

ACDB5011 CW

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Submission date: 16-Dec-2024 01:58AM (UTC+0000)

Submission ID: 246241357

File name: 42302_Quinn_Dunbar_ACDB5011_CW_628421_973191181.docx (210.19K)

Word count: 1622

Character count: 8679

A basic control system for a Close In Weapons System

ACDB5011

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2217666

Abstract

Abstract - results

A Close-in Weapon System, such as the Phalanx, must be able to move quickly in order to eliminate incoming threats such as missiles. To do this it must be able to acquire fast-moving targets automatically using information from its pair of radars. By examining one portion of this control system, the rotational controller, it is possible to determine the characteristics of the control system. Utilising a proportional, integral, derivative controller, the control system is tuned to allow for a response time below two seconds, and an overshoot of less than five percent. Consideration is also taken to eliminate oscillations in the turret motion, as these can cause both damage and an unstable system, reducing the weapon's effectiveness. It is also possible to reduce the control system to a single transfer function, in order to conduct stability analysis, and hence demonstrate the system is stable and will not get caught in unstable configurations.

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Introduction

A Close In Weapons System (CIWS) is a, primarily naval, defensive weapon used to intercept incoming missiles. It is an automated system consisting of a Gatling gun, search and firing radars and fire control-computers mounted in an automated turret with two degrees of rotational freedom for aiming the weapon [1]. Due to the speed and proximity of targets engaged by a CIWS, the system must be able to get on-target quickly.

The speed a CIWS can get on target is controlled by a number of factors, such as the velocity and lag of the motors used in the system, and the processing speed of the computer in acquiring a lock. The control system must take all of these factors into account. The control system does this by use of a transfer function, which is a mathematical simplification of the relation between the input into the system and the associated output [2]. The Phalanx [3] (the most-common CIWS) utilises a closed-loop control system, which applies a corrective factor to the aiming calculations based on the trajectory of the previously fired round [3].

This report examines an arbitrary transfer function and closed-loop control system to simulate a CIWS, this is based on the fact the Phalanx aiming system operates as a linear control system [5]. The system is then tuned to meet requirements deemed necessary for the rotational speed and accuracy of a CIWS turret's rotation.

Simulation

The system was simulated using MATLAB SimuLink software [6]. The following transfer function, $G(s)$, was used to represent the CIWS (eqn. 1).

$$G(s) = \frac{1}{7s^2 + 7s + 7}$$

Eqn. 1 – the transfer function representing the CIWS

The closed feedback loop is represented by the following block diagram (fig. 1). The input for this system is a step-function, with this representing the angle information passed to the attitude controller from the targeting radar. Closed-loop feedback is provided by an error signal, which is the signal produced by the output of the transfer function. A minus comparator alters the input that enters the PID controller, which then results in an altered output.

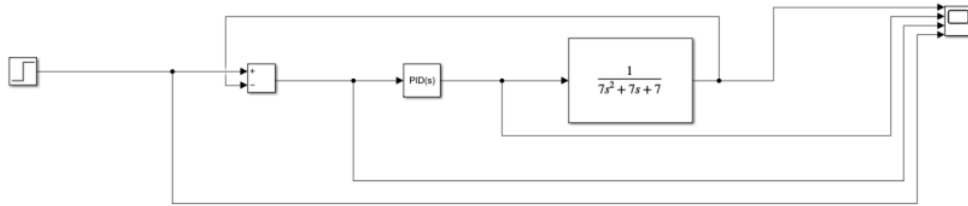


Figure 1 - Block diagram of control system

The requirements of the control system are; a settling time of under two seconds, and an overshoot of less than five percent. In the context of a CIWS, the settling time represents the time to get the gun on-target, and the overshoot represents the rotation beyond the required location. A proportional integral derivative (PID) controller is used to process error signal (any gun bias or other cause of the round trajectory being different from the optimal solution), and the values of the three components in the controller determine both the overshoot and settling time. A balance must be struck between these two factors, as a faster settling time will result in a greater overshoot and oscillations until the desired angle is reached. In the case of the CIWS, a large overshoot and oscillations poses safety and mechanical issues, as the system is part of an active ship so unpredictable movements will pose a hazard to the crew, and the rapid and violent acceleration associated with the oscillations will result in additional wear to the components.

Using the tuning tool in Simulink, the following coefficients were found. $P = 185.587923779309$, $I = 86.6417309159221$, $D = 92.3298636687879$ and $N = 1522.75546441253$, with the controller's transfer function, $C(s)$ given by equation 2.. This resulted in a settling time of 1.5 seconds and an overshoot of 4.5 percent, as show in fig. 2 below. These coefficients also produced no oscillation, and a gentle ramp to the target value, reducing acceleration and jerk of the turret.

$$C(s) = 185.587923779309 + \frac{86.6417309159221}{s} + \frac{92.3298636687879 s}{1522.75546441253 s + 1}$$

Eqn. 2 – the transfer function representing the PID controller

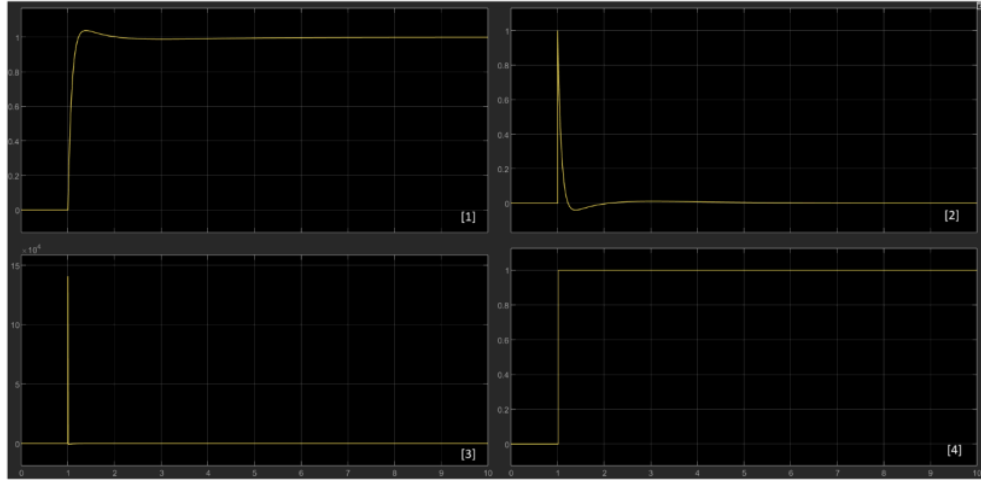


Figure 2 - Oscilloscope readout of control system signals

[1] – system output, [2] – PID controller output, [3] – comparator output, [4] – step input

As this system is only part of a larger control system for the CIWS, it is necessary to simplify the system representation, so the entire system can be efficiently computed. This can be achieved by reducing the entire system to a single transfer function. The composite forward transfer function is given by $G'(s) = G(s)C(s)$. For this system the composite transfer function $G'(s)$ is given in equation 3.

$$G'(s) = \frac{20111.627479s^2 + 40384.523828s + 18847.738457}{s^4 + 1523.7554644s^3 + 1523.7554644s^2 + 1522.7554644s}$$

Eqn. 3 – the composite forward transfer function

To include the error signal and comparator in a single transfer function, the overall transfer function, TF, is given by equation 4. H represents the transfer function of the feedback loop, as there are no calculations performed on the error signal between the output and the comparator, $H = 1$. Equation 5 gives the overall transfer function for the entire system.

$$TF = \frac{G'(s)}{1 + HG'(s)}$$

Eqn. 4 – formula for overall transfer function

$$TF = \frac{20111.627479 s^2 + 40384.523828 s + 18847.738457}{s^4 + 1523.7554644 s^3 + 21635.382944 s^2 + 41907.279292 s + 18847.738457}$$

This transfer function can be shown as equivalent by using a minus comparator between the output of the original system and the output of the new system, with a combined output of zero showing that their behaviours match (fig. 3).

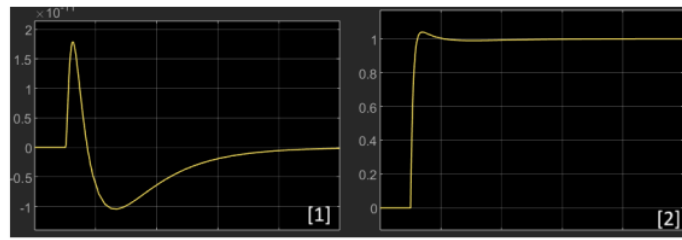


Figure 3 - TF oscilloscope outputs

[1] output of comparator, signal is noise only, as indicated by scale of 10^{-11} , [2] – TF output, identical to output [1], fig. 2.

Results and discussion

Once the system has met the response requirements, it is necessary to determine the stability of the system over a range of inputs. This can be done graphically through a pole-zero plot. Pole-zero plots map the behaviour of the system in the complex frequency plane (S-plane). Root are areas where the overall gain approaches zero, and poles are areas where the gain approaches infinity [7]. Both of these present problems for the system, as it is impossible to reach configurations that are represented by poles, due to requiring infinite gain, and the system can get stuck in configurations represented by zeros, as the gain of the function falls to zero. The pole-zero plots for this system (fig. 4) show it to be stable, as both the poles (represented by crosses) and the zeroes (represented by circles) lie on zeroes of the graphs, so are effectively cancelled out by this.

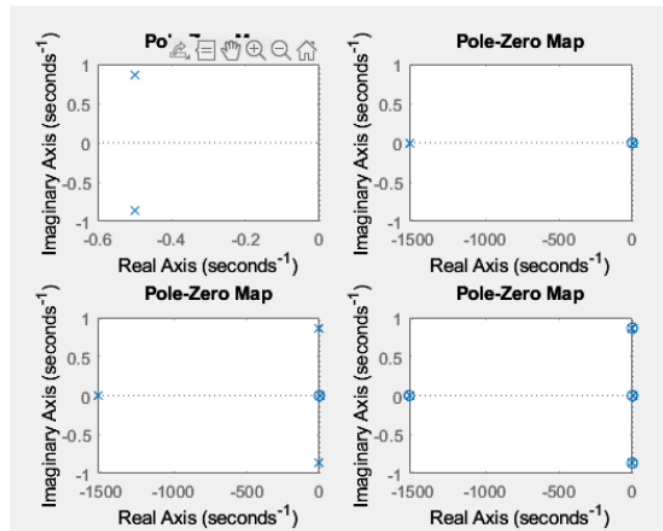


Figure 4 - Pole-zero plots for $G'(s)$ and TF

Another method of analysing system stability is through a root locus plot, that shows the range of variable feedback loop gain of a system [8]. In a system with variable loop gain, the resulting graph forms a locus of stable gain values across the S plane. As the simulated system has no feedback loop gain, as H , the feedback transfer function, is one. Hence the root locus diagram consists of a flat line. As there is no area bounded by this plot, the system is stable.

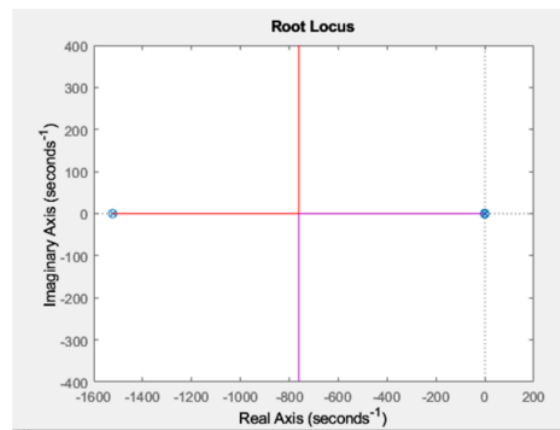


Figure 5- Root locus diagram for simulated system

Conclusion

This report covers the basic principles required to design a control system for a CIWS. The system developed simulates a rotational controller that is fed information from a targeting radar and must adjust the angle of the gun to line up with the incoming target. By using a closed-feedback loop into a PID controller, it was possible for the system to get on-target in the required time with no oscillations. As the system discussed is only a subsystem for the CIWS as a whole, reducing it to a single transfer function allows for both more efficient computation when considering the entire control system and signal path, but also allows for stability analysis of the designed system. As the system is relatively simple, and the poles and zeros, lie on the axes (i.e. at zero values) on the graphs, it is possible to demonstrate that the system as designed will not enter any failure states and be unable to function correctly as it lacks inherent instability.

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Appendix A – Calculation of overall transfer function, TF

FINAL GRADE

GENERAL COMMENTS

78/100

PAGE 1

PAGE 2



Abstract - results

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

PAGE 3

PAGE 4

PAGE 5



Comment 1

In this case, the error signal is the difference between the desired and actual azimuth angles.

PAGE 6



Comment 2

This shouldn't be the same as the forward transfer function.

PAGE 7

PAGE 8

PAGE 9

PAGE 10

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QUINN DUNBAR

78

ENGAGEMENT WITH LITERATURE*including reading, referencing, academic conventions and academic honesty*

Outstanding knowledge of research-informed literature embedded in the work. Outstanding selection of relevant and credible sources. High-level referencing skills consistently and professionally applied.

8.5

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.

22.5

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.



"Exceptional work; judiciously selected and evaluated evidence. Very high quality analysis, developed independently or through effective collaboration.
Ability to investigate contradictory information and identify reasons for contradictions.
Highly persuasive conclusions
"

24

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 established conventions. Innovation and creativity evident throughout.
"

15

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 with an exceptionally high level of professionalism.

Can work exceptionally well and professionally within a team, showing advanced leadership skills.

Work is exceptionally coherent, very fluent and is presented professionally.

"