

2219350 instrumentation and control

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Simulations of a closed loop control systems for angular positioning applied to CIWS

Abstract

In this report it covers the principles of design a control system to stabilize the angular positioning of system withing specific performance criteria. MATLAB with the Simulink add on was used for the for designing, simulation and analysis of the control systems. The results are tuned to be within a 2 second settling time and within 5% overshoot. This criterion sets the out the overall function of the control system. MATLAB is an industry standard for simulating many areas of engineering. The [Abstract - results](#) creates a more user-friendly environment by creating a graphical editor [function blocks](#). This software package is a powerful system for simulating dynamic systems.

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ACDB5011 – Instrumentation and control

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Introduction

A Control system on a basic level is something that controls or manages the behaviour of another device or system using loop controls [1]. This ranges from a thermostat regulating the house boiler to control the temperature to industrial control systems which control industrial machines/process. Control systems are all around us in everyday life. A control system can be mechanical and electrical. Control systems are significant for improving efficiency, safety and quality. Control systems keep yield high and defects low. Control systems also keep systems in safe operating conditions i.e temperature which can be missed due to human error. Control systems therefore are used across all manufacturing sectors and are a part of everyday life.

There are 2 types of systems, Open loop and closed loop [2]. Closed loop systems use the output to modify the control action in real time. This allows for the system to adapt to the current condition of the process. Closed systems are often used in automated settings and high precision scenarios. Open systems are based purely off the input and do not use the output to modify the control action. Open systems are often less expensive and less complex. In this report a Closed system was created due to the nature of the scenario.

Transfer functions [3] are mathematical models that describe the relationship between the input and the output. The Performance metrics for the simulations were Settling time, overshoot and stability. Settling time is duration for the system to reach and maintain a steady state after an input. Overshoot is the targeted percentage allowable deviation from the steady state. Stability is the ability of the system is maintaining the desired output by correctly responding to the varying input. A system with stability will have predictable responses and bounded outputs.

It is important to align the performance parameters with the system its being applied to as this can set limiters to systems performance. It is not feasible to heat a house up by 10Degrees c instantaneously due to capability of the boiler and the cost to the resident. Therefore, the system needs to be realistically applied to the real world. Other factors such as where the the temperature is being measured as this will affect the systems performance.

For the purposes of the system in this report it is applied to the CIWS (Close in weapon system) turret aiming system. This is naval mounted weapon systems used for close targets such as missiles, aircrafts and other small ships. The weapon system weighs 6120kg and shoots 3000 rounds [4] a minute. The control system in this report is used to control the aiming system. The real-world factors that should be accounted for in the control system is the weight of the weapon system and the targets its aiming for and the torque put into the ship.

The objective for this control system is to have a settling time of less than 2 seconds and an overshoot of less than 5%. This requires tuning the system to be within these parameters, getting both within the specification.

Simulation Setup

The transfer function of the CIWS turret is,

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

Where $a = 3$ $b = 6$ $c = 1$ based of the writer's student number plus 1.

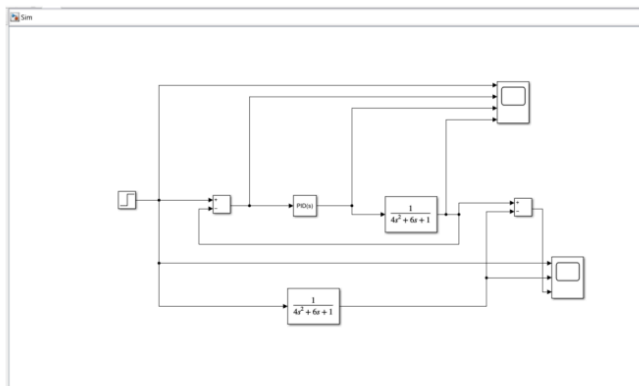


Figure 1 - model of control system

The Control system begins with a step function which allows for immediate plotting of the scalar input. Next is a subtract function used to subtract the inputs, this moves into the PID controller. This is how the system is tuned to get the performance parameter required. To do this the Proportion, integral, derivative and filter coefficients are set. The transfer function of the CIWS turret is next. This determines the relationship between the input and output

ultimately effecting the movement of the CIWS turret next. Finally, another subtract function. The scopes are used to measure the response at different stages of the system to allow for comparison.

PID Controller

To investigate a PID controller more closely, Pid controllers are one of the most commonly used control mechanism for feedback control [6]. PID Stands for Proportional-integral-derivative control which uses the 3 components to mitigate the error between the set point and the actual system output. PID use the compensator formula shown below.

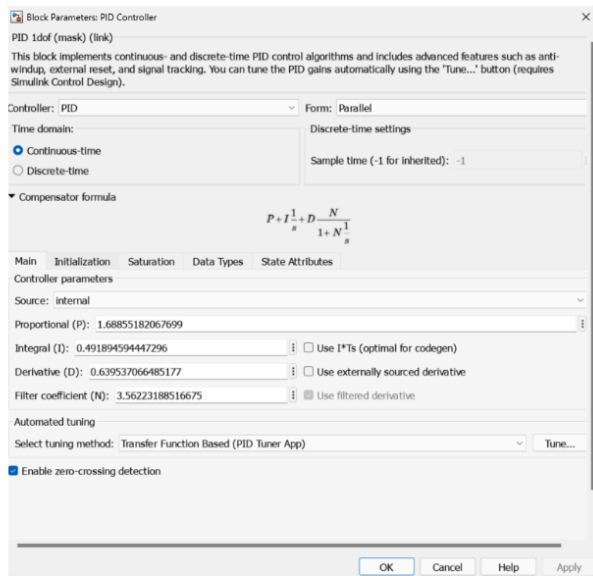


Figure 2 initial PID settings

Proportion [7] is directly proportional to the current error which reduces rise time and bring the system to the set point quicker however it can lead to overshooting and instability.

Integral accumulates the error over time which eliminates the steady state error increasing the systems accuracy to reaching the set point however it can lead to integral wind up causing overshoot and sluggish response.

The derivative reacts to the rate of change error causing the system to be able to predict future error to counter act rapid changes and reduce over shooting and dampens oscillations/ It can lead to sensitivity to noise in the error signal which can amplify high frequency disturbances.

Matlab has a built-in tool to tune the PID controller using algorithms allowing for easy use.

PID are simple to understand and implement and flexible due the ability to tune for speed, accuracy or stability. PID's are also effective on many types of systems.

PID controllers to be effect must be tuned, they are poor at controlling highly nonlinear systems and can be susceptible to noise.

Theoretical calculations

Using the initial data gained from the PID simulation and using the student number a forward path transfer function can be calculated Shown below

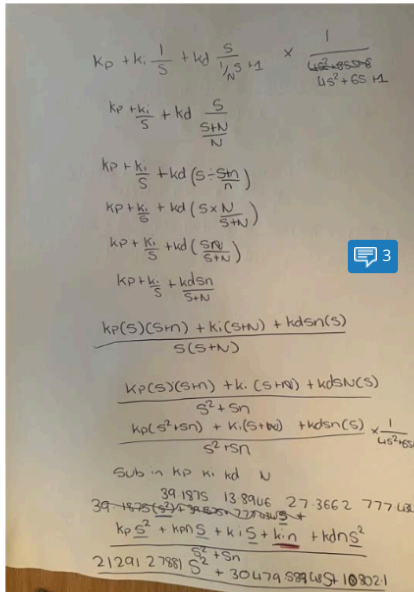


Figure 4 Maths 1 forward transfer

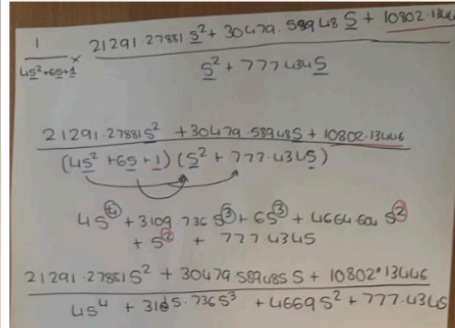


Figure 3 Maths 2 forward transfer function

Shown below removing the feedback loop the transfer function of the whole system can be calculated as whole using

$$TF = \frac{G}{1+GH} [5]$$

TF is the transfer function of the whole system and G is the forward path function calculated previously. H is the transfer function of the feed back loop which in the case is 1.

$$TF = \frac{\Theta}{1+GH}$$

$$= \frac{21291.278815 S^2 + 30479.589485 S + 10802.13446}{U S^4 + 3115.7365^3 + 4669 S^2 + 777.4345}$$

$$1 + \left(\frac{21291.278815 S^2 + 30479.589485 S + 10802.13446}{U S^4 + 3115.7365^3 + 4669 S^2 + 777.4345} \right) \times H \quad H=1$$

$$\text{Denom} \rightarrow U S^4 + 3115.7365^3 + 4669 S^2 + 777.4345 + 21291.278815^2$$

$$\frac{21291.278815 S^2 + 30479.589485 S + 10802.13446}{U S^4 + 3115.7365^3 + 4669 S^2 + 777.4345 + 21291.278815^2 + 30479.589485 S + 10802.13446}$$

$$\frac{454 + 3115.7365^3 + 25960.278815^2 + 38257.02395 + 10802.13446}{U S^4 + 3115.7365^3 + 4669 S^2 + 777.4345}$$

$$\frac{21291.278815 S^2 + 30479.589485 S + 10802.13446}{454 + 3115.7365^3 + 4669 S^2 + 777.4345} \times \frac{U S^4 + 3115.7365^3 + 4669 S^2 + 777.4345}{U S^4 + 3115.7365^3 + 4669 S^2 + 777.4345}$$

$$\frac{21291.278815 S^2 + 30479.589485 S + 10802.13446}{454 + 3115.7365^3 + 4669 S^2 + 777.4345}$$

Figure 5 maths 3 overall system function

$$\text{Num} \rightarrow (21291.278815^2 + 30479.589485 + 10802.13446)(U S^4 + 3115.7365^3 + 4669 S^2 + 777.4345)$$

$$U S^4 + 3115.7365^3 + 99062500.9 U S^2 + 23705000.4 + 10802.13446$$

$$\text{Denom} \rightarrow U S^4 + 3115.7365^3 + 4669 S^2 + 777.4345 + 21291.278815^2 + 38257.02395 + 10802.13446$$

$$165^3 + 124625^2 + 103341.153 S^6 + 153029.119 S^5 + 43203.53734 S^4$$

$$12462.946 S^7 + 9707313.277 S^6 + 909048025 S^5 + 11989823.2 S^4 + 3350004.64 S^3$$

$$18786 S^6 + 146253525 S^5 + 121883309 S^4 + 179616751 S^3 + 50710071 S^2$$

$$3109.78 S^4 + 20192186.0 S^3 + 2974.2262 S^2 + 839.7946 S S^3$$

$$\rightarrow 165^6 + 20924.57 + 9999999.933 S^6 + 953470379 S^5 + 241128630.3 S^4 + 233449841.7 S^3$$

$$29793003.2$$

$$N \rightarrow 8516 U S^6 + 66337105.2 S^5 + 9999999.933 S^4 + 953470379 S^3 + 241128630.3 S^2 + 233449841.7 S$$

$$121919 S^5 + 94966275.8 S^4 + 143101531 S^3 + 237800000 S^2$$

$$U S^4 + 3115.7365^3 + 4669 S^2 + 777.4345$$

$$\rightarrow 8516 U S^6 + 7852030 S^5 + 104994000 S^4 + 14663300 S^3 + 287769371.5 S^2 + 840173.75 S$$

$$165^3 + 20924.57 + 9999999.933 S^6 + 953470379 S^5 + 241128630.3 S^4 + 233449841.7 S^3 + 29793003.2$$

Figure 6 maths 4 overall system function

Simulation parameters

The simulation parameters are the simulation is run for 10 seconds and is samples every seconds. It the scope measures 4 points across the control system shown below. 1 after the step function. 2 after the subtract function. 3 after the PID controller and 4 after the function. These are highlighted on the diagram below [1]

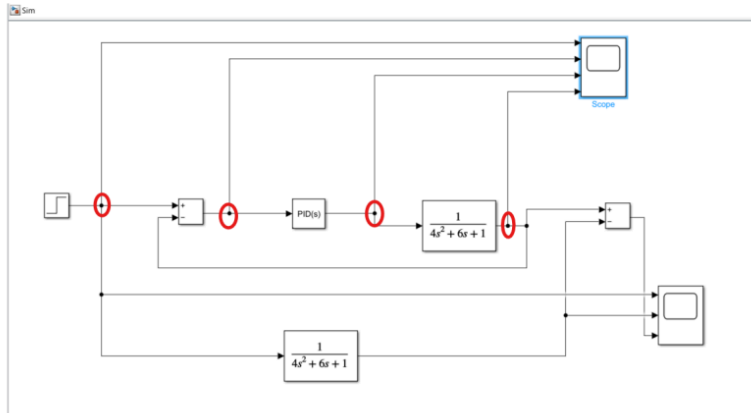


Figure 7 scope viewpoints

Results

Performance and Robustness		
	Tuned	Block
Rise time	0.321 seconds	4.38 seconds
Settling time	0.551 seconds	16.3 seconds
Overshoot	1.96 %	7.16 %
Peak	1.02	1.07
Gain margin	Inf dB @ Inf rad/s	Inf dB @ Inf rad/s
Phase margin	90 deg @ 6.8 rad/s	69 deg @ 0.34 rad/s
Closed-loop stability	Stable	Stable

Figure 8 - performance data

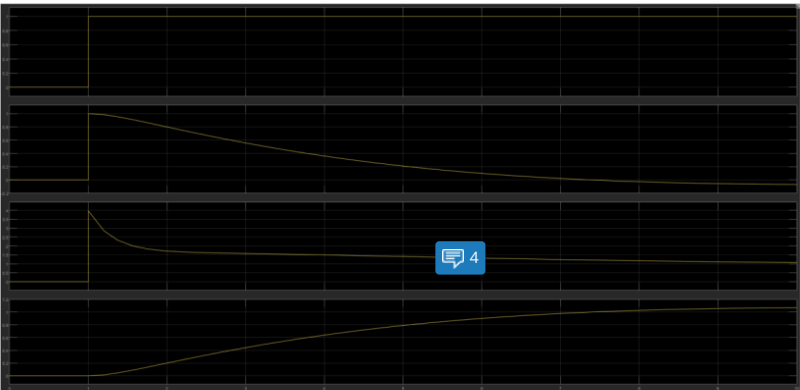


Figure 9 Scope results

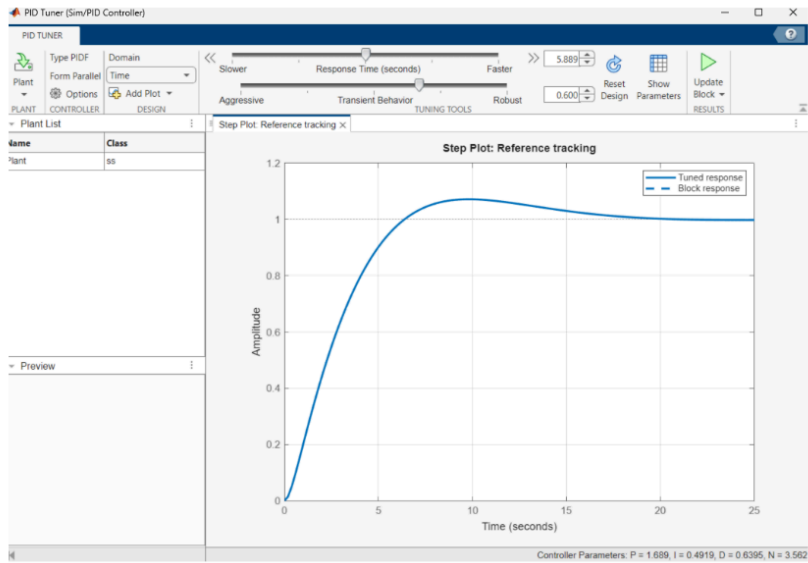


Figure 10 untuned results

The figure above is the untuned results of the control system, As can be seen it is stable system and with a relatively slow response time. It has a settle time of 16.3 seconds so therefore the PID needs to be tuned to cut this down to under 5 seconds. There is an overshoot of 7.16% which is too great for the CIWS application. It also has 6 second times to reach the set point.

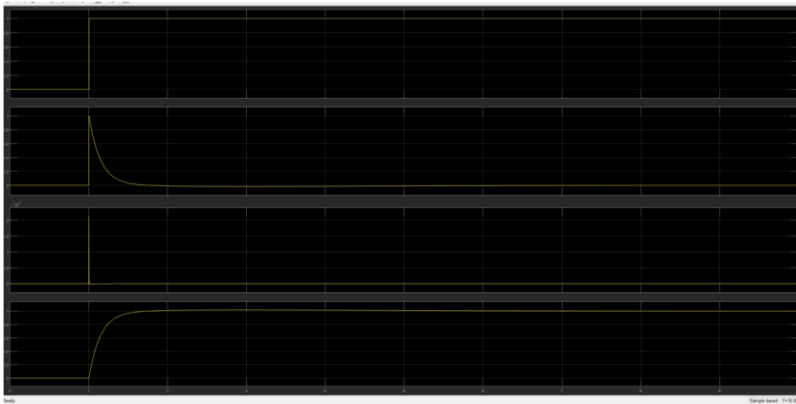


Figure 11 Tuned scope

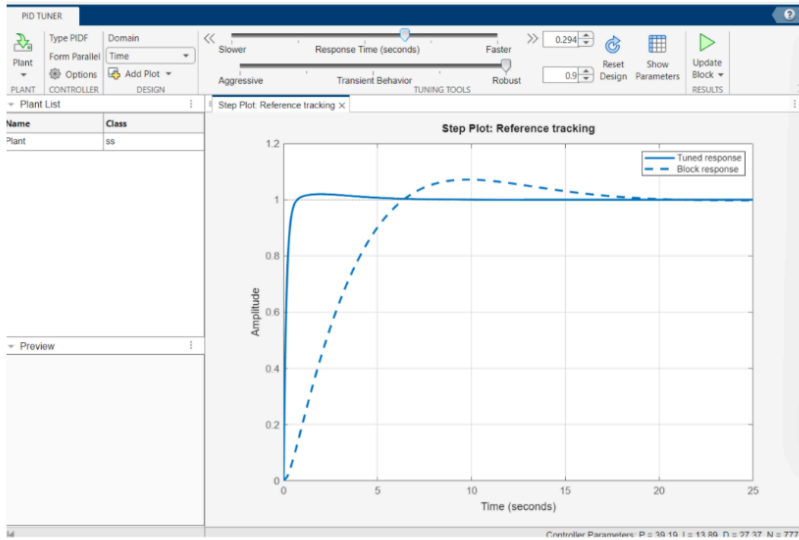


Figure 12 Tuned results comparison

As shown above the tuned PID [7] causes the system to be more efficient at controlling the system to the set point. To tune the PID the sliders at the top for Response time and transient behaviour are adjusted to get the desired parameters. Adjusting the transient behaviours refers to any behaviour that isn't constant. The settling time is now 0.551 seconds and only has an overshoot of 1.96%. By 6 seconds the system is at the set point constantly. This causes the system to be more accurate

Controller Parameters		
	Tuned	Block
P	39.1875	1.6886
I	13.8946	0.49189
D	27.3662	0.63954
N	777.434	3.5622

Figure 13 PID settings

Above it the differences in the PID settings between tuned and untuned P, I, D, N.

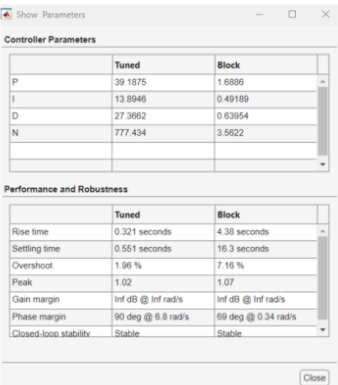


Figure 14 -simulation parameters

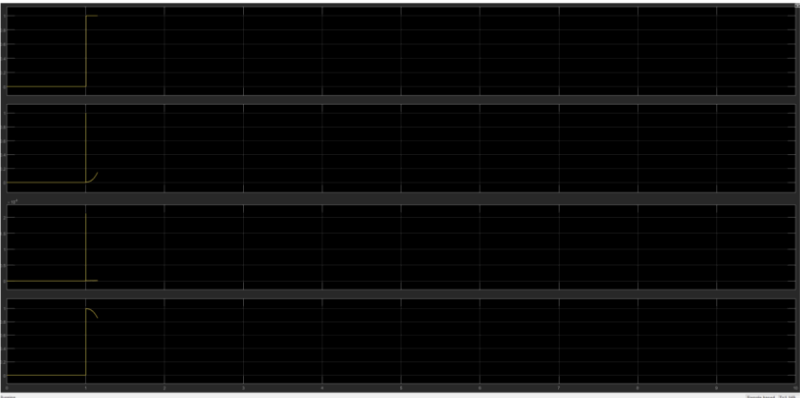


Figure 6 scope results

Using the calculations above and inputting these into the simulation created this graph. As can be seen the control system fails which indicates an error in the calculations. Due to the nature of these larger calculations human error could create issues. This means that this data can't be used in the simulation.

Discussion

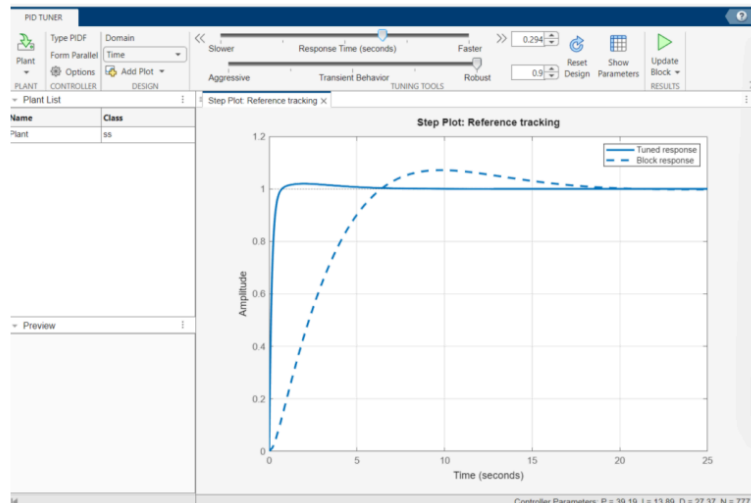


Figure 16 results

diagram above shows the untuned (Dotted) and tuned system response (Whole). The untuned response has a slower reaction taking 5.5 seconds longer to reach the set point. In the situation of the CIWS this would lead to the turret reaching the targeted point too late for a successful firing. The targets this weapon system aim is moving, and the turret must keep up. 5 seconds allows for a target an anti-ship missile (like trident) can travel almost 30km in those 5 seconds. The machine requires quick response but also great accuracy due to the small size of the target. Trident is 13.4m long and 2.11m wide [8]. This creates a small target area which means the weapon system is required to be accurate with little overshoot and little noise. The tuned simulation shows the settling time of 0.551 seconds and an overshoot of 1.96% which is drastically better then the initial system. Furthering this the system needs to be reliable and stable the system has a phase margin of 90 degrees [9] and a gain margin of infinite. The phase margin is a measure how stable a closed loop control system is [10]. The gain margin is how much a system can gain before becoming unstable. This demonstrates the stability of the system which is required as noise could cause the system to fire around the target and miss. The minimal overshoot prevents the turret moving past the target wasting time and energy. Without the tuning the system would not be suitable to the CIWS scenario due to the slow response time and inaccurate settling time which would cause the weapon systems to be a failure in combat.

When manually tuning the PID controller there are 2 settings to adjust, Response time between slower and faster and transient behaviour from aggressive to robust. These both are positive and negative effects on the system. Putting the response time faster decreases the time to initially reach the set point but will create a large overshoot which takes time to be

corrected. Setting transient behaviour to aggressive allows for the amplitude to oscillate above and below the set point.

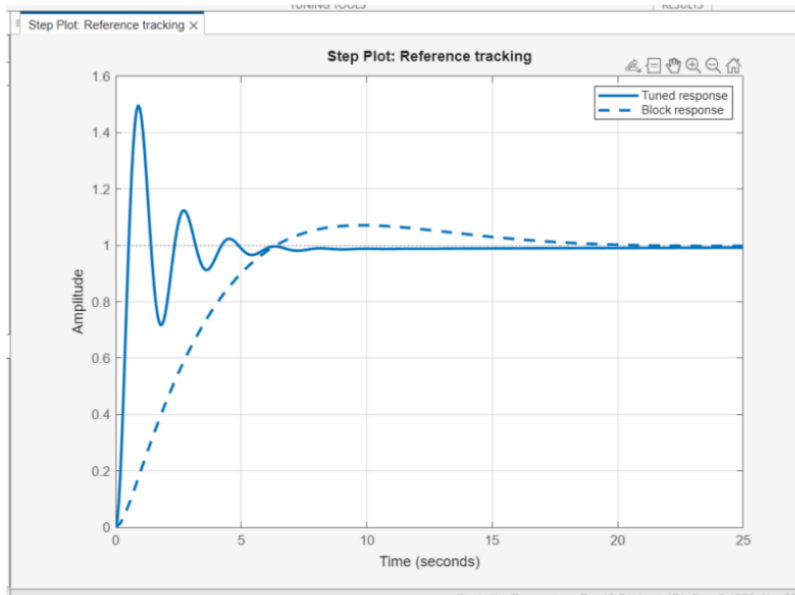


Figure 17 - oscillating results

Whilst setting it to robust stops the amplitude from oscillating but only gradually corrects to the set point. Both these variables need to be tuned together and carefully to get the characteristics required in the system.

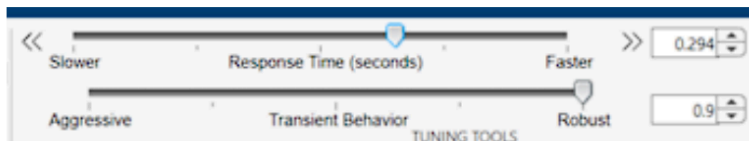


Figure 18 Tuning settings

The final tune of the response and the transient [11]behaviour ended up a very robust transient behaviour response and a marginally faster response time. This created the efficient settle time and small overshoot achieved. Increasing the response time any more negatively impacted the parameters significantly.

Conclusion

In another simulation the PID could be more tightly tuned to get the lowest possible parameters. The maths completed for the forward transfer function was incorrect. This meant the simulation can't be validated by the theoretical calculations. 8

In the report it was found that the simulation showed to successfully create as closed loop control system to control the angular positioning of a CIWS turret. The data isn't able to be validated through theoretical calculations. Therefore, there is no validation to these results. The results are entirely dependent on the accuracy of the simulation. Adding simulated noise and other negative factors into the simulation and assessing how the system responds would allow for more accurate simulation as talked about below.

Some variables the simulation won't account for is motor responses in the movement of the turret and tracking processing time. These will both effect the overall system response. The firing of the turret will introduce noise into the tracking the systems which the system will have to mitigate. This Means the ideal simulated response won't necessarily be the most practical in the real world. The simulation will simulate the ideal condition of the system compared to the real system which won't be running in ideal conditions. 9

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PAGE 1

QM

Abstract - results

Good abstract, although you should include a statement of your results.

PAGE 2

QM

Sp.

Spelling error

QM

Sp.

Spelling error



Comment 1

two, not 2.

For numbers up to 10, it is common to write the number in words (where it isn't the result of some calculation you've done)

PAGE 3



Comment 2

The subtract block actually calculates the angular position error of the system by subtracting the current position (system output) from the desired position (set point input).

PAGE 4

PAGE 5



Comment 3

Any equations should be written using the equation editor in word. including them as photographs looks unprofessional

PAGE 6

PAGE 7

**Comment 4**

What do each of the data series relate to? you should say in the caption.

Figure 9, Scope results. T to B: Step input, Error signal,... etc.

**Comment 5**

Use the figure number. Tell the reader what to look at, you have lots of figures above, which one?

**Comment 6**

Why include failed results? This makes no sense.

**Comment 7**

No pole zero diagrams to prove stability.

**Comment 8**

Why was it incorrect? You should have gone over it until you managed to get it right,

**Comment 9**

But this will introduce a difference between output and setpoint, which the controller will try to remove automatically.

**Comment 10**

This is not a reference list. It is a list of figures.

**Comment 11**

This IS a list of references, not a bibliography.

**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.

**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.

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Ref Qual

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57

ENGAGEMENT WITH LITERATURE

including reading, referencing, academic conventions and academic honesty



A comprehensive range of research informed literature embedded in the work. Excellent selection of relevant and credible sources. High-level referencing skills, consistently applied

7

KNOWLEDGE & UNDERSTANDING

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



Knowledge is extensive. Exhibits understanding of the breadth and depth of established views.

19.5

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.



Evidence of some logical, analytical thinking and synthesis. Can analyse new and/or abstract data and situations without guidance. An emerging

15

awareness of different stances and ability to use evidence to support the argument.
Valid conclusions and recommendations, where relevant

Including pole-zero or nyquist plots to prove stability would have increased your marks here.

PRACTICAL APPLICATION SKILLS

Different approaches to solving problems in particular contexts.



"A good and appropriate application of standard methods, materials, tools and/or techniques.
Good appreciation of the context of the application, with some use of examples, where relevant.

10

a little more perseverance in the fault-finding your maths would have given you a better mark here as your simulations would have worked.

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 effectively in a suitable format, but may have minor errors.
Mostly coherent work and is in a suitable structure.

5.5

"