**ASEN 2803 Dynamics & Controls Lab**

**Lab 3: Rotary Arm Control – Lab Worksheet**

Spring 2025

**TEAM INFORMATION**

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| **Group Number** |
| [Section #]-[Group #] |

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| **Group Members** |
| Alexander Tilbury |
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**INSTRUCTIONS**

* Before proceeding, make sure that every member of your group has read the Lab 3 Assignment Document, including the Appendix section.
* Please read each question on the Lab Worksheet carefully and then fill in the boxes with your answers.
* Note that the size of the answer boxes is not intended to limit your response. Feel free to make the boxes larger if necessary.
* When attaching figures, please make sure to include plot titles, axes labels (including units), and a legend if multiple plots are shown in the same figure.
* When complete, save your Lab Worksheet as a **PDF document** and submit the completed PDF via Gradescope.
* ***Please remember to assign pages to your submission in Gradescope***.

**THEORY & SIMULATION**

**Question 1.1**

Review the derivations provided in the appendices and derive Eq. 17 and 18 beginning with Eq. 13.

Hint: First, solve Eq. 13 for . Substitute the resulting expression into Eq. 16. Finally, arrange like terms and divide through to get the closed loop transfer function.

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| *Insert derivation or picture of derivation* |

Next, develop a MATLAB simulation for the closed loop behavior of the rigid arm (Eq. 17). Use the physical and electrical parameters given in the spreadsheet to determine the parameters for the equations of motion derived in Question 1.1. The following sample code can help you get started:

**%% Closed Loop System**

num = n1;

den = [d2 d1 d0];

sysTF = tf(num,den);

**%% Step Response**

[x,t] = step(sysTF);

Note 1: If you want to simulate a more complicated input, explore the lsim command in MATLAB to find the theoretical response of your system to a specified input . This is useful when performing comparisons with experimental data, where the reference values and time are also recorded in the data file.

**Note 2: You will need to have the “Control System Toolbox” installed in MATLAB for certain functions to work.**

**Question 1.2**

Use the simulation developed in the previous question to investigate the behavior of the step response of the Rigid Arm system for the gain values provided below. Explore the effects of increasing and decreasing the proportional and derivative gains. Set the amplitude of the step response to be **0.5 rad**.

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| **Gains** | **Set 1** | **Set 2** | **Set 3** | **Set 4** | **Set 5** | **Set 6** |
| K1 – Proportional | 10 | 20 | 5 | 10 | 10 | 10 |
| K3 – Derivative | 0 | 0 | 0 | 1 | -1 | -0.5 |

Explain the differences and similarities you see between the different sets of gains:

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| Set 1: Has some overshoot but returns to equilibrium after a couple of oscillations, which take about two seconds in total.  Set 2: Has some overshoot of greater magnitude than Set 1, as well as more oscillations, but returns to equilibrium in about the same time.  Set 3: The magnitude of overshoot is much less than in Sets 1 and 2 and has fewer oscillations before returning to equilibrium.  Set 4: The magnitude of overshoot is the lowest and hardly oscillates before returning to equilibrium.  Set 5: Has the greatest number of oscillations of large magnitude before returning to equilibrium.  Set 6: Very similar to Set 2. The oscillations seem slightly more spread out and are of greater magnitude. |

**EXPERIMENT**

**Question 2.1 – Exploring the Hardware**

Using the rigid arm **hardware**, input the gains given in Question 1.2. Set the “Reference Amplitude” to **0 rad**. This will make the system want to stay at **0 rad**.

Perturb the system (ie. give the rigid arm a little push or move the arm about 45 deg to one side). What do you notice? Does it feel different for different gains? Explain what differences you notice/feel? Does this make sense?

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| Set 1: It overshoots slightly.  Set 2: More overshoot with a larger magnitude and then goes back to the reference value.  Set 3: It is much easier to move and undershoots the reference value.  Set 4: Much harder to perturb and has a little less undershoot than set 3.  Set 5: It has more overshoot and oscillates around two times.  Set 6: Not as much overshoot as set 5 but it still overshoots the reference value. |

**Question 2.2 – Conceptual Understanding**

Using the rigid arm **hardware**, explore the effects of increasing and decreasing the proportional and derivative gains with the gain values provided in Question 1.2. Make sure to set the “Reference Amplitude” to **0.5 rad**. Compare the behavior of the hardware with **your MATLAB simulation** and with the **provided MATLAB/Simulink simulation**.

**2.2 a)** What does a higher/lower ***proportional*** gain do to the system? What are the similarities and differences between the hardware, your MATLAB simulation, and the Simulink simulation?

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| Higher proportional gains results in less damping in the system, causing more oscillations and large overshoots. They also increase time and the level of responsiveness of the system. Lower proportional gains have the opposite effect. But can make the system more stable.  The hardware, the MATLAB simulation, and the Simulink simulation all displayed similar results that aligned with these conjectures. However, due to other factors such as friction affecting the hardware, those results were a little less clear. |

**2.2 b)** What does a higher/lower ***derivative*** gain do to the system? What are the similarities and differences between the hardware, your MATLAB simulation, and the Simulink simulation?

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| Higher derivative gains increase damping in the system resulting in more control response. They also reduce settling time. Lower derivative gains reduce damping and will make it more unstable and increase settling time.    Comparing our observations in MATLAB Simulink with the HARDWARE we will see that the observations for each set will result slightly the same in the MATLAB simulation, the Simulink simulation, and the hardware. However, changing the derivative gain in the hardware seems to have a less clear effect due to other factors such as friction affecting the system. |

**2.2 c)** How can the ***overshoot*** be increased/decreased? What are the similarities and differences between the hardware, your MATLAB simulation, and the Simulink simulation?

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**2.2 d)** How can the ***settling time*** be increased/decreased? What are the similarities and differences between the hardware, your MATLAB simulation, and the Simulink simulation?

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| To decrease the settling time we must increase Kp (trying to not makes changes in the overshoot) and also tune Kd to provide a good damping.    To increase the settling time we must use less Kp and try to add more damping.    The sets are also so similar although with a little bit of difference and that is for the forces considered in the real world (HARDWARE) than the ideal conditions (MATLAB Simulink). |

**Question 2.3 – Overall System and Software**

**2.3 a)** Sketch a functional block diagram of the rigid arm system below:

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| *Insert picture of Functional Block Diagram* |

**2.3 b)** What does each part of the system do (ie. the arm, sensors, myRIO, actuator)? What is the function of each component, and how do they interact with each other?

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**2.3 c)** Sketch the control block diagram below, and highlight the transfer function(s):

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| *Insert picture of Control Block Diagram*    HIGHLIGHT TRANSFER FUNCTIONS |

**2.3 d)** Describe how the control system works to achieve the desired arm position. What is the function of each block, what are their inputs and outputs, and how do they interact with each other?

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**Question 2.4 – Design Controls and Behavior Response**

Now you are going to design your own control gains such that your system meets a set of requirements. Your controlled rigid arm should:

* Have **less than 20% overshoot**
* Achieve a **5% settling time in less than 1 second**

Your reference step signal should have an **amplitude of 0.5 rad** and a **period of 10 s**.

*Make sure to show at least 1 cycle in your plots. Make sure to plot the reference step input in all of your plots.*

**2.4 a)** What proportional and derivative gains did you arrive at?

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| **Gains** | **Value** |
| K1 – Proportional | 7 |
| K3 – Derivative | 1 |

**2.4 b)** Input these gains into **your MATLAB simulation**. Do you meet the requirements? Check your time response plot (by inspection) and include it below. If you don’t meet the requirements, explain why.

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| *Insert picture of your time response plot* |

**2.4 c)** Now, input these gains into the rigid arm **hardware VI**. Record data and then plot that data in MATLAB. Include the figure of your time response below. Do you meet the requirements in the hardware? If you don’t, explain why.

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| *Insert picture of your time response plot* |

**2.4 d)** Now, compare the response from **your MATLAB model** with the response from the **hardware**. Plot both time responses together and explain the differences between the two. What do you think is causing the difference?

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| *Insert picture of your time response plot with both time responses plotted on the same figure* |

**2.4 e)** How can you modify your gains to meet the requirements in the hardware? Try these new gains in the hardware and show if they meet the requirements by plotting the output of the VI in MATLAB.

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| *Insert picture of your time response plot* |

**2.4 f)** Beware of the 10V limit on . How does your model and experimental data differ if the control output reaches this value? Look at the Control Voltage plot in the hardware VI.

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**RESULTS AND ANALYSIS**

**Question 3.1 – Results**

**NOTE: It has been observed that the physical units may exhibit different behavior when moving clockwise vs. counterclockwise. You only need to analyze a single transition. This means you are free to pick the direction that reasonably matches your model and ignore the opposing transition.**

For the rigid arm, plot and compare the experimental results with the model results from the gains you selected to meet the performance objectives. Label the **overshoot** and **5% settling time** on the plot. Attach the result and explanation below:

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| *Insert picture of your time response plot and your explanations* |

**Question 3.2 – Analysis**

**3.2 a)** How and why do the experimental results differ from the theory?

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**3.2 b)** We assumed negligible natural damping () to be zero. Is this a good assumption for this experiment? Why or why not?

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**3.2 c)** How can you determine an approximation for the natural damping in the real system?

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**3.2 d)** Compare your improved model (the one that includes the effects of natural damping in the real system) to the model without friction and to the real system.

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