.91s^3 + 11140.91s^2 + 5567.955s} \times \left(\frac{10s^4 + 11145.91s^3 + 11140.91s^2 + 5567.955s}{10s^4 + 11145.91s^3 + 11140.91s^2 + 5567.955s} \right) + \left(\frac{107701.3811s^2 + 181596.5s + 75753.80952}{10s^4 + 11145.91s^3 + 11140.91s^2 + 5567.955s} \right) \times 1$$

$$TF = \frac{(107701.3811s^2 + 181596.5s + 75753.80952)(10s^4 + 11145.91s^3 + 11140.91s^2 + 5567.955s)}{(10s^4 + 11145.91s^3 + 11140.91s^2 + 5567.955s)(10s^4 + 11145.91s^3 + 11140.91s^2 + 5567.955s)}$$

$$TF = \frac{1077013.811s^6 + 1202245866s^5 + 3224707177s^4 + 3467171844s^3 + 1855087508s^2 + 421793799.6s}{100s^8 + 222918.25s^7 + 125531141.7s^6 + 1450708385s^5 + 3472946847s^4 + 3591235959s^3 + 1886089603s^2 + 421789790.7s}$$

Figure 8 shows the block diagram redrawn as a single block.

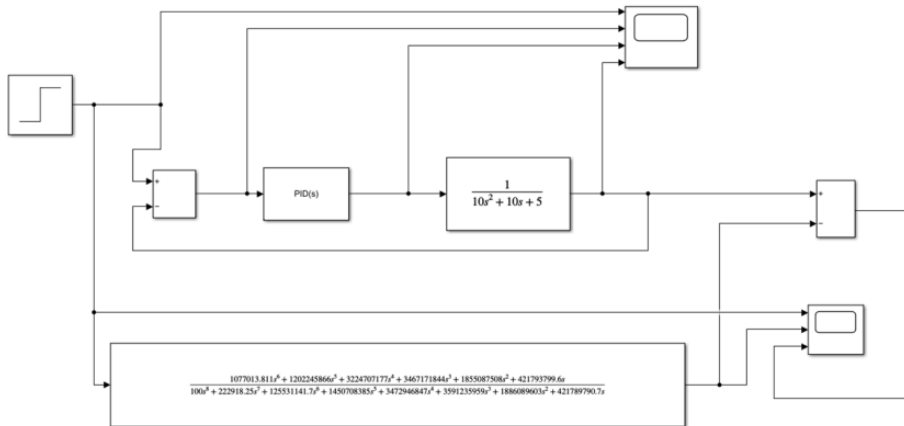


Figure 8 Control system and TF calculations added into simulation as a transfer function block

Both scopes were compared to ensure the transfer function of the whole systems was correct, see Figure 9 for scope 1 and Figure 10 for scope 2. Analysis of these displays are discussed in the discussion part of this report. The scope inputs can be seen in Figure 8.

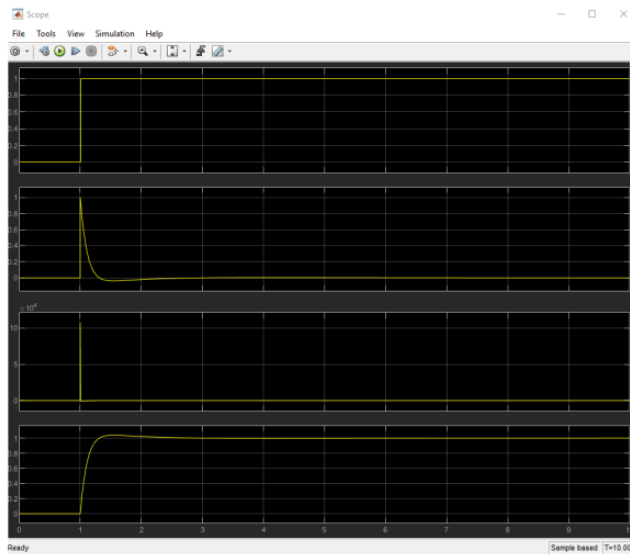


Figure 9 Oscilloscope readings from control system

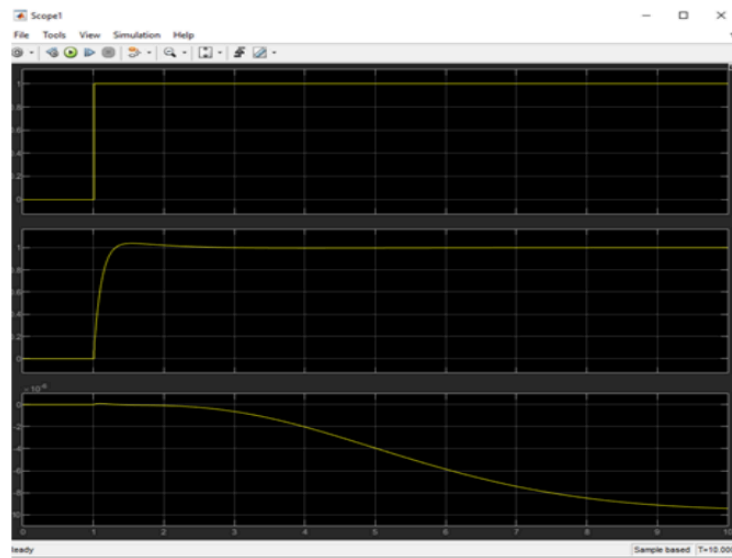


Figure 10 Oscilloscope of control system after mathematical validation

Figure 11 shows the MATLAB programming for the pole-Zero plots to be drawn.

```

Command Window
New to MATLAB? See resources for Getting Started.

Continuous-time transfer function.

>> G=C*P

G =

      163.1 s^2 + 68.17 s + 0.06109
-----
      10 s^4 + 10.01 s^3 + 5.009 s^2 + 0.00449 s

Continuous-time transfer function.

>> P=tf(1,[10 10 5])

P =

      1
-----
      10 s^2 + 10 s + 5

Continuous-time transfer function.

>> figure
>> subplot(2,2,1)
>> pzplot(P)
>> subplot(2,2,2)
>> pzplot(C)
>> subplot(2,2,3)
>> pzplot(G)
>> subplot(2,2,4)
>> pzplot(CLTF)
>> rlocus(CLTF)
>> CLTF

CLTF =

      6107 s^6 + 6.981e05 s^5 + 2.032e06 s^4 + 2.334e06 s^3 + 1.319e06 s^2 + 3.255e05 s
-----
      100 s^8 + 2.247e04 s^7 + 1.291e06 s^6 + 3.223e06 s^5 + 4.534e06 s^4 + 3.579e06 s^3 + 1.629e06 s^2 + 3.255e05 s

Continuous-time transfer function.

```

Figure 11 MATLAB control window

3 Results

Figure 12 left- shows the scope for the control system compared to right - transfer function of the whole system. Both the top graphs show the input, this should be the same as the signal is coming from the same input block. The second graph on the left displays the signal after the comparator block. The third graph on the left shows the signal after going through the PID controller. The last graph on the left shows the output of the control system, after the PID controller and transfer function block, this is the same as the middle graph on the right, showing the signal after going through the transfer function of the whole system, both signals displayed on the scopes appear to be the same. The final graph on the right is the difference between both outputs using a subtract comparator block. The difference is minimal as displayed by the 10^{-6} value on the top of the graph. The difference is also in the negative and appears to settle at the right of the graph, no longer declining.

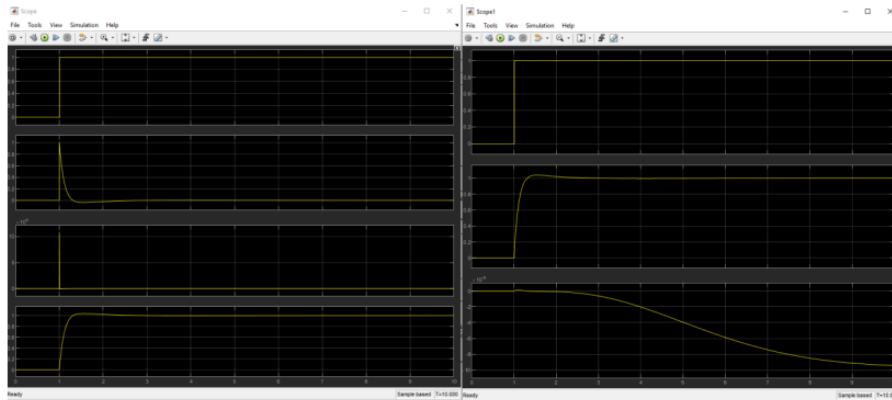


Figure 12 Oscilloscope values from the control system and after the mathematical validations, compared

Figure 13 shows the Pole-Zero plots from the simulation of the closed loop control system. The graphs in this figure show the poles are denoted by 'X' and the zeros, denoted by 'O'. Shown on the graphs is all the poles of the system are in the negative real part of the graph. Furthermore, shown in Figure 14 there are no poles with the real part equal to zero on the real axis.

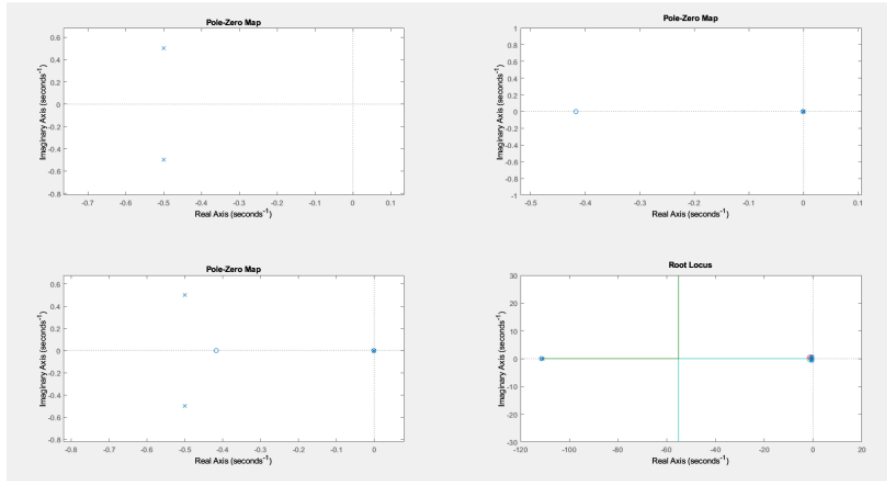


Figure 13 Pole Zero and Root Locus Plots of the control system

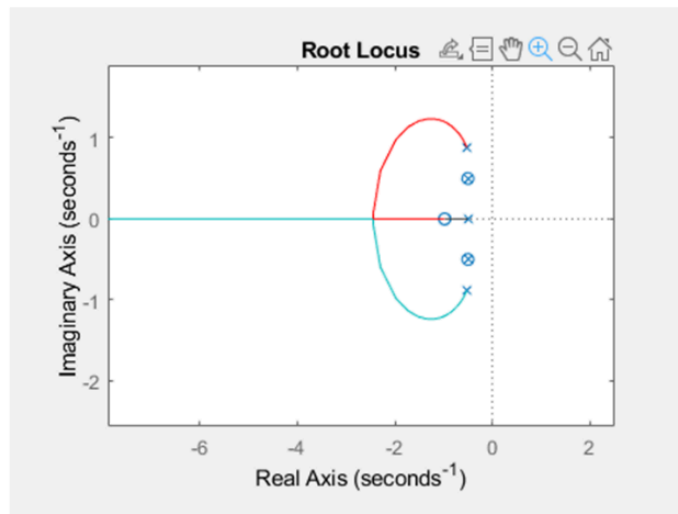


Figure 14 Root Locus Plot of the control system

4 Discussion

Firstly, the mathematical calculations validated the simulation as the difference between the outputs in the simulation displayed on the scope, Figure 12, showed a very minimal difference of 9×10^{-6} .

The simulation also displayed stability shown in the root locus plots calculated by the software, Figure 14. The poles of the closed loop system are all on the negative real axis of the graph, also when zoomed in to the graphs there were also no poles equal to zero, Figure 13 and 14 [4] [7].

The system stability was again proved during the tuning of the PID controller, there is no ringing and little overshoot displayed in the PID controller produced a system with the settling time of 1.02 seconds and an overshoot value of 3.88% Figure 5, both values are within the scope of the brief.

5 Conclusion

To conclude, the results from the simulation show that the model of the CIWS turret was successful and within the design parameter. With the values given at the start of this report from the brief the overshoot and settling time were able to be achieved with an overshoot of 3.88% and 1.02 seconds. The system stability was investigated, and the conclusion stands that the system is suitable stable. Thus, meaning the CIWS turret can perform adequately.

To improve this system more time could have been allocated to the finer tuning of the controller parameters to further reduce the overshoot and settling time. The mathematical validation of the model would have to be recalculated but this could theoretically be completed quickly as the process is already laid out.

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 7 [https://uk.mathworks.com/help/control/ref/controllib.chart.pzplot.html?searchHighlight=pole%](https://uk.mathworks.com/help/control/ref/controllib.chart.pzplot.html?searchHighlight=pole%20zero%20plots&s_tid=srchtitle_support_results_1_pole%20zero%20plots)
] [20zero%20plots&s_tid=srchtitle_support_results_1_pole%20zero%20plots](https://uk.mathworks.com/help/control/ref/controllib.chart.pzplot.html?searchHighlight=pole%20zero%20plots&s_tid=srchtitle_support_results_1_pole%20zero%20plots).

Instrumentation and control assignment

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

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QM

Eqn. No.

You should include an equation number to allow you to identify the equation in your text e.g. "this can be calculated using equation 2".

PAGE 5



Comment 1

Excellent background work

PAGE 6

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PAGE 12

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Comment 2

What do each of these data series relate to? You should state in the caption...

Figure 9 T to B: Step input, error signal... etc.

PAGE 14

PAGE 15

PAGE 16

PAGE 17

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QM

Ref Qual

You should try to use more high quality reference sources, such as textbooks from reputable academic publishers and articles from peer reviewed journals.

QM

Ref Qual

You should try to use more high quality reference sources, such as textbooks from reputable academic publishers and articles from peer reviewed journals.

GRADING FORM: SMU GENERIC_SMOSEY

JESS EARDLEY

69.60

ENGAGEMENT WITH LITERATURE

including reading, referencing, academic conventions and academic honesty



"Inclusion of a wide range of research-informed literature, including sources retrieved independently.
Selection of relevant and credible sources. Very good use of referencing conventions, consistently applied."

6

KNOWLEDGE & UNDERSTANDING

Knowledge of the basic underlying concepts and principles of a subject.



Excellent knowledge and understanding of the main concepts and key theories. Clear awareness of challenges to established views and the limitations of the knowledge base.

21.6

COGNITIVE & INTELLECTUAL

Evaluate underlying concepts and principles of a subject and interpret qualitative and quantitative data in order to develop lines of argument and make sound judgements.



"Sound, logical, analytical thinking; synthesis and evaluation. Ability to devise and sustain persuasive arguments, and to review the reliability, validity and significance of evidence. Ability to communicate ideas and evidence accurately and convincingly. Sound, convincing conclusions / recommendations. The foundations of a very good analysis are here, a little more explanation would have got you a higher mark here.

20.4

PRACTICAL APPLICATION SKILLS

Different approaches to solving problems in particular contexts.



"An advanced application of a range of methods, materials, tools and/or techniques. The context of the application is well considered, with extensive use of relevant examples. Application and deployment extend beyond

14

established conventions. Innovation and creativity evident throughout.

TRANSFERABLE SKILLS

Communicate the results of their study/work accurately and reliably, and with structured and coherent arguments; the qualities needed for employment requiring the exercise of some personal responsibility within a structured and managed environment.



"Can communicate professionally and, confidently in a suitable format.

Can work professionally within a team, showing leadership skills as appropriate, managing conflict and meeting obligations.

Work is coherent, very fluent and is presented professionally.

"

7.6