

Assignment 1

by Paul Austin

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P Number: P148321

Module: Instrumentation and Control

Assignment Title:

“Create with simulation software mathematical models of control and instrumentation systems, solve their time response and compare their transient and steady-state responses with given specifications”

Lecturer: Dr Stephen Mosey

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As expected, the above demonstration has shown that it is possible to reduce a complex control system to a single block. Why was this expected?

Mathematicians always reduce a formula / equation to its simplest form prior to solving – the results demonstrated show that this methodology can therefore be applied to the design of a control system.

Why would this be an advantage – why not keep things in separate and perhaps simpler steps?

Similar to how a computer programmer would work, the advantages to this would be:

1. Maintenance / modification of the control system – the single block allows for an easier method to accomplish this.
2. Documentation – the fewer blocks in your control system makes it easier to document.
3. Testing – the fewer blocks there are in your system makes it easier to fault find.
4. Improved stability of the system – fewer things to go wrong.

However, breaking tasks down into individual constituent components makes for less ambiguity when designing a system in response to a particular specification. Individualising each step allows for analysis to take place to ensure that the designed system is compliant towards the design specification and fulfils the requirements of this.

8	It can therefore be suggested that both the initial model and the more simplistic single block model each have their own individual roles to play. In other words, a step-by-step complex system can be used to develop a controller and answer the question “Does it do what it is meant to?”. This system (as demonstrated here) can then be simplified into a single block (or fewer blocks). Conclusion References	23
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2. Abstract

An industrial process has the transfer function $G(s)$ given by the equation below, where a , b , and c are values which have been assigned. These set values are shown at the bottom of this page.

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

Using MATLAB and Simulink, the task is to design a control system capable of controlling the above process. Following a unit step input, the control system should be able to bring the process under control within two seconds, with overshoot of less than 5%.

Using this created control system, a further task is to find the closed loop transfer function of the system as a whole, i.e. the industrial process and the control system which has been designed. This can then be validated by comparing the results of simulations of the single transfer function and the simulation results from initial control system.

The aim is to then critically analyse each control system through the use of pole-zero diagrams and Nyquist diagrams to ensure the plots are stable.

For the scope of the model to be used in this assignment the following values for the Transfer Function have been provided:

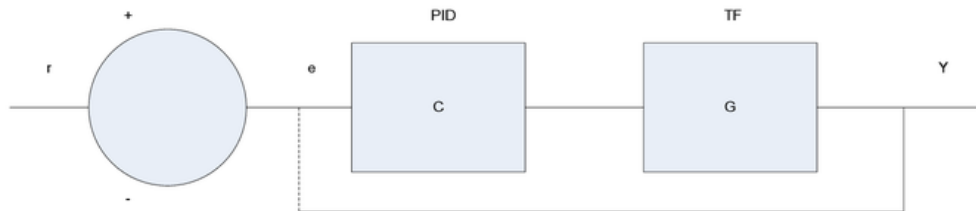
- a. 3
- b. 2
- c. 2



2.1. Control System Schematics...

Task 1 – Control System

The following diagram shows the schematic for the initial control system:



Task 2 - Finding the Closed Loop Function.

Task 2 – Step 1 → removal of the Proportional Integral Derivative (PID) control:



Task 2 – Step 2 → removal of the feedback loop:



3. Introduction

Industry today is progressively looking towards intuitive methods for reducing cost & increasing the efficiency of work. Amongst the many ways in which such initiatives can be implemented is the automation of tasks rather than having them carried out through human interaction. Control systems are designed into engineering systems to allow for a greater level of controlled automation and optimisation.

Why use control systems?¹

1. To allow for a level of accuracy within the system.
2. To ensure operational boundaries or safety limits are not exceeded.

There are two types of Control Systems:²

1. Feedback – Closed Loop System.
2. No Feedback – Open Loop System.

A Feedback (Closed Loop) System includes:

1. On / Off.
2. 3 State Control.
3. Proportional Control (P).
4. Proportional Integral Control (PI).
5. Proportional Integral Derivative (PID) Control.

Proportional Control is the difference between the start point and a process variable, deviation should not be large or sudden. The PI allows for a variable within the controller to be turned back to a set point should an error occur. The Derivative controller is usually used either with a Proportional Control (Proportional Derivative → PD) or with the Proportional Integral (PID). This gives the advantage of improving the response of the system.

What is a Transfer Function?

"A mathematical function relating the output or response of a system such as a filter circuit to the input or stimulus."⁴

In other words, it is a mathematical function that describes the characteristics of a system(s) concerning the relationship between the input and output of the system.

¹ Digital control system analysis and design, Charles L. Phillips H. Troy Nagle (Hubert Troy), London : Prentice-Hall c1984.

² Control system design and simulation, Jack. Golten Andy Verwer, London : McGraw-Hill 1991.

³ PID Controller Design Approaches - Theory, Tuning and Application to Frontier Areas, Publisher: InTech, ISBN: ISBN 953-510-405-5. Accessed 1st June 2017.

⁴ https://en.oxforddictionaries.com/definition/transfer_function.

As previously mentioned, one aim of the system is to bring the process under control within two seconds, with overshoot of less than 5%, a process known as PID Tuning will have to take place. This can be carried out using a number of techniques:⁵

1. Direct Synthesis (DS) method
2. Internal Model Control (IMC) method
3. Controller tuning relations
4. Frequency response techniques
5. Computer simulation
6. On-line tuning after the control system is installed
7. Trial and error

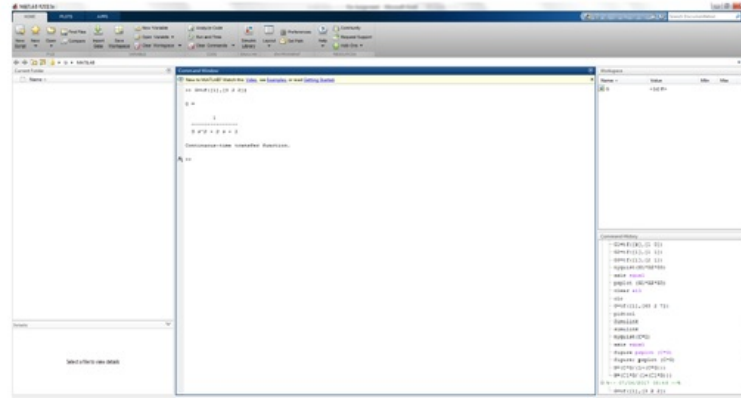
As MATLAB & Simulink are being used for the purpose of this exercise, computer simulation combined with trial and error will be used for the process of PID Tuning.

⁵ PID Controller Design Approaches - Theory, Tuning and Application to Frontier Areas, Publisher: InTech, ISBN: ISBN 953-510-405-5. Accessed 1st June 2017.

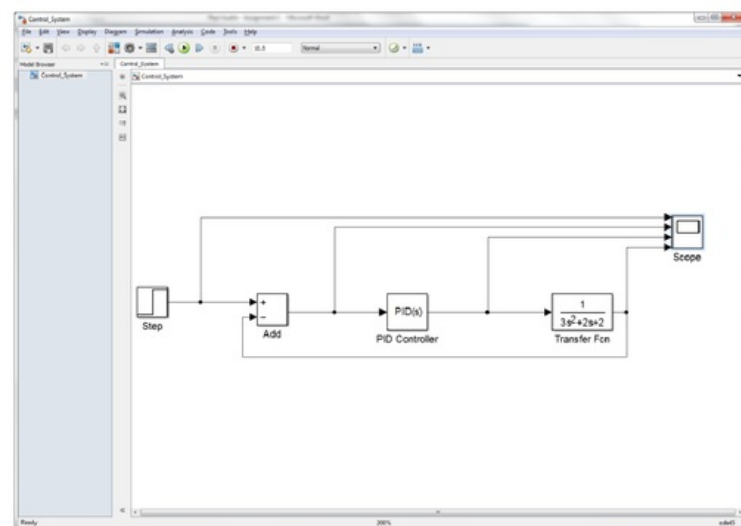
4. Method

4.1. To create the initial Control System...

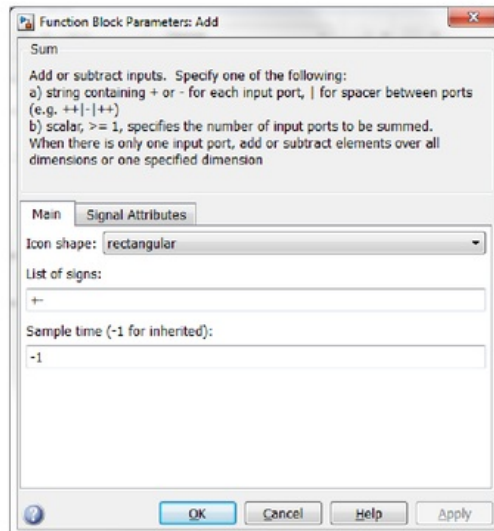
Step 1: Create a variable in MatLab to store the Transfer Function:



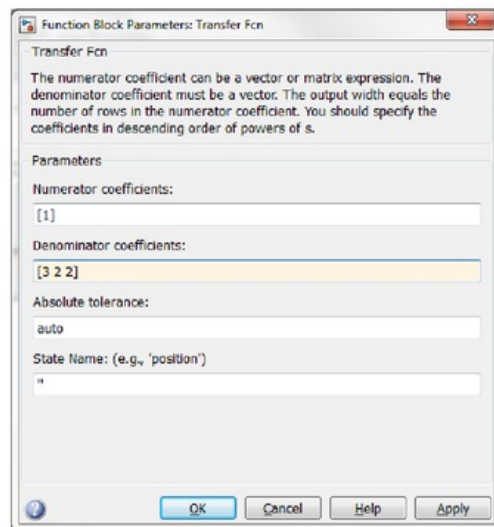
Step2: Create the initial Control System in Simulink:



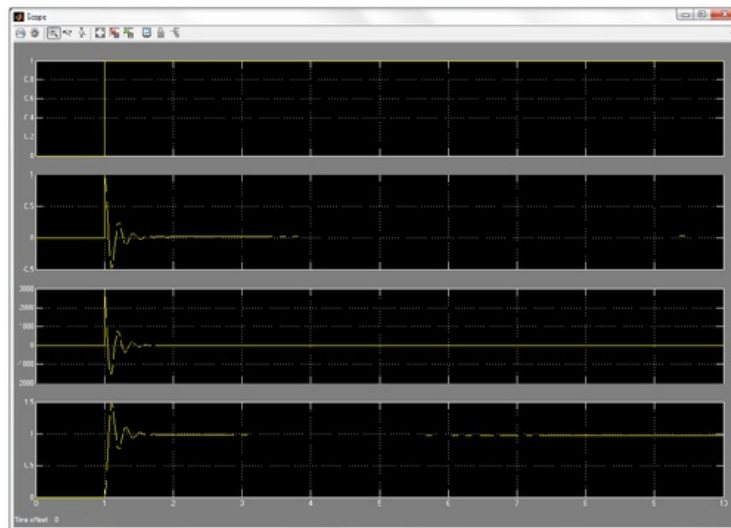
Ensure the “Add” function is set to “add” and “minus” – this allows the monitoring of the feedback for the control system:



Double Click on Transfer Function → Assign Denominator values for controller:



Run this function to verify the system:



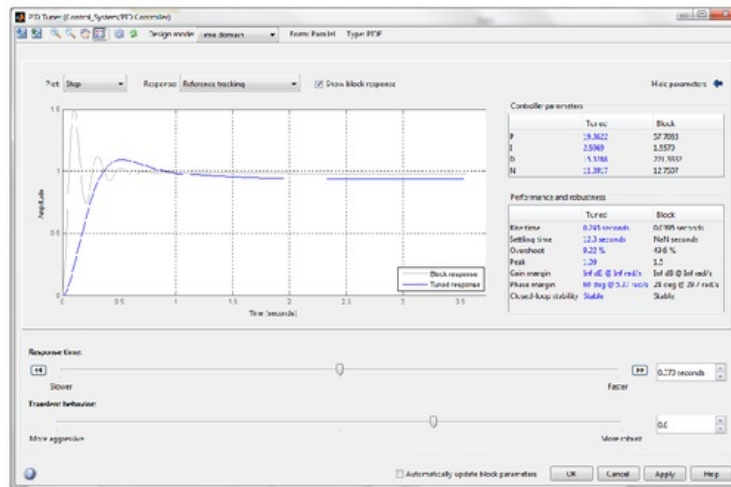
Open the parameter setting dialog within PID:

The Function Block Parameters: PID Controller dialog box is shown. It contains the following sections:

- PID Controller**: This block implements continuous- and discrete-time PID control algorithms and includes advanced features such as anti-windup, external reset, and signal tracking. You can tune the PID gains automatically using the "Tune..." button (requires Simulink Control Design).
- Controller**: PID (dropdown menu)
- Form**: Parallel (dropdown menu)
- Time domain**:
 - ☒ Continuous-time
 - ☐ Discrete-time
- Main**: PID Advanced (selected tab), Data Types, State Attributes
- Controller parameters**:
 - Proportional (P): 22.7983183224311
 - Integral (I): 1.55386897532098
 - Derivative (D): 221.3332321173
 - Filter coefficient (N): 12.7506909964737
- Compensator formula**:
$$P + I \frac{1}{s} + D \frac{N}{1 + N \frac{1}{s}}$$
- Tune...** button
- Initial conditions**:
 - Source: internal
 - Integrator: 0
 - Filter: 0
- External reset**: none
- ☐ Ignore reset when linearizing
- ☒ Enable zero-crossing detection

Buttons: OK, Cancel, Help, Apply

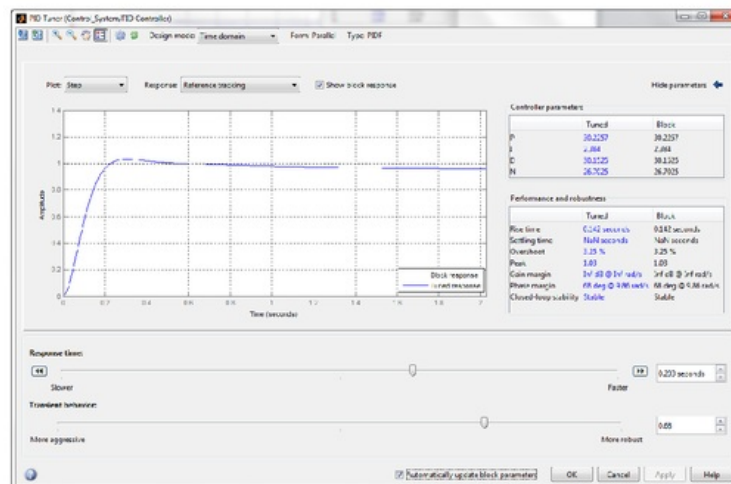
Select Tune:



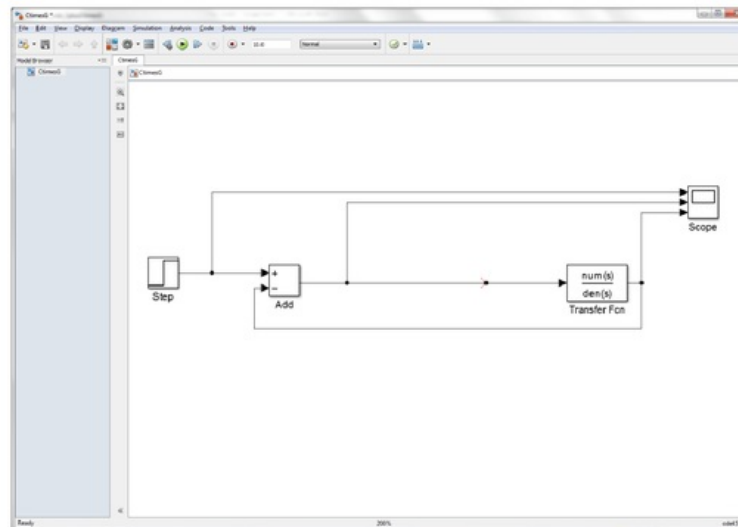
The PID Tuner automatically provides a best fit tuned response in relation to the existing setup – this can be used as a guide to tune the system.

As per the guidelines of the assignment, the control system should be able to bring the process under control within two seconds, with overshoot of less than 5%.

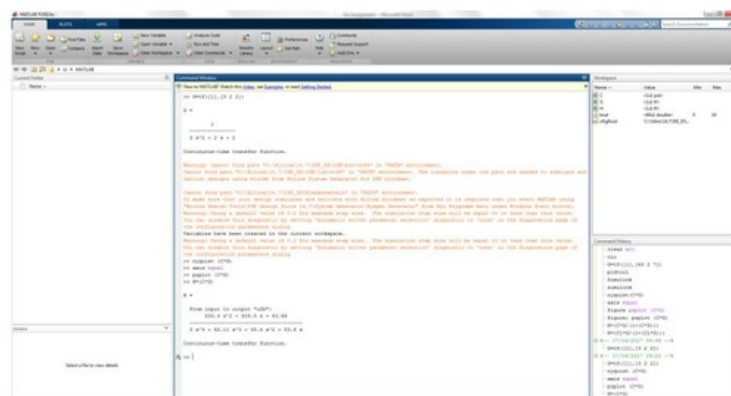
Tuning the system to within the specified parameters has the following settings:



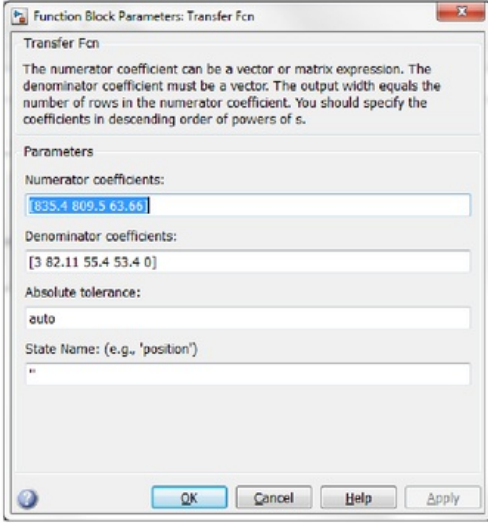
To create a Closed Loop System within Simulink, the PID Controller has to be removed:



Verification can be obtained as to whether a Closed Loop System works when compared to the original Control System by applying the following values to the Transfer Function:



These values are entered into the Closed Loop Transfer Function on the new control system:



The image shows a MATLAB/Simulink dialog box titled "Function Block Parameters: Transfer Fcn". It contains instructions and input fields for configuring a transfer function block.

Transfer Fcn
The numerator coefficient can be a vector or matrix expression. The denominator coefficient must be a vector. The output width equals the number of rows in the numerator coefficient. You should specify the coefficients in descending order of powers of s .

Parameters

Numerator coefficients:
[835.4 809.5 63.66]

Denominator coefficients:
[3 82.11 55.4 53.4 0]

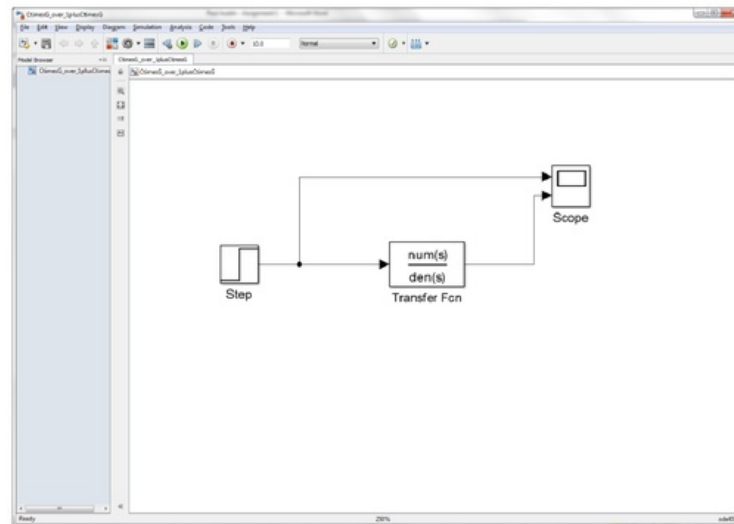
Absolute tolerance:
auto

State Name: (e.g., 'position')
"

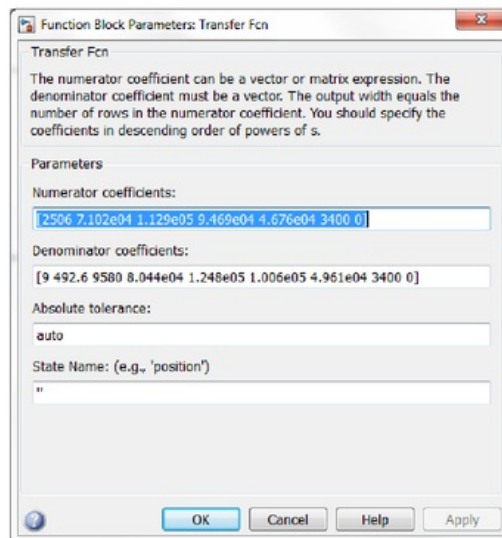
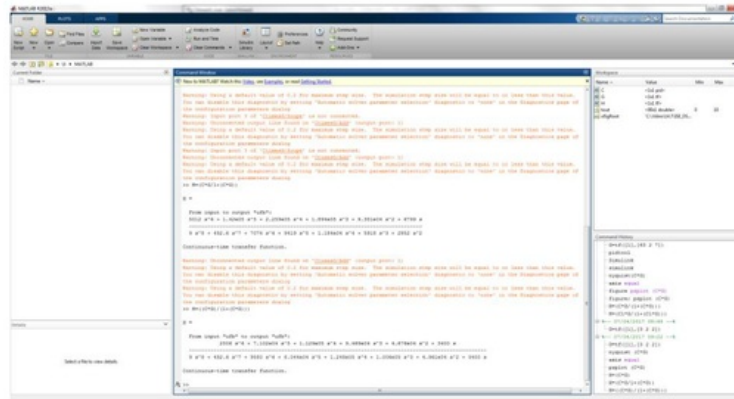
Buttons: OK, Cancel, Help, Apply

4.3. Closed Loop Transfer Function ($C*G/1+C*G$)....

Further verification of the Closed Loop system can be obtained by removing the feedback loop within Simulink:



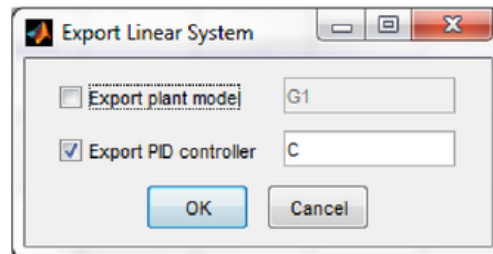
Then, using the following as the control values for the Transfer Function further comparison can be made:



5. Results

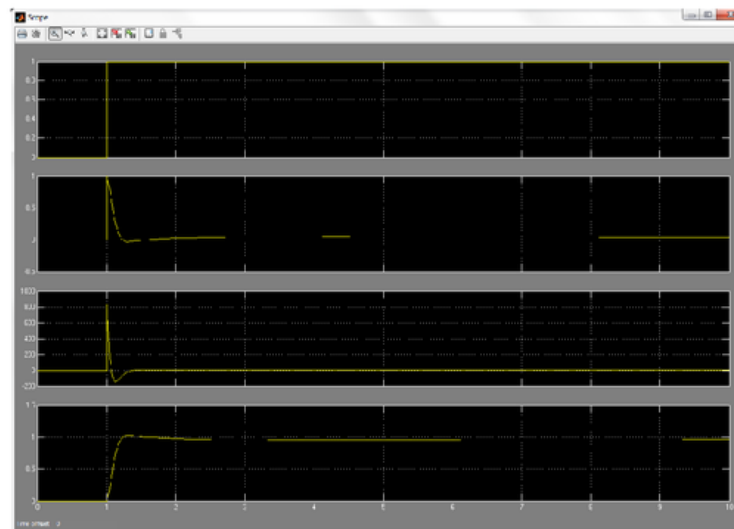
5.1. Initial Control System....

Once tuned, the system can be run and checked:



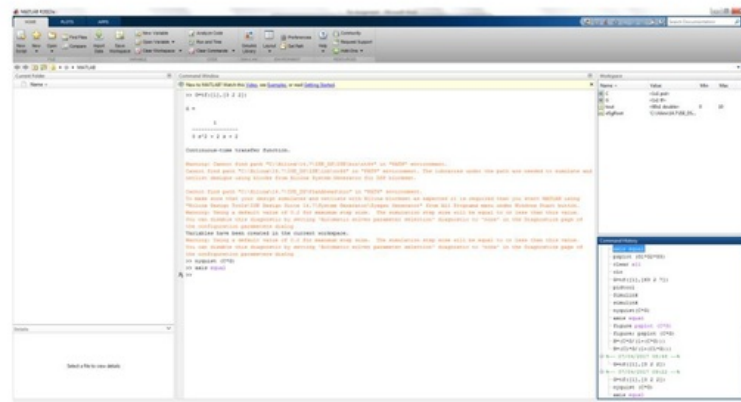
Exporting the system allows for this to take place.

Re-Running the simulation makes it possible to evaluate the tuned system:

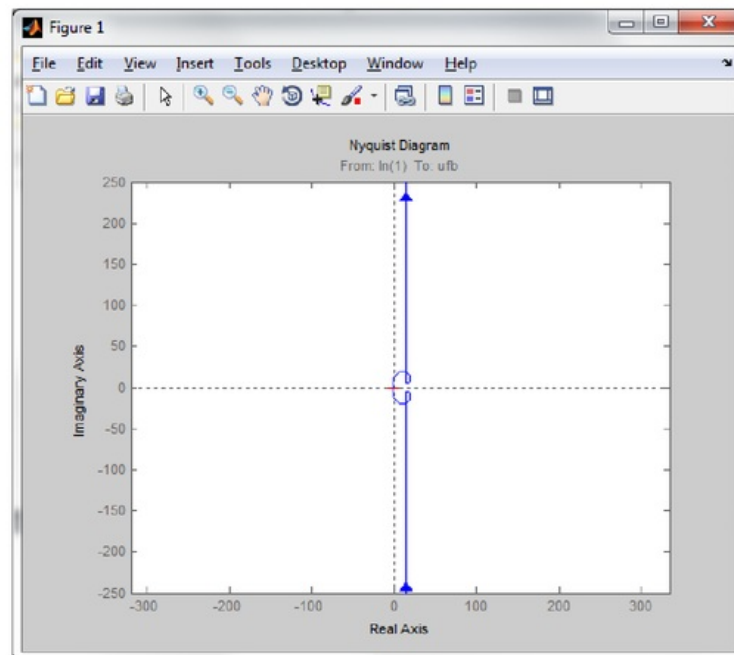


Additionally, once exported, a NYQUIST plot and PZPLOT can be used on the exported system to verify if this system is stable or not.

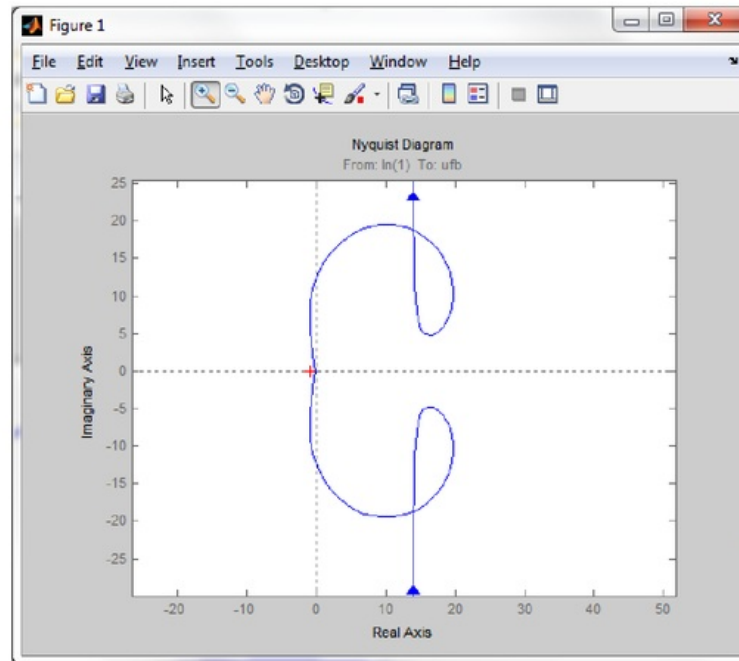
5.1.1. NYQUIST:



This produces the following plot:



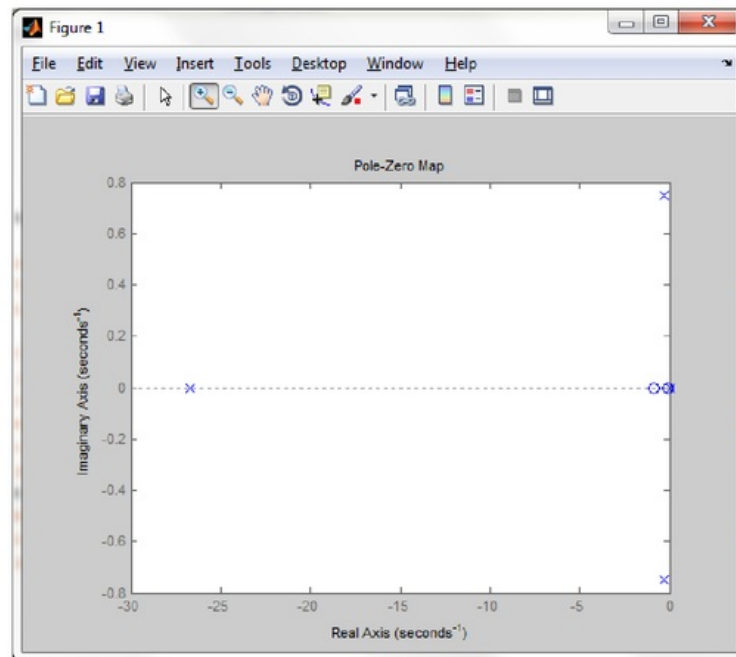
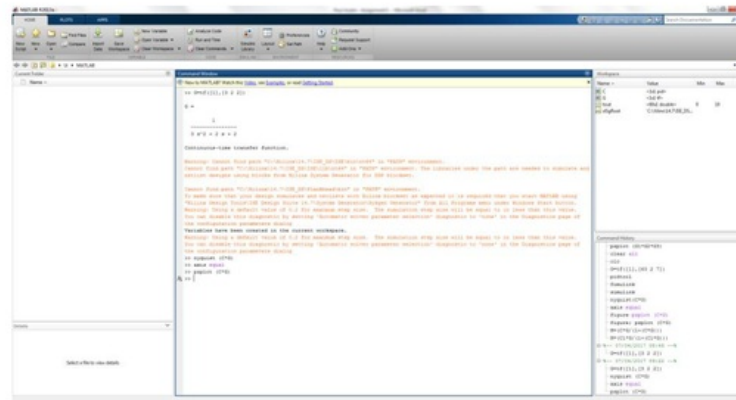
It is useful to zoom in on the plot. The purpose of this is to verify whether point -1 is or is not included under the curve:



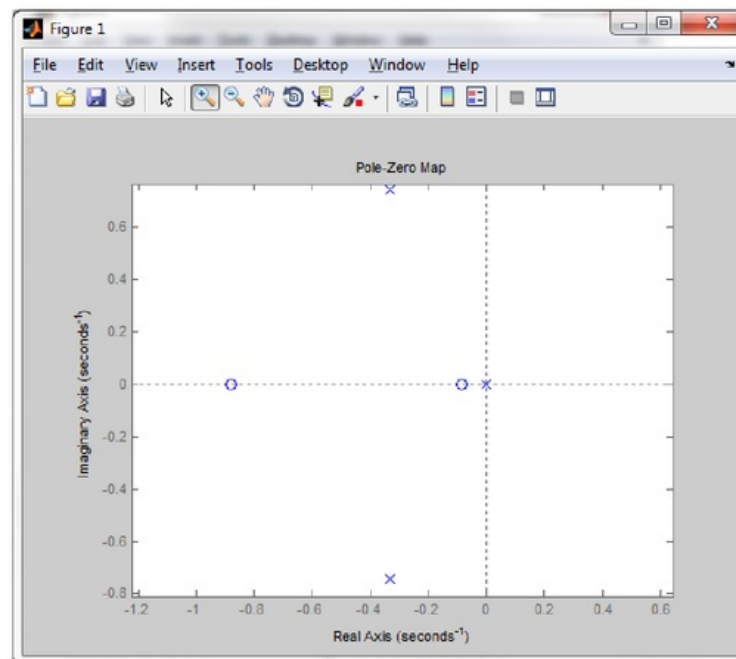
As this is not included under the curve, it can be seen that this is a stable system.

5.1.2. PZPLOT:

A Polar Zero plot verifies where the Poles are for this system:



Again, this needs to be zoomed in to verify the results:

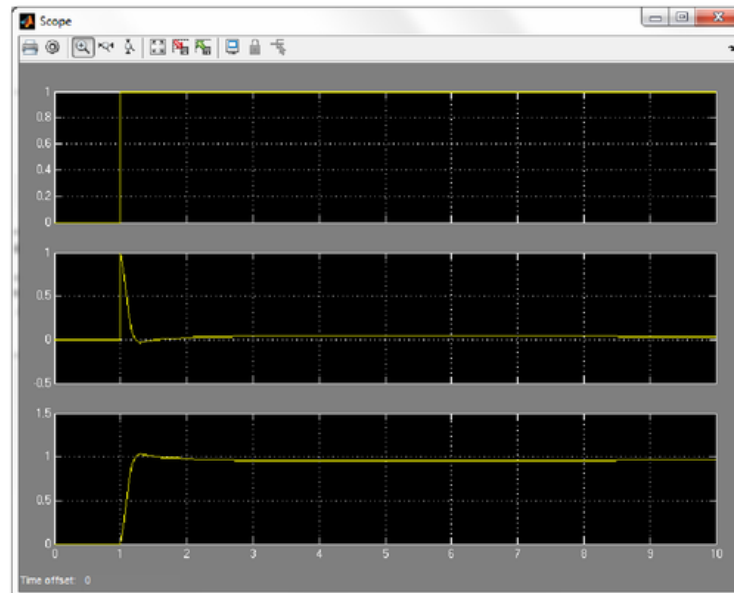


As the points are greater than -1 this also signifies a stable system.

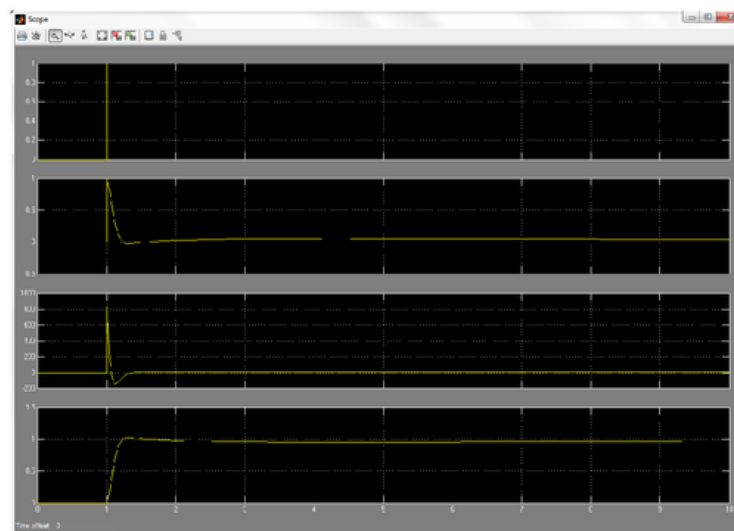
5.2. Closed Loop Transfer Function ($C*G$)...

Running the Control System containing the new Closed Loop Transfer Function allows for verification to be obtained as to whether a Closed Loop system will work.

The following shows the Closed Loop System:

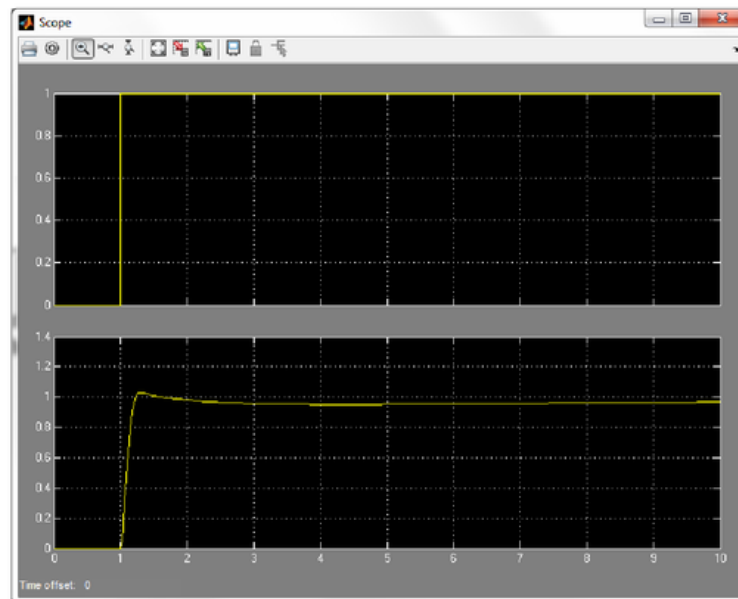


Comparing this to the initial system:

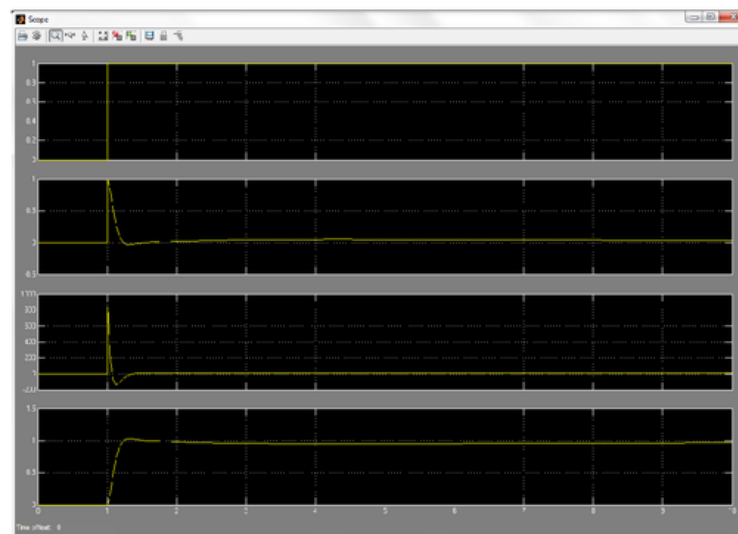


5.3. Closed Loop Transfer Function ($C*G/1+C*G$)....

The following shows the output for this System:



Comparing this to the initial system:



6. Discussion

As expected, the above demonstration has shown that it is possible to reduce a complex control system to a single block. Why was this expected?

Mathematicians always reduce a formula / equation to its simplest form prior to solving – the results demonstrated show that this methodology can therefore be applied to the design of a control system.

Why would this be an advantage – why not keep things in separate and perhaps simpler steps?

Similar to how a computer programmer would work, the advantages to this would be:

5. Maintenance / modification of the control system – the single block allows for an easier method to accomplish this.
6. Documentation – the fewer blocks in your control system makes it easier to document.
7. Testing – the fewer blocks there are in your system makes it easier to fault find.
8. Improved stability of the system – fewer things to go wrong.

However, breaking tasks down into individual constituent components makes for less ambiguity when designing a system in response to a particular specification. Individualising each step allows for analysis to take place to ensure that the designed system is compliant towards the design specification and fulfils the requirements of this.

It can therefore be suggested that both the initial model and the more simplistic single block model each have their own individual roles to play.

In other words, a step-by-step complex system can be used to develop a controller and answer the question “Does it do what it is meant to?”. This system (as demonstrated here) can then be simplified into a single block (or fewer blocks).

7. Conclusion

As shown the initial control system was established in order to provide a comparison (or control) to demonstrate the effectiveness of any changes. This was tuned to bring the process under control within two seconds, with overshoot of less than 5%.

Within the results for the initial control system, the NYQUIST and POLAR ZERO plots verified first of all that the original controller is a stable system. The results then progressed to show that the Closed Loop Transfer Function ($C*G/1+C*G$) behaved in the same manner as the original system.

As such, verification of this was then carried out to show that the feedback loop can be removed and it has been shown that a control system still works in this case. Additionally, comparison has been made to the initial control system indicating that the two systems behave in the same way.

Therefore it has been possible to calculate and verify a new transfer function to replace the PID controller.

This ultimately means that "A complex control system can be described through the combined action of several subsystems".⁶

⁶ https://www.samson.de/pdf_en/l102en.pdf

8. References

Literature Sources:

- Digital control system analysis and design, Charles L. Phillips H. Troy Nagle (Hubert Troy), London : Prentice-Hall c1984.
- Control system design and simulation, Jack. Golten Andy Verwer, London : McGraw-Hill 1991.
- Control system technology C. J. Chesmond (Colin J), London : Edward Arnold 1984.

UWTSD Online Library Sources:

- PID Controller Design Approaches - Theory, Tuning and Application to Frontier Areas, Publisher: InTech, ISBN: ISBN 953-510-405-5. Accessed 1st June 2017.
- CDM-based closed-loop transfer function design for ramp input, Haeri, Mohammad, Mohammad Saleh Tavazoei. Is Part Of: Transactions of the Institute of Measurement and Control, Jul 2011, Vol.33(5), pp.558-572 [Peer Reviewed Journal].
- Controller design using closed-loop transfer function, Lozgachev, G. Computational Mathematics and Modeling, 1998, Vol.9(2), pp.153-159 [Peer Reviewed Journal].

Web Based Sources:

The following were accessed on 15th May 2017:

- https://en.wikipedia.org/wiki/Closed-loop_transfer_function
- http://www.cds.caltech.edu/~murray/courses/cds101/fa04/caltech/am04_ch6-3nov04.pdf
- <https://www.its.bldrdoc.gov/fs-1037/dir-037/5543.htm>
- <https://www.collinsdictionary.com/dictionary/english/transfer-function>

The following was accessed on 30th May 2017:

- https://en.oxforddictionaries.com/definition/transfer_function

The following was accessed on 9th June 2017:

- https://www.samson.de/pdf_en/l102en.pdf

Assignment 1

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

49/100

PAGE 1

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Comment 1

Your abstract should contain a statement of your results.

PAGE 5

PAGE 6



Comment 2

examples of a feedback system include...?

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GRADING FORM: SMU GENERIC_GJ

PAUL AUSTIN

48.80

RESEARCH-INFORMED LITERATURE



Inclusion of a range of research-informed literature, including sources retrieved independently. Referencing conventions mostly consistently applied.

2.75

KNOWLEDGE AND UNDERSTANDING



Evidence of basic knowledge and understanding of the relevant concepts and underlying principles.

14.4

ANALYSIS



Evidence of some logical, analytical thinking and some attempts to synthesise, albeit with some weaknesses. Some evidence to support findings/ views, but evidence not consistently interpreted. Some relevant conclusions. You have performed the required tests on your control systems, but your analysis of this is very limited. You could have indicated what the poles/zeros would have done for the response of the system.

14.4

PRACTICAL APPLICATION AND DEP.



A good and appropriate application of standard methods, materials, tools and/or techniques. Good appreciation of the context of the application.

12.75

SKILLS FOR PROFESSIONAL PRAC.



Can communicate in a suitable format but with some room for improvement. Work lacks coherence in places and could be better structured. Your method section has turned into an instruction manual, the reader is assumed to either have some knowledge of the techniques involved, or can find them out independently. Your images should be captioned to allow you to refer to them in your text.

4.5