The University of Windsor

ELEC3240: Control Systems I

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Final Project

Control of Antenna Azimuth Position Control System

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Emmanuel Mati

UWin ID: mati1

Student Number:104418019

Contents

Pretext & Definitions

When the PID controller is referred to as un-tuned, this means it is tuned with the default Zeigler-Nichols (method two) tuning rules table. When referring to the tuned or fine-tuned PID controller, this means that the PID controller has been tuned with custom parameters through trial and error to improve tracking, overshoot, etc. The unit-step input was set to have an initial value of 1.

Untuned PID: Zeigler-Nichols (method two) tuning rules table for Kp, Ti, and Td

Tuned/Fine-Tuned PID: Custom parameters for Kp, Ti and Td

Response: Refers to the output of the Antenna's Azimuth control system

Abstract

This project aims to develop a system used for controlling an antenna's azimuth position through a unit-ramp input. To do this, a block diagram is designed with a set of given requirements such as two potentiometers, a single power amplifier, a single motor, etc. Configuration parameters and design specifications are pre-defined and used for calculating the system's transfer functions. Once the system's transfer functions are synthesized, a PID controller must be added to control the antenna's output for a unit-ramp input. The PID is tuned to improve performance for its transient process, stability, and signal tracking. With the help of Zeigler-Nichols's rule (Co, 2004) and through trial and error, suitable parameters can be found to tune the antenna's PID controller. Tuning the PID is done using a unit-step input which helps in deciding the Kp, Ti, and Td parameters. The system's design is generated using Simulink. Graphs of the output response are obtained and presented using Simulink's scoping feature.

Introduction

Antenna azimuth position controls require very precise movement-controls to function properly. Antenna's need to communicate with very small moving objects in space (Woodford, 2008) such as satellites and thus, accurate controls are essential. One way to achieve precise azimuth control is through using a PID controller.

Throughout this project report, a PID will be implemented as an antenna's controller to ensure input controls have the proper corresponding output. To properly design the PID controller, Zeigler-Nichols tuning rules (second method) are used until the desired response is generated. This only acts as a starting point for tuning the Antenna's PID controls. Through test trials, new values for Kp, Ti, and Td are calculated to make sure the input response has the same output response. If Zeigler-Nichols tuning rules are used without fine-tuning, it will be impossible to ensure precise controls for the antenna whenever an input signal is applied. Poor tuning will result in unreliable tracking performance; poor performance will negatively affect the antenna's azimuth controls. Figure 1 shows the Antenna's layout and general design.

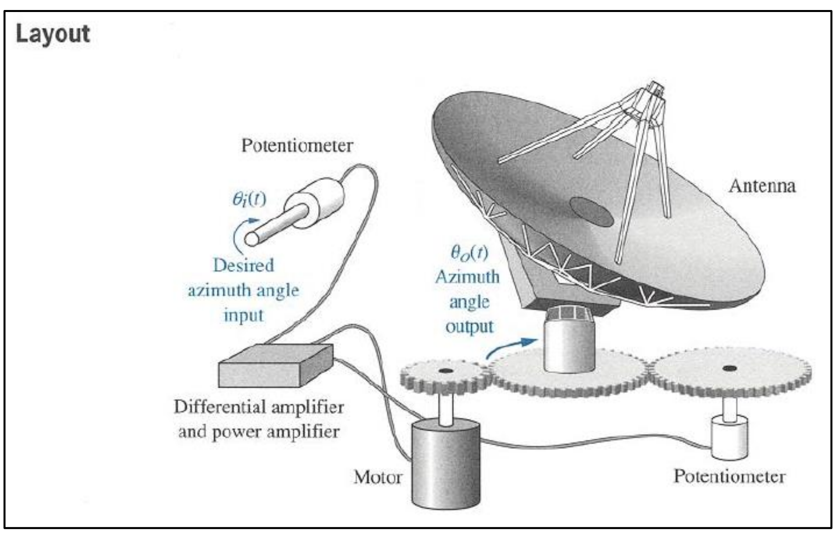

Figure 1 Antenna Layout

Methodology

1) Components in the antenna's layout need to be transferred to a schematic layout. Fortunately, this was already given and can be seen below in figure 2.

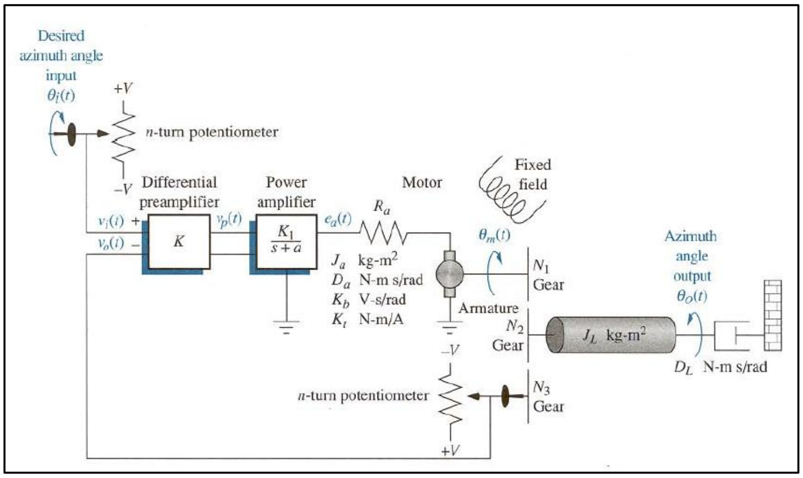

Figure 2 Antenna schematic design

2) From the schematic layout, key components' transfer function can be deduced and used when building the antenna's block diagram. Component transfer functions have already been given and are as follows:

$$\boxed{\frac{V_i(s)}{\theta_i(s)} = \frac{10}{10\pi} = \frac{1}{\pi}}$$

Equation 1 Potentiometer

$$\boxed{\frac{V_p(s)}{V_e(s)} = K, \quad K = 1 \sim 10}$$

*Equation 2 Preamplifier**

**Note: throughout this project, K is left at a constant 1*

$$\boxed{\frac{E_a(s)}{V_p(s)} = \frac{100}{s+100}}$$

Equation 3 Power Amplifier

$$\boxed{\frac{\theta_m(s)}{E_a(s)} = \frac{K_t/(R_a J_m)}{s\left[s + \frac{1}{J_m}\left(D_m + \frac{K_t K_b}{R_a}\right)\right]}}$$

Equation 4 Motor and Load

$$\boxed{J_m = J_a + J_L\left(\frac{25}{250}\right)^2}$$

Equation 5 Motor Inertia

$$\boxed{D_m = D_a + D_L\left(\frac{25}{250}\right)^2}$$

Equation 6 Viscous Damping

$$\boxed{\frac{\theta_o(s)}{E_a(s)} = 0.1\frac{\theta_m(s)}{E_a(s)}}$$

Equation 7 Gear ratio relative to load-displacement and armature voltage

3) Using these equations, every component's transfer function can be synthesized. It is important to note that the motor load transfer function still needs to be solved. To do this, configuration 1 parameters must be used in combination with the above equations. Figure 3 contains the provided project parameters required to build the control system.

Schematic Parameters

Parameter	Configuration 1
V	10
n	10
K	—
K_1	100
a	100
R_a	8
J_a	0.02
D_a	0.01
K_b	0.5
K_t	0.5
N_1	25
N_2	250
N_3	250
J_L	1
D_L	1

Figure 3 Schematic parameters requirements

With the provided schematic configuration parameters, Jm and Dm can be solved. With Jm and Dm, the motor and load transfer function can be calculated which paves the way for solving the gear relation relative to load-displacement and armature voltage. The gear relation relative to load-displacement and armature voltage acts as part of the plant in the system. Calculations to solve this are provided below in figure 4.

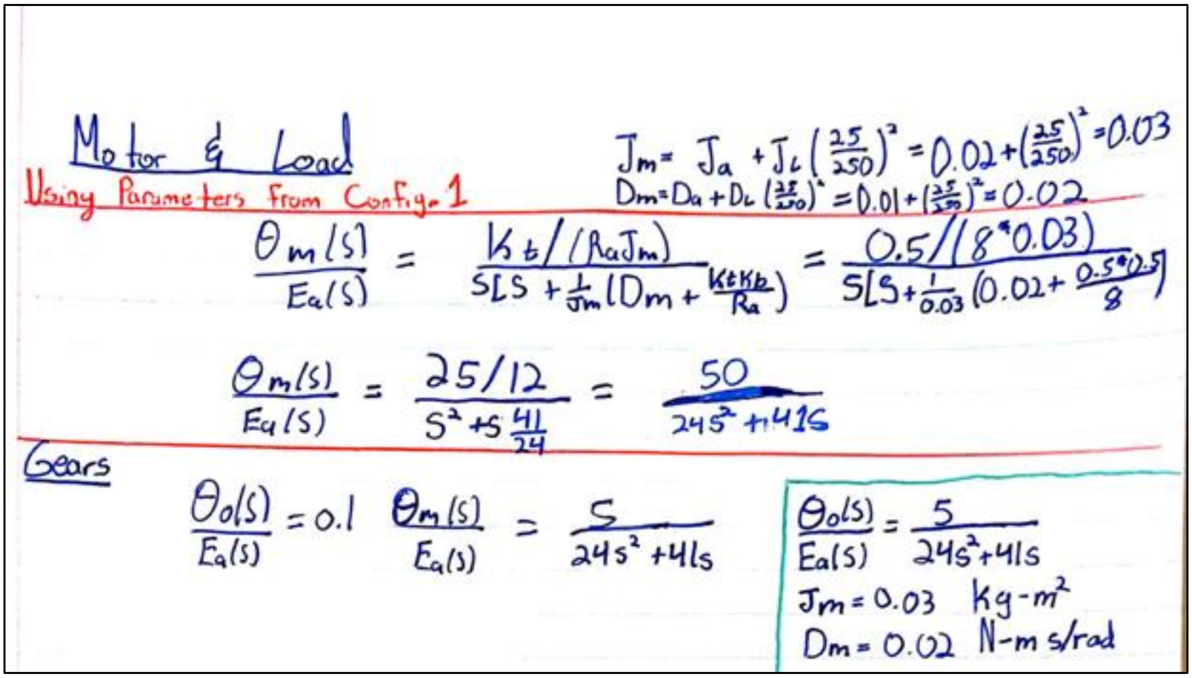

Figure 4 Calculations used in finding the gear ratio relative to load-displacement and armature voltage

4) After step 3, all transfer functions for the antenna's components (minus the PID) have been obtained. Now, the antenna's block diagram **without a controller** can be created in Simulink. The components in question are the potentiometers connected to the input and feedback, the preamplifier that is set to 1, a power amplifier, and lastly the gear ratio relative to load-displacement and armature voltage.

5) After the block-diagram is designed, PID controls need to be added to improve the performance of the system. This is done using Ziegler-Nichols's Tuning Rule-II (Co, 2004). A P-control is added to the system between the preamplifier and the power amplifier, and test values are used for the Kp parameter until oscillation is achieved for a unit-step input. This can be observed by adding a scope to the system's output. Once the output begins to oscillate, the critical period between oscillations is taken as Pcr.

6) With the Pcr calculated, the Kcr value for the system is taken as the Kp that reached oscillation of the output. Obtaining the Pcr and Kcr allows the project to move forward into the PID design phase. This is done by using the table given below as a guide for setting initial PID parameters Kp, Ti, and Td.

Table 1 Ziegler-Nichols Tuning Rule-II

Type of Controller	K_p	T_i	T_d
P	$0.5K_{cr}$	∞	0
PI	$0.45K_{cr}$	$\frac{1}{1.2}P_{cr}$	0
PID	$0.6K_{cr}$	$0.5P_{cr}$	$0.125P_{cr}$

7) When the table's parameters are found, the PID controller can be constructed. The figure below shows a general PID design; the parameters inside of the PID can be adjusted and fine-tuned as needed.

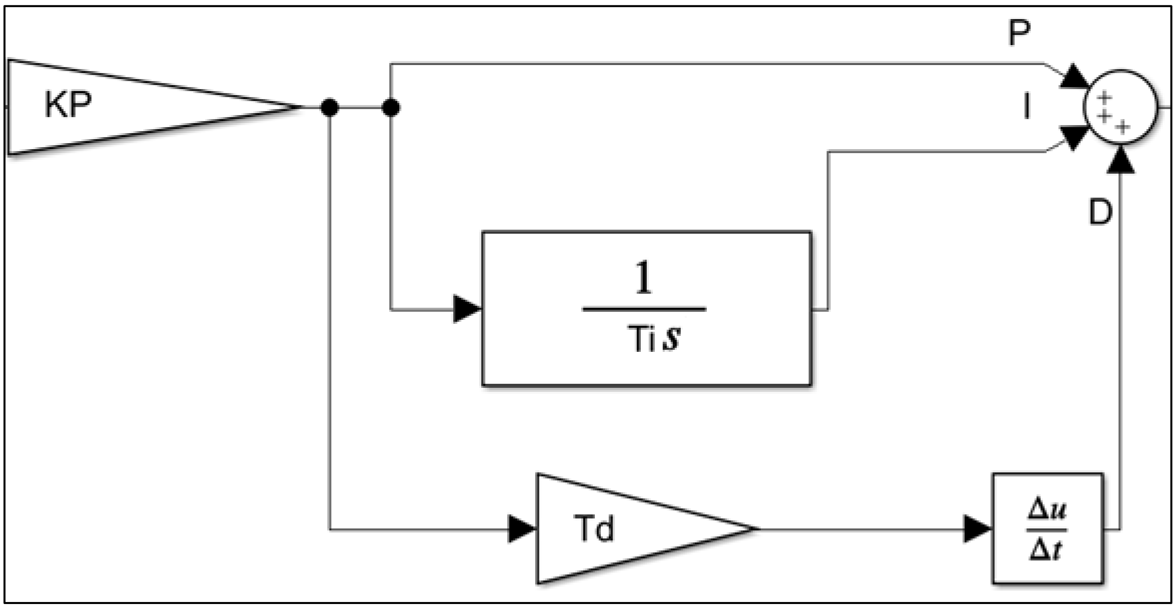

Figure 5 PID Control Design

8) Finally, adjust the PID's Kp, Ti, and Td parameters until near perfect unit-step tracking is achieved. Connect a ramp-step input to the antenna design with and without the PID controller to observe the tracking performance.

Results

Phase 1: Block Diagram Design

Using the transfer function equations, the antenna's block-diagram without controls was created

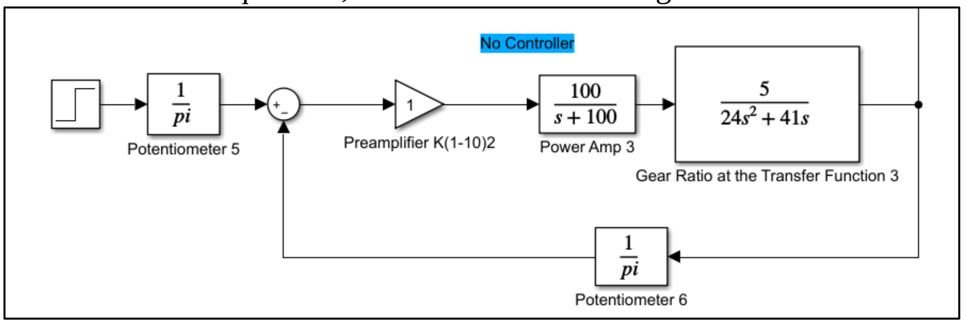

Figure 6 Block diagram achieved without the PID controller

Phase 2: P-Controller used in finding Kp

Adding a P-Controller and adjusting Kp until oscillation is reached, produced the following graph which was used for calculating the critical period, Pcr.

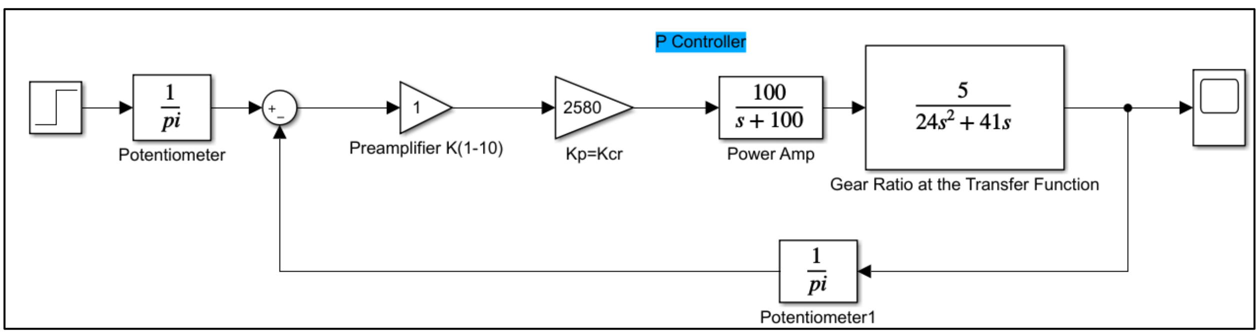

Figure 7 Block Diagram of the Antenna system without PID control

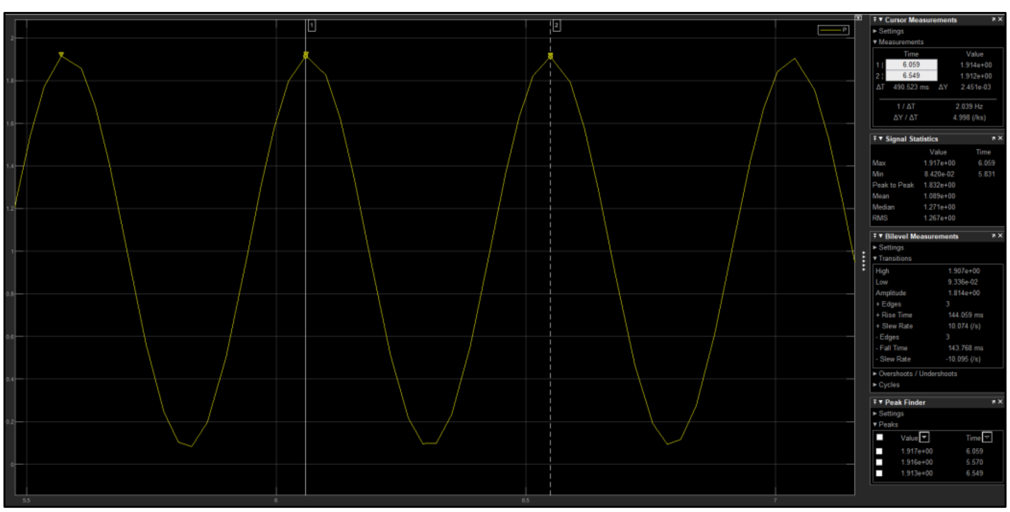

Figure 8 Antenna's Response when P control is applied to find Critical Period Pcr

Phase 3: Ziegler-Nichols table calculations and PID Implementation

From the plot's critical period and the block diagram's Kp value above, the Kcr and Pcr values were obtained. Ziegler-Nichols's Tuning Rule-II table could now be applied to provide initial tuning for the PID's controls as seen below.

Table 2 Values Used to Calculate Kp, Ti, and Td for PID controller

Pcr:	0.49			
Kcr:	2580			
	Type of Controller	**Kp**	**Ti**	**Td**
	P	0.5*Kcr=1290	infinity	0
	PI	0.45*Kcr=1161	Pcr/1.2=0.408333	0
	PID	0.6*Kcr=1548	0.5*Pcr=0.245	0.125*Pcr=0.06125

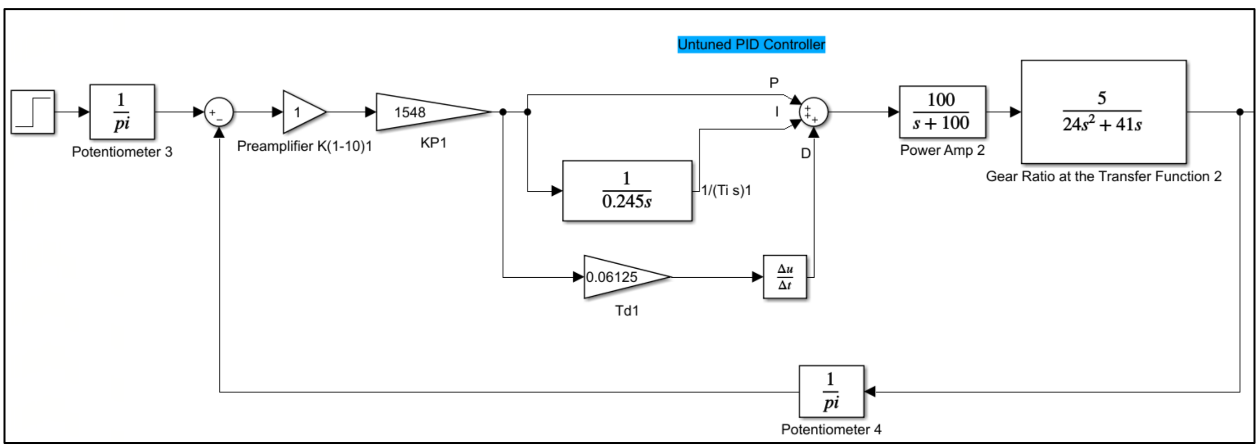

Figure 9 Ziegler-Nichols Tuning Rule (Second Method) Design

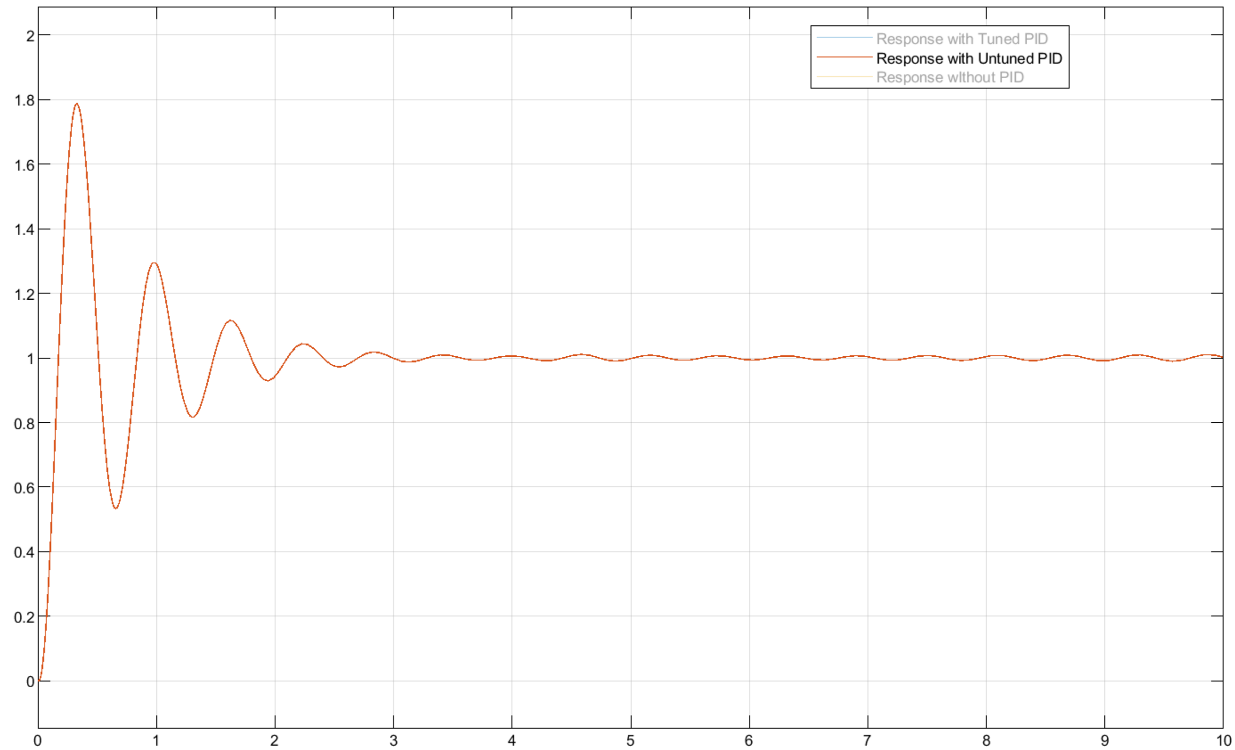

Figure 10 Output of figure 8; untuned PID

Although the response started looking like a unit-step input, further tuning was required to improve on the overall tracking so that it could better match the unit-step input. The unit-step input was set to initially start at 1 instead of the default 0 in Simulink.

Phase 4: Tuning PID via Test Trials

After performing multiple test-trials the following tuned PID controller seen in the top of the figure below was found to improve on the system's overall performance.

The new tuned values are as follows: **Kp = 10 000**, **Ti = 8.5**, and **Td = 0.053**

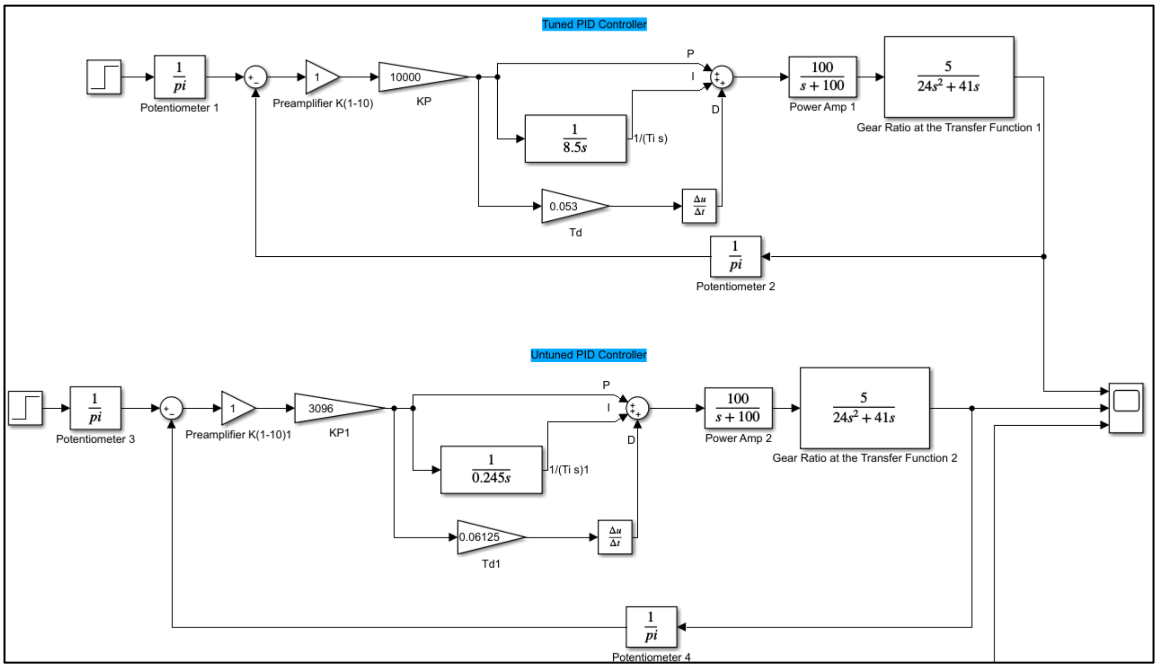

Figure 11 PID controls tuned to Kp = 10 000, Ti =8.5, and Td = 0.053 to improve output response

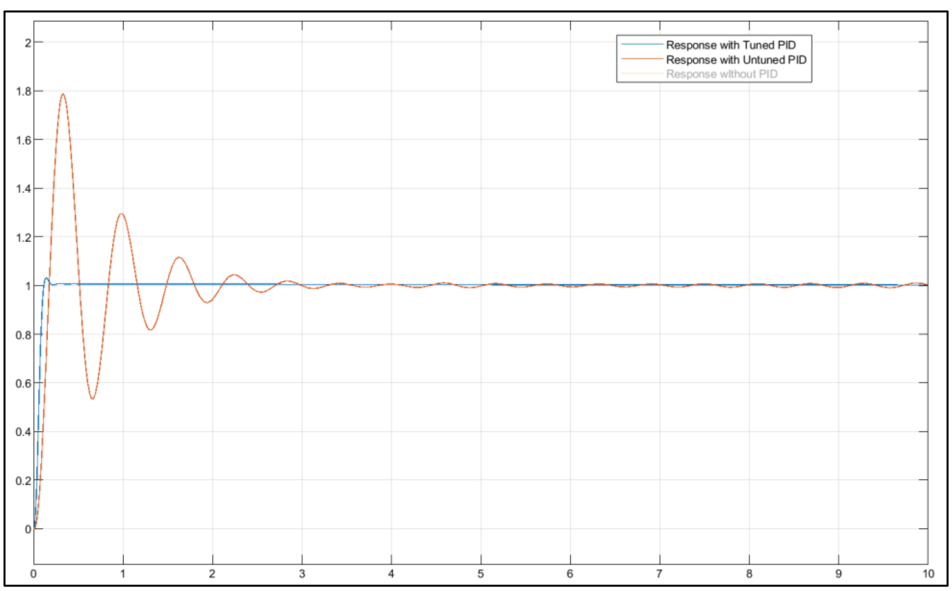

Figure 12 Output Response

Notice in figure 12 that the response has improved quite a lot in comparison to its original output. The new response obtained is very suitable considering it closely mimics that of the unit-step input. Below are the characteristics of the **tuned** and **untuned** PID controller. Observe the massive improvements made regarding overshoot and undershoot. Further improvements can be seen in the rise-time; the untuned PID already had a good rise-time but the tuned PID controller further improved on it with a time of 67 milliseconds.

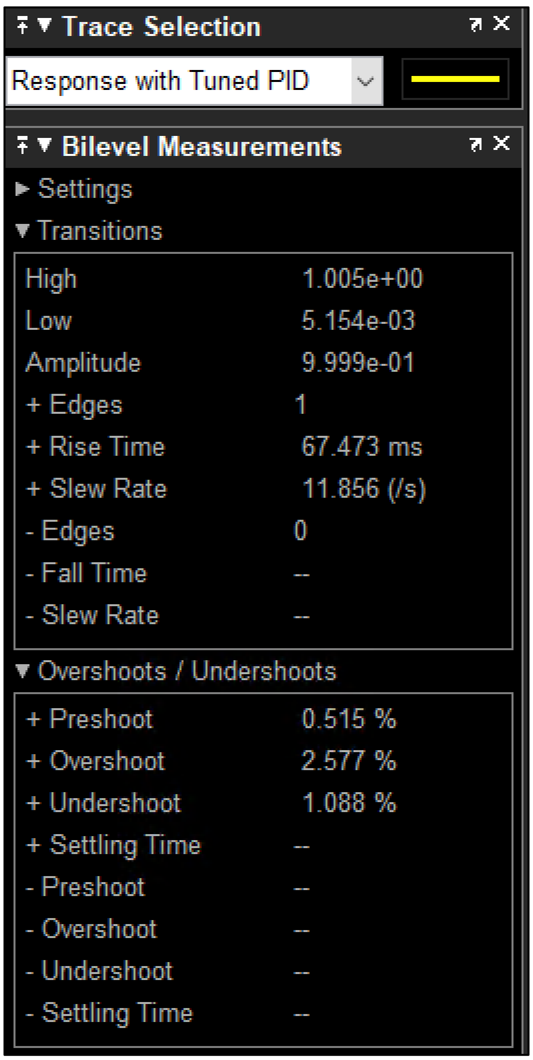

Figure 13 Characteristics of Tuned PID

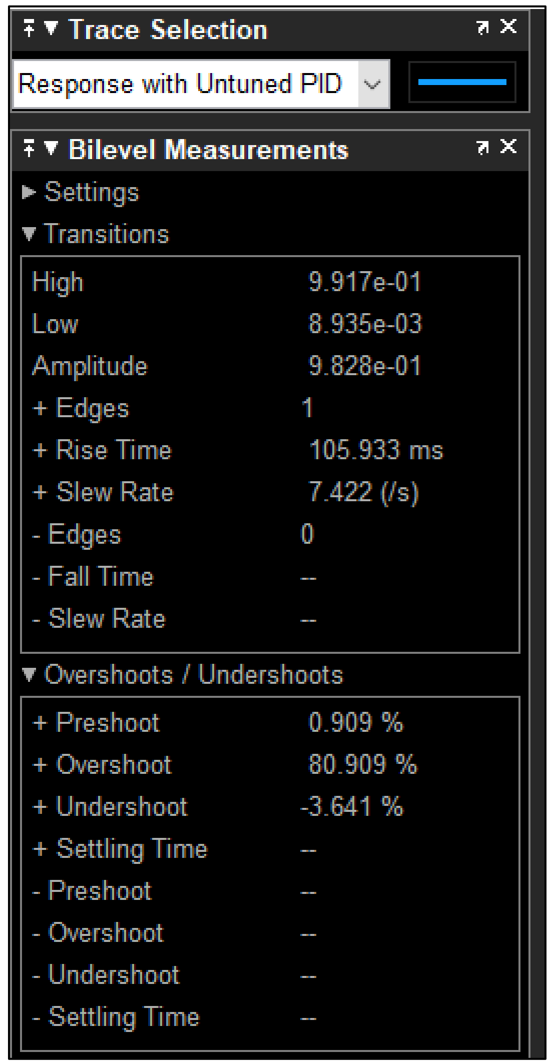

Figure 14 Characteristics of Untuned PID

Phase 5: Applying Unit-Ramp input and comparing PID performances

Now that tuned Kp, Ti, and Td parameters have been achieved for the PID controls, the antenna can be tested for its unit-ramp input response seen below.

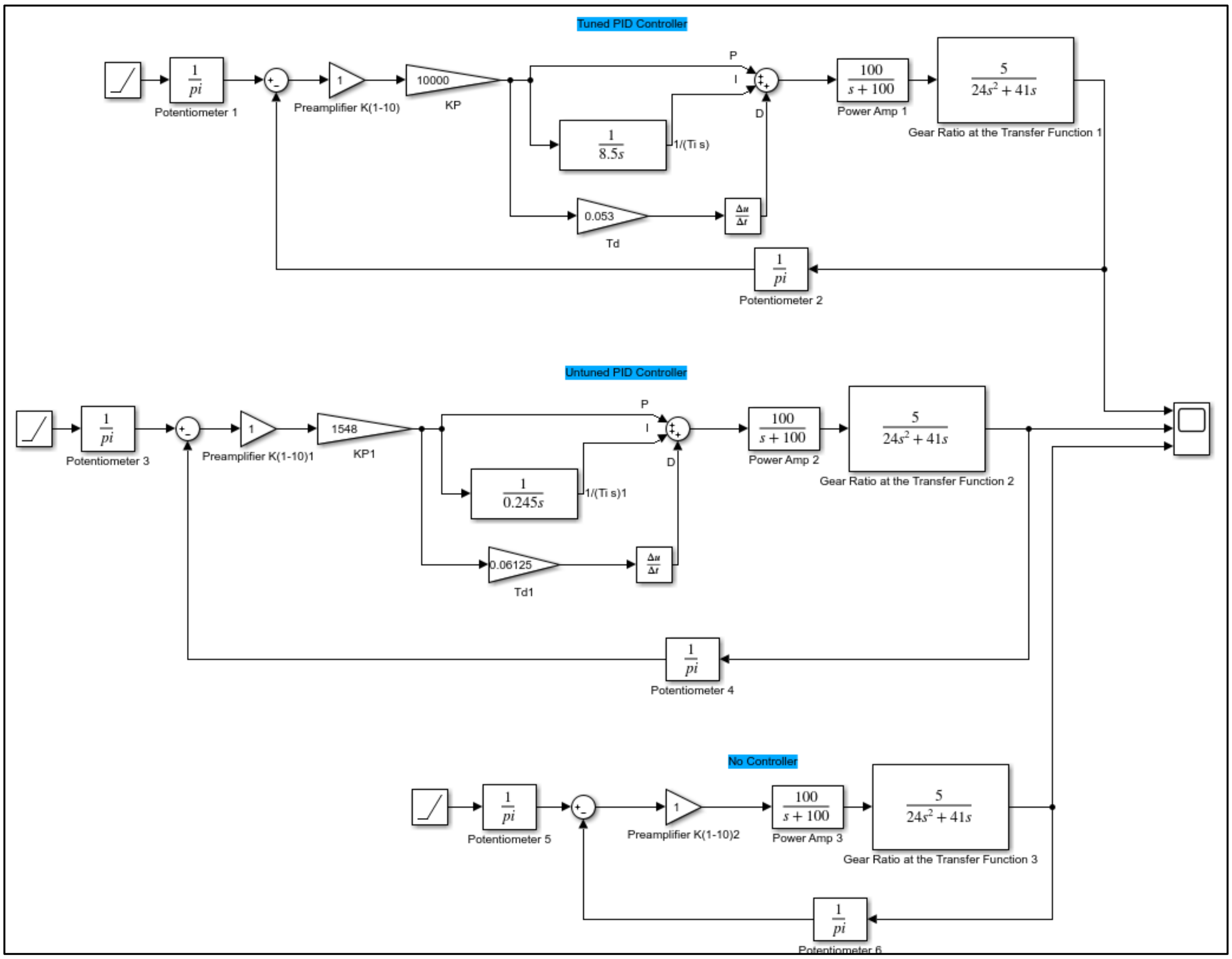

Figure 15 Inputs changed to Unit-Ramp to Observe Performance

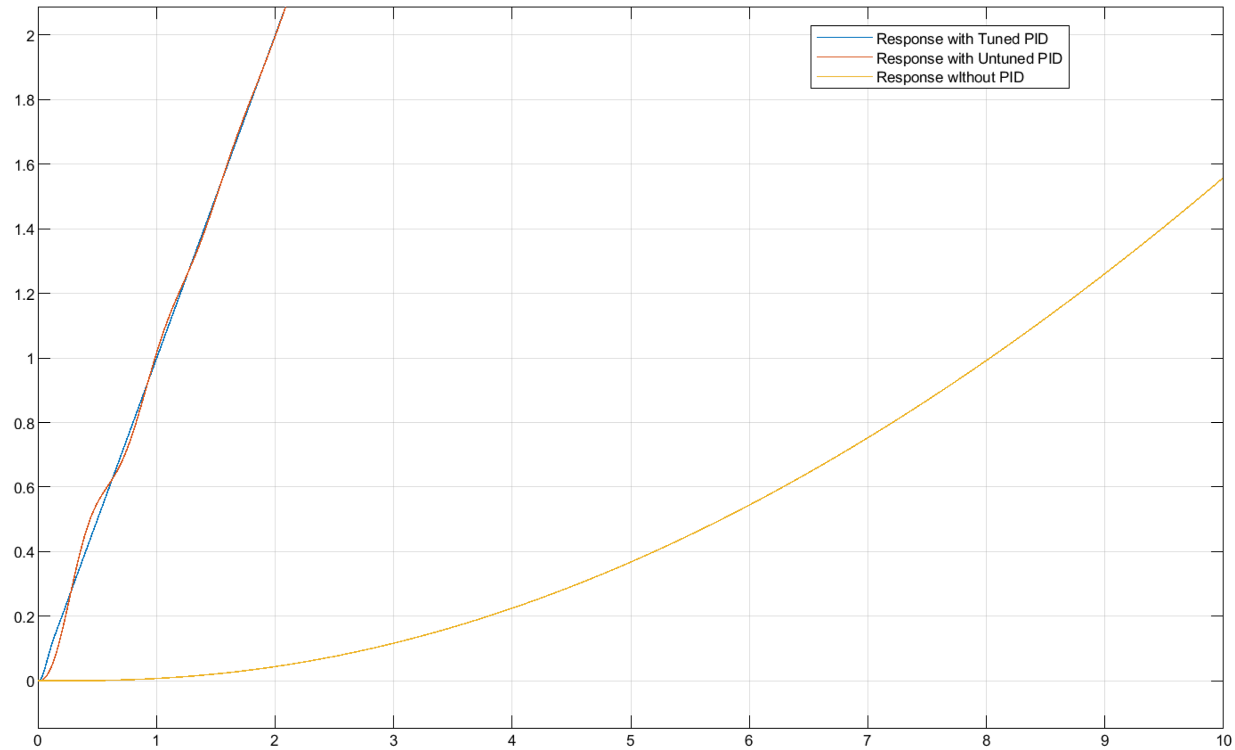

Figure 16 Graphs of the Output Response for the Unit-Ramp input

From analyzing the figure above, it is concluded that this project is a success as the Response mimics that of the Unit-Ramp input which has a slope of 1. Both the tuned and untuned PID controllers show very similar responses but the untuned PID controller still oscillates at the start of the sample time. Meanwhile, the response of the antenna without a PID control is observed to have very poor response characteristics and grows exponentially instead of linearly as it is supposed to do.

Discussion

Overall, the experimental results yielded satisfactory outcomes and the project successfully produced its intended purpose; to implement a PID from an antenna's azimuth position controls. For starters, by implementing a P control and through countless trials, values for the critical period were found which allowed for the implementation of a PID controller. By using the PID controller and fine-tuning it, overshoot values went from 80.9% without fine-tuning to 2.5%. Rise times went from 105 milliseconds to 67 milliseconds. Considering the base-case Ziegler-Nichols tuning parameters already yielded very good rise-time, cutting it down further to 67 milliseconds helped improve the overall tracking of the system. Although the fine-tuning could have been better to lower the overshoot, doing so would increase the rise time which affects the overall performance of the system. Moreover, the tuned PID controller removed virtually all oscillation that existed with the un-tuned PID controller. The success of this experiment was further proven when a unit-ramp input was applied to the system and the resulting response displayed linear growth with a slope of one as seen in figure 16.

Conclusion

In conclusion, the project was successful because critical values were successfully found and used to apply Ziegler-Nichols tuning rules on the PID to produce a linear unit-ramp output for the antenna's azimuth position controls. Moreover, the PID was tuned to generate outputs that mimicked that of the input more-closely. Key parameter values deduced in this experiment include **Pcr=0.49**, **Kcr=2580**, **Kp=1548**, **Ti=0.245**, **Td=0.06125**. After fine-tuning of the PID to produce a better response, PID values were changed to: **Kp = 10 000**, **Ti = 8.5**, and **Td = 0.053**. When comparing the **transient processes** for the un-tuned and tuned PID controllers, the tuned PID exceeds the un-tuned PID in every measurable way possible. Rise-time was reduced from **105 milliseconds** to **67 milliseconds**. Oscillation on the Tuned PID was visually removed; overshoot went from 80% to 2%. Due to the improved tracking, it can be concluded that the overall **stability** had improved since oscillation was virtually eliminated as seen in figure 12. **Signal tracking** had been substantially improved as the response of the PID system far exceeded that of the uncontrolled system as shown in figure 16. In conclusion, we can say that the overall performance of the antenna's azimuth position control system was successfully designed and that the overall project was a success. Further room for improvement could have been made regarding overshoot and rise-times, although not necessary.

References

Co, T. B. (2004, 2 13). *Ziegler-Nichols Method*. Retrieved from Michigan Technical University: https://pages.mtu.edu/~tbco/cm416/zn.html

Woodford, C. (2008). *Antennas and transmitters*. Retrieved from Explain That Stuff!: https://www.explainthatstuff.com/antennas.html

Appendix

Simulink models attached to submission with the following names:

P control: Emmanuel_Mati_Simulink_Project_P_Control

Antenna with Unit-Step Input: Emmanuel_Mati_Simulink_Project_Unit_Step_Input

Antenna with Unit-Ramp Input: Emmanuel_Mati_Simulink_Project_Unit_Ramp_Input

Hand Calculations attached to submission with the following name:

Hand Calculations

Excel sheet with PID values:

PID Table