MXET 375
Applied Dynamic Systems

Multidisciplinary
Engineering Technology
COLLEGE OF ENGINEERING

LABORATORY # 6

Manipulating Robot Arm

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Name: Kyle Rex
Section: 906
UIN: 932008894

Introduction

The purpose of Lab 6 is to simulate the movement of a 5-degree-of-freedom (DOF) robotic arm with a claw gripper in MATLAB Simulink using motion data from a physical demonstration. The main objective is to replicate the robot's physical motion by importing real-world joint position data into a premade Simulink model and configuring it to simulate the robotic arm's dynamics. Key tasks include generating a visual representation of the motion data, integrating the motion profile into the Simulink model, and adjusting various parameters, such as revolute joint settings and input filters. Task 1 focuses on analyzing and plotting the motion profile data from the physical demonstration of the robotic arm using Excel. Task 2 involves setting up the premade Simulink model of the robotic arm by importing the motion profile data and reconfiguring system parameters to ensure an accurate simulation of the arm's movement. By completing this lab, individuals will gain experience in simulating robotic systems, configuring dynamic models, and analyzing mechanical motion using Simulink, Simscape Multibody, and MATLAB.

Procedure & Lab Results

This lab has two tasks total. Each task includes a detailed description of the setup, procedure, results, relevant figures, and discussion focusing on developing a better understanding and interpretation of what the results mean and how they were derived. Both tasks focus on a five degree of freedom robot arm, that is made up of seven HEBI actuators, which can be seen in Figure 1.

Figure 1: HEBI 5DOF Arm with Gripper [1]

Task 1

Following the live demonstration of the HEBI robot arm, and obtaining the data collected from that demonstration, task 1 can begin. Task 1 involves examining the motion profile data collected from the physical demonstration of the robotic arm. This data, stored in an Excel file titled "HEBI_motion_profile.xlsx," consists of time values and joint position data for each of the robotic arm's joints. The first step is to open the file and observe the dataset, which includes columns representing the positions of all the joints in radians. The task then requires the creation of a visual plot using a "Scatter with Smooth Lines" chart, which provides a graphical representation of the motion profile. The plot will then be properly formatted with a title, labeled axes, and a legend to clearly show the movement of each joint over the duration of the arm's motion. The final formatted plot can be seen in Figure 2.

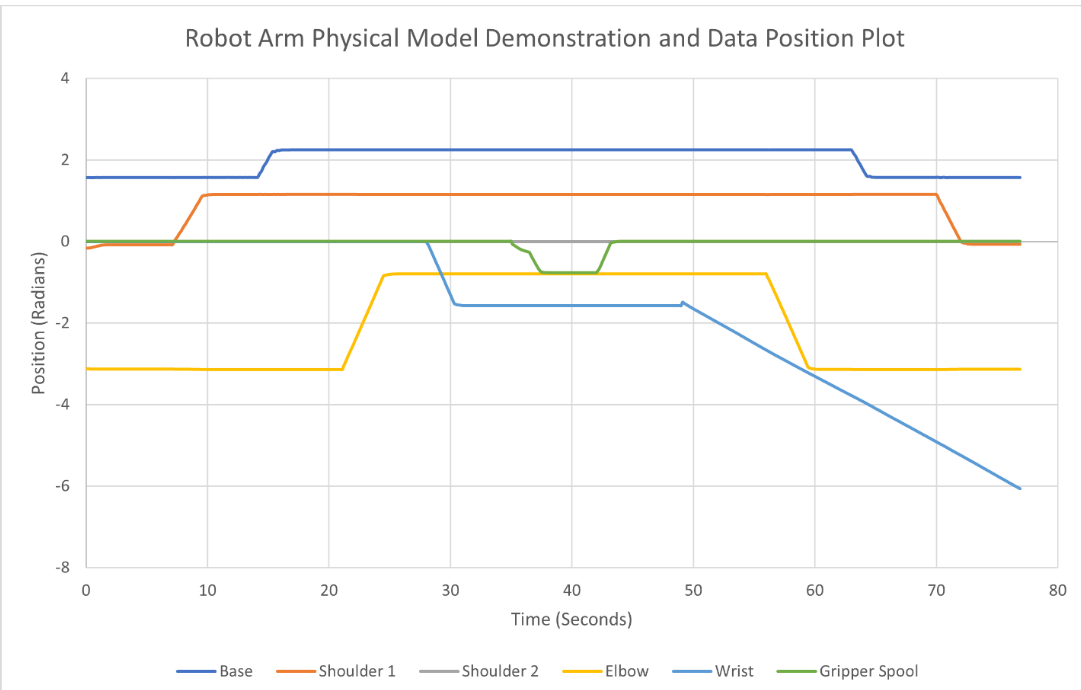

Figure 2: Multibody Robot Arm Physical Demonstration and Data Angular Position Vs. Time Plot

This graphical representation offers valuable insight into how the robot's joints behaved during the demonstration. The plot represents the motion of various joints of the robotic arm during the physical demonstration, with time on the x-axis and position (in radians) on the y-axis. The base joint (dark blue line) experiences a brief upward shift around 15 seconds, maintains its position until about 60 seconds, and then sharply moves in the negative direction returning to its original position. Shoulder 1 (orange line) shows a steady rise until 10 seconds, maintaining that position until it experiences a drop down to its original position at around 70 seconds. Shoulder 2 (gray line) remains constant throughout the demonstration and does not move. The elbow joint (yellow line) demonstrates sharp movement starting around 20 seconds, then remains in the same position until around 55 seconds where it returns to its original position. The wrist joint (light blue line) shows steady downward movement after 25 seconds, culminating in a sharp drop in its position after 50 seconds. Finally, the gripper spool (green line) remains relatively stable, showing only minor movement at around 40 seconds. Overall, this data shows that most of the robotic arm’s joints experience subtle movements all returning to their original positions besides the wrist joint.

Task 2

With the completion of task 1 that provided a position plot of the physical data of the robot a simulation plot can be created and compared to better understand how this system can be modeled using Simulink. In Task 2, the focus is on simulating the robotic arm’s motion using the premade Simulink file, which models the physical arm based on the motion profile data collected earlier. The first step is to retrieve the HEBI_5DOF_Gripper.zip file and extract its contents. Inside the extracted folder is a Simulink file (HEBI_5DOF_Gripper.slx) which contains the primary system block for the robotic arm. Upon opening the file, the model workspace must be initialized by linking it to the correct data file, HEBI_5DOF_Gripper_DataFile.m, located in the same folder. After reinitializing the data, the block diagram, which can be seen in Figure 3, should be free of errors and the system will be ready for further configuration.

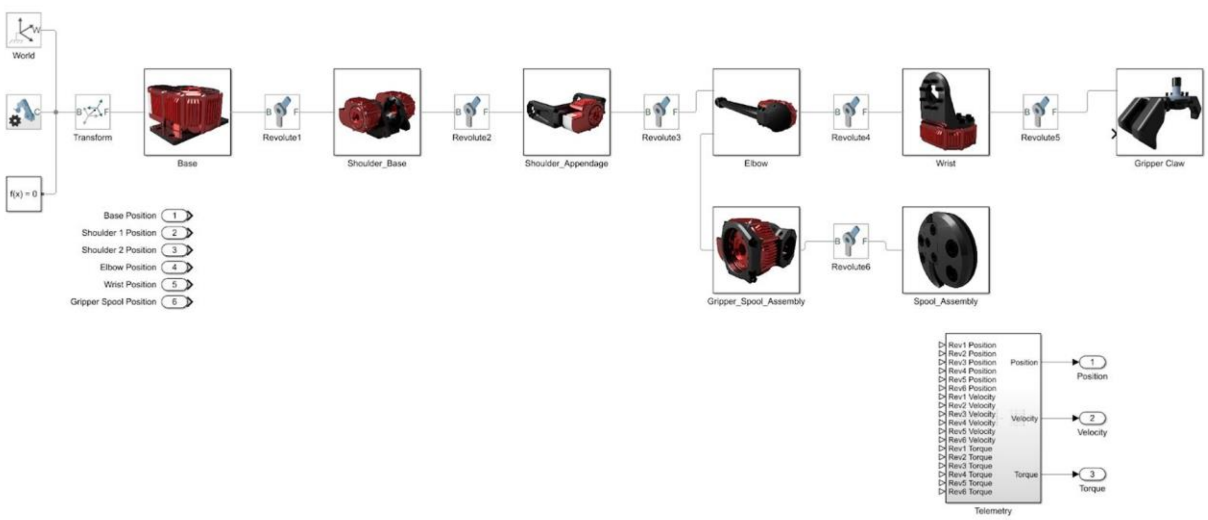

Figure 3: Multibody Robot Incomplete Initial Block Diagram Before Measurement Alterations

Next, adjustments are made to the Gravity parameter in the Mechanism Configuration block, ensuring that gravity is set in the negative Z direction to simulate Earth’s gravity. Following this, various configuration parameters such as the stop time (set to 80 seconds), solver method (set to ode23t (mod.stiff/Trapesoidal)), and maximum step size (set to 0.1 seconds) are adjusted to ensure the model runs correctly. The Revolute joints of the robotic arm are then configured by updating each joint’s parameters to ensure that the movement units are consistent and measured in radians rather than degrees. These configurations include setting the equilibrium position to 0 rad, spring stiffness to 70 N*m/rad, damping coefficient to 0 N*m/(rad/s), Torque to “Automatically Computed”, Motion to “Provided by Input”, and lastly setting the position, velocity, and actuator torque sensors to on. This setup is completed for each of the robotic arm’s six revolute joints.

Once these initial configurations are completed, Simulink-PS Converter blocks are added to convert the Simulink signals to the physical signal domain for each of the robot arm's position ports. These Simulink-PS Converter blocks are configured by setting the filtering and derivatives tab to "Filter input, derivatives calculated" and the Input filtering order tab to "Second-order filtering". These blocks are connected to the joints' respective ports, and a telemetry subsystem is configured to monitor the position, velocity, and torque for each joint. After the signal conversion and telemetry connections are complete, the Gripper Spool Subsystem is created by grouping related components, adjusting input ports, and naming the subsystem appropriately. The subsystem is then assigned an image, representing what the subsystem looks like, and resized to match the dimensions of other subsystems in the diagram, maintaining visual consistency in the block diagram. The final complete block diagram of this system can be seen in Figure 4.

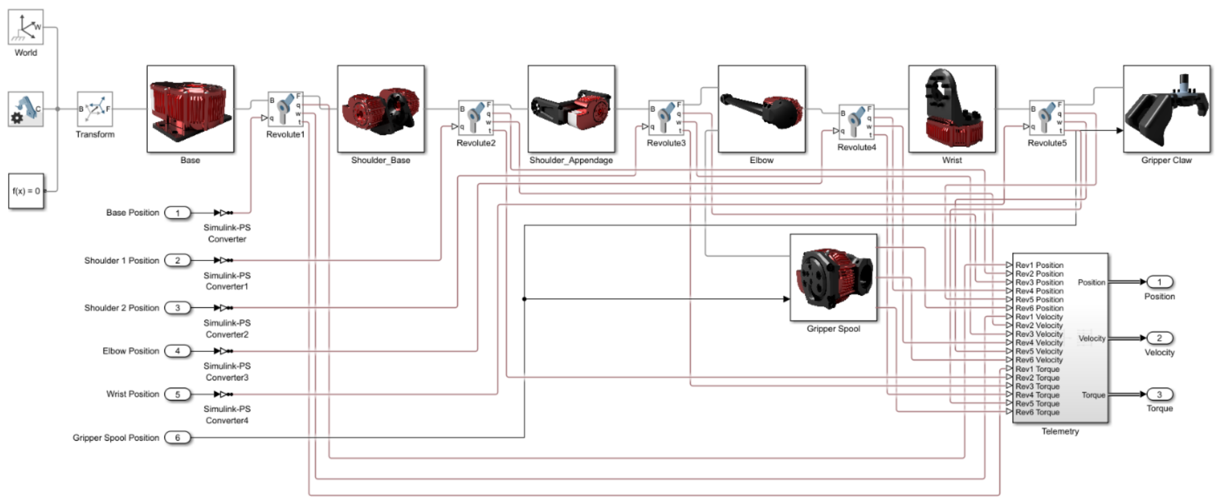

Figure 4: Multibody Robot Complete Final Block Diagram After Measurement Alterations

The final steps involve setting up a Signal Editor block, which will import the previously collected motion profile data from the HEBI_motion_profile.xlsx file. The Signal Editor then generates output signals for each joint's position over time, which are connected to the respective input ports on the robotic arm subsystem. A Scope block is added to visualize the results, providing plots of the position, velocity, and torque for each joint during the simulation. The final complete block diagram of this system can be seen in Figure 5.

Figure 5: Complete HEBI 5DOF Gripper System Block Diagram

After ensuring proper formatting and layout for the simulation results, the model is run, allowing for observation of the simulated robotic arm's movements. The final plot of the position of all the joints can be seen in Figure 6.

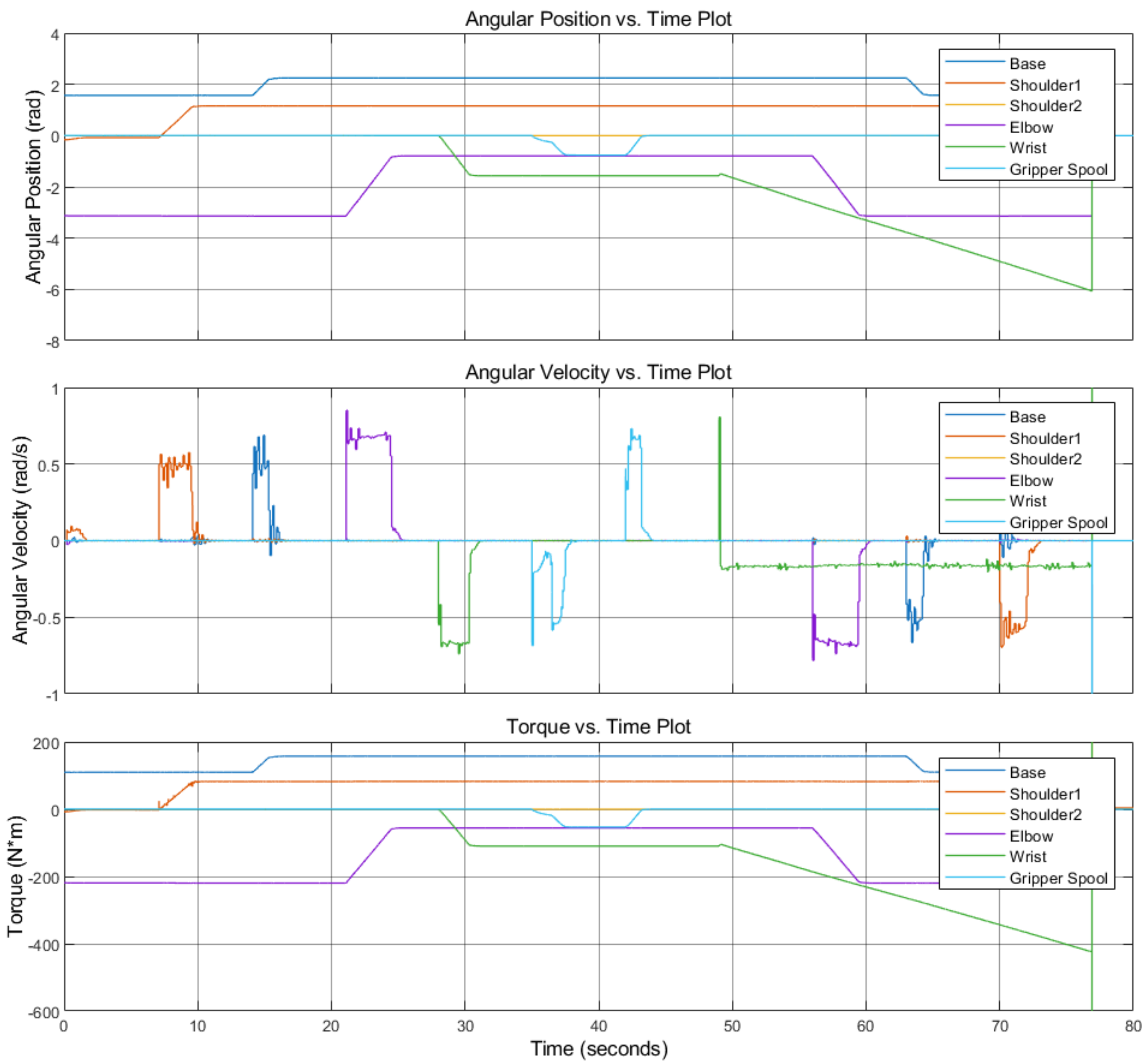

Figure 6: Multibody Robot Arm Angular Position, Angular Velocity, and Torque Vs. Time Simulation Plot

The three resulting plots from Task 2, angular position, angular velocity, and torque versus time, offer valuable insights into the simulated robotic arm's behavior and its comparison with the physical arm from Task 1. Beginning with the angular position plot, the data closely aligns with the corresponding plot from Task 1, suggesting that the simulated model replicates the physical arm's movement profile quite accurately. For instance, the base joint (represented by the blue line) follows a downward trend around the 60-second mark, mirroring the same behavior seen in the physical model's plot. While the angular position data confirms the consistency between the two tasks, the angular velocity plot in Task 2 adds further detail. This plot highlights the speed at which each joint moves during the simulation, offering insights that were not present in the Task

1 physical demonstration. The spikes in angular velocity reflect moments of rapid movement, such as when the base and elbow joints undergo significant position changes between 55 seconds to 65 seconds. In contrast, the wrist joint has a much more controlled velocity profile, indicating smoother, less abrupt movements compared to the base and elbow joints. These velocity changes provide a more granular view of how the robotic arm transitions between positions. Lastly, the torque plot in Task 2 shows the forces applied to each joint during the simulation. The torque values are directly proportional to the position values as seen by it being an exact mirror image of the position plot. Overall, the plots from Task 2 not only mirror the physical arm's behavior from Task 1 but also provide additional data on angular velocity and torque, which were absent in the first task. This allows for a deeper understanding of the robotic arm's dynamics, reinforcing the accuracy of the Simulink model in replicating the actual system's performance.

Further analysis of the robot's position can be conducted at certain points throughout its 80 second movement in the mechanics explorer window. An example of this can be seen in Figure 7 which shows the HEBI arm in its entirety with the gripper facing the camera at the 40th second.

Figure 7: Multibody Robot Within Mechanics Explorer Simulation Window Position at 40 Seconds

Inside of the Simulink Scope block there are measurement tools that can be used to gain valuable insight into the movement of the robot. Accessing these tools can be done by using the Cursor Measurements tool within the top toolbar to toggle on the "Cursor Measurements", "Signal Statistics", and the "Peak Finder" side panel tools. An example of what the scope should look like with these tools enabled is shown in Figure 8.

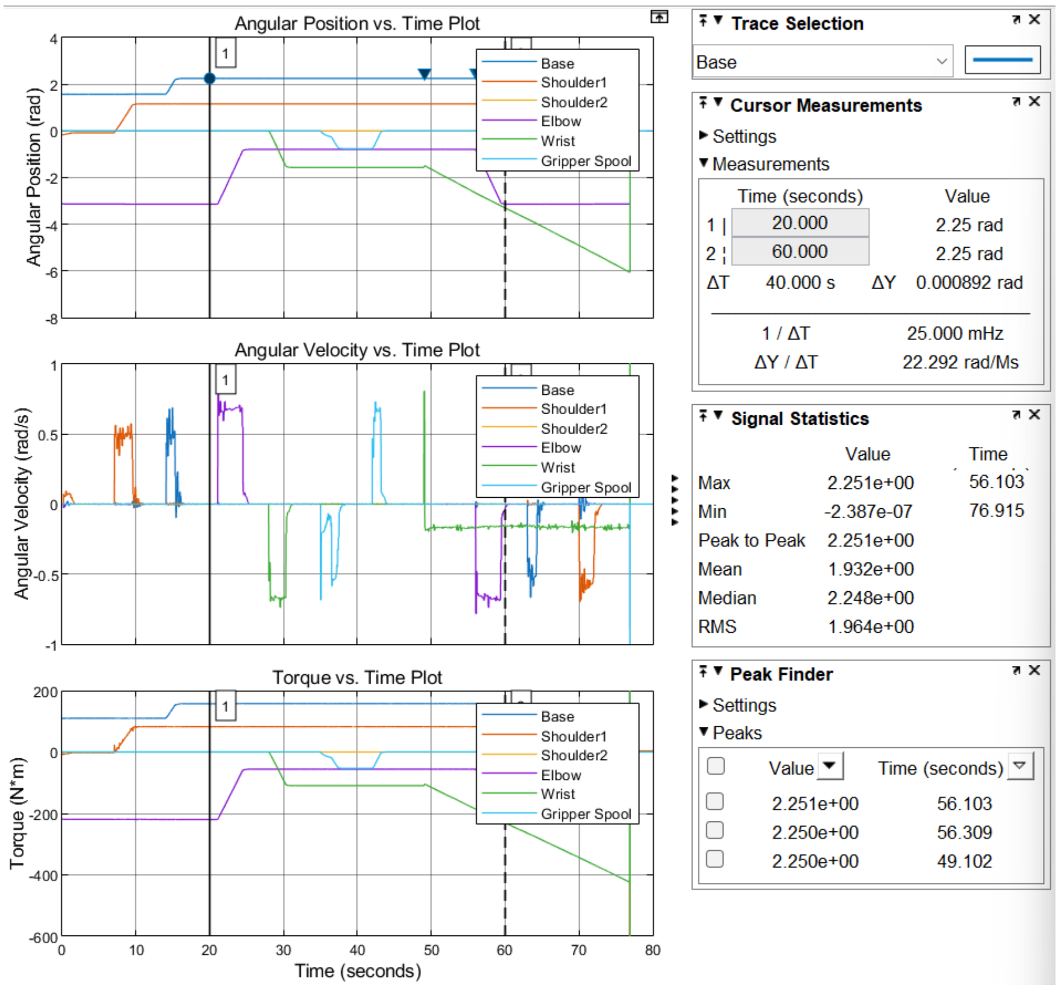

Figure 8: View of Multibody Robot Arm Scope with Measurement Tools Enabled

Using these tools the position of the base, shoulder1, and gripper spool joints of the robot arm at the 40th second can be determined. These results can be seen in Table 1.

Table 1: Measured Values for Angular Position of Multibody Robot Joints at 40 Seconds

	Position (rad)
Base	2.25
Shoulder 1	1.16
Gripper Spool	-0.767

Using these tools again the peak velocity and peak torque of the base, shoulder1, and gripper spool joints of the robot arm can be determined. These results can be seen in Table 2.

Table 2: Measured Peak Values for Angular Velocity and Torque of Multibody Robot Joints

	Peak Velocity (rad/s)	**Peak Torque (N*m)**
Base	0.6879	142.5
Shoulder 1	0.5754	76.20
Gripper Spool	0.7306	33.18

Using the peak finder tool and signal statistics tool provided values well outside of the expected range of values for the max/ peak values for certain traces. Usually, these values were towards the end of the simulation when erratic behavior in the plots occurs (Around 76.9 seconds to be exact). So, using common reasoning the value that seemed the most relevant and applicable out of the peak values was selected. This value being selected was usually the second or third peak finder value that isn't around that 76.9 second mark.

The values in Tables 1 and 2 provide key insights into the behavior of the robotic arm joints, specifically, the base, shoulder 1, and gripper spool, at different time points and operational metrics. At the 40th second, the base joint has an angular position of 2.25 radians, indicating that the base is rotated approximately 129 degrees from its initial position. This suggests that the base has undergone significant movement, potentially to position the arm in an optimal orientation for further operations or reaching a target. The shoulder 1 joint has a position of 1.16 radians, or roughly 66.5 degrees, showing a moderate elevation of the arm, which is critical in positioning the end effector (gripper) for precise tasks. The gripper spool joint, which directly controls the movement of the gripper mechanism, is at -0.767 radians (about -44 degrees), indicating that the gripper has moved into a closed or gripping position, aligning with the arm's purpose at this stage in the operation. This is reflected in the image of the position of the arm at 40 seconds shown previously.

The peak values for angular velocity and torque provide insight into the dynamic behavior and forces acting on each joint. For the base joint, the peak velocity is 0.6879 rad/s, indicating a relatively moderate speed at which the base moves when it reaches its fastest motion during the operation. The corresponding peak torque is 142.5 N*m, showing that significant force is applied to move the base, which is expected as it handles the rotational movement of the entire arm. For shoulder 1, the peak velocity is slightly lower at 0.5754 rad/s, reflecting a more controlled movement compared to the base, possibly because shoulder joints typically need to adjust in finer increments for precision tasks. The peak torque of 76.2 N*m suggests moderate resistance or force required to move this joint, which is lower than that of the base, likely due to the smaller load carried by the shoulder joint compared to the base. Lastly, the gripper spool shows the highest peak velocity at 0.7306 rad/s, indicating rapid movement in the gripping mechanism, which aligns with the function of quickly opening or closing the gripper for object manipulation. Despite this high velocity, the peak torque is the lowest among the three joints at 33.18 N*m, which makes sense as the gripper spool generally deals with less mechanical resistance compared to larger joints like the base or shoulder.

These measurements suggest that the robotic arm's design and control prioritize the base's rotational movement and the gripper's ability to rapidly adjust. The relatively high torque and angular position of the base reflect its central role in positioning the arm, while the rapid velocity and moderate torque of the gripper spool show that quick but low-force adjustments are made to complete tasks. The shoulder 1 joint's moderate velocity and torque indicate that it plays a supporting role, ensuring smooth and accurate movement in lifting and positioning the arm during operation. These values demonstrate that each joint's characteristics are optimized for specific roles, balancing speed, force, and precision.

Conclusion

Lab 6 provided an in-depth exploration of simulating the movement of a 5-degree-of-freedom (DOF) robotic arm using real-world motion profile data. Through this lab, key concepts related to the manipulation and dynamic simulation of robotic systems were emphasized. Task 1 analyzed the motion data from a physical demonstration, providing a graphical representation that highlighted how each joint of the arm behaved over time. This data offered a clear understanding of the robotic arm's physical movement, setting the stage for the simulation in Task 2. In Task 2, the collected motion profile data was imported into a pre-made Simulink model of the robotic arm, allowing for the simulation of its dynamic behavior. The process involved configuring revolute joints, adjusting parameters like gravity, and setting up a telemetry subsystem to monitor the position, velocity, and torque of each joint. The final simulation closely replicated the physical arm's movements while providing additional insights into angular velocity and torque, data that was not available in the physical demonstration. Overall, Lab 6 reinforced the importance of configuring and simulating dynamic systems in engineering. It highlighted the ability to analyze and interpret the behavior of robotic systems through both physical demonstrations and simulations, offering valuable skills in model-based design, control, and mechanical analysis. The lab demonstrated how motion data can be used to create accurate simulations, enhancing the individuals understanding of robotic arm dynamics and system modeling in MATLAB and Simulink.

References

[1] Author not listed, *Texas A&M University MXET375 - Lab 06 - Importing Solid Model Parts & Assemblies*. College Station, TX, USA: Date not listed.
[2] Rex K., *MXET375 - Kyle Rex - Lab Report 5*. College Station, TX, USA: 10/10/2024.