EXERCISE NO.: 3

MODELLING OF A POSITION CONTROLLED PLANAR MECHANISM METHOD 2

DATE: 28-08-2020

Reg. No.: RA1711018010101

LAB PREREQUISITES:

Introduction to Physical Modelling

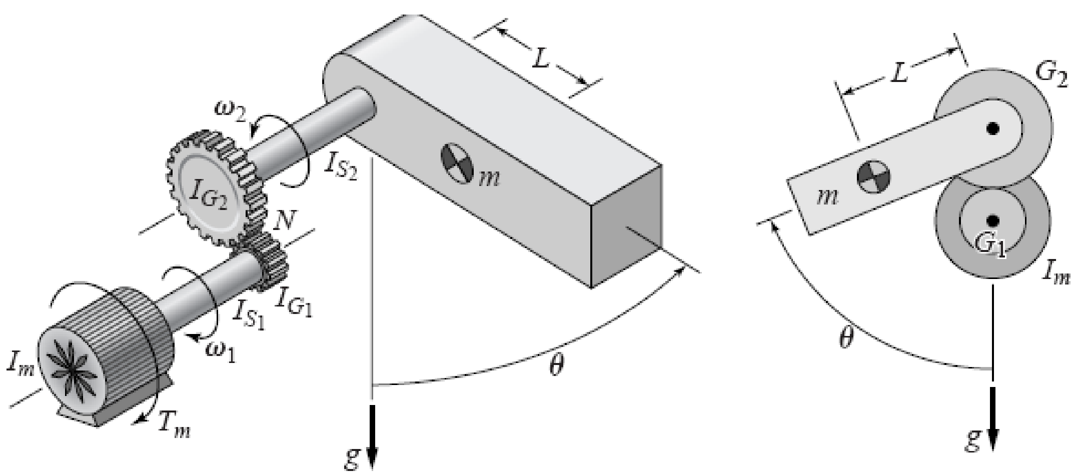
PREREQUISITE KNOWLEDGE:

Fundamentals of SIMULINK modelling of physical systems.

OBJECTIVES:

- To model a one degree of freedom joint constituting a planar mechanism using the SimMechanics Library in Simscape.
- Understand the dynamics of the mechanism for an applied torque by the actuating element with a suitable drive.
- To add a controller to the actuator connected to the mechanism and observe the controlled behavior.

THEORY



Dimensions of the Links

Physical Parameter	**Specification**
Fixed Pivot	
Length	4 cm
Width	4 cm
Thickness	4 cm
Density	2700 kg/m^3
Driven Link	
Length	20 cm
Width	1 cm
Thickness	1 cm
Density	2700 kg/m^3

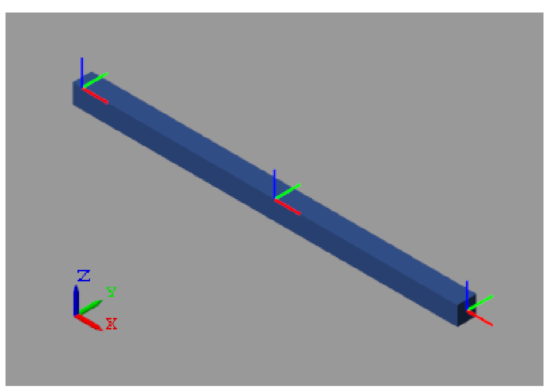
Modelling Gravitational Torque

SimMechanics automatically model the effect of gravity on rigid based on the geometry, density and rigid body pose transformations involved.

EXERCISE TASKS

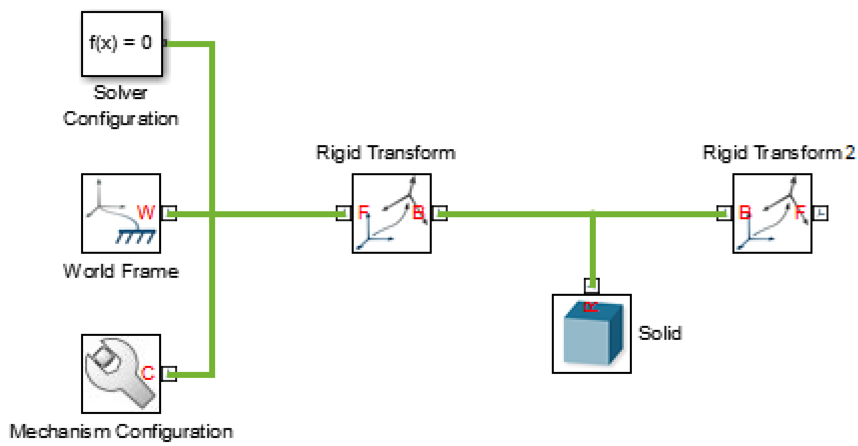
<u>Task 1 : Modelling of a Link in SimMechanics</u>

- Model adriven link as per the dimensions given in the table.
- Follow the procedures listed below,after which the link must look something like the following image



Procedure for Link Modelling

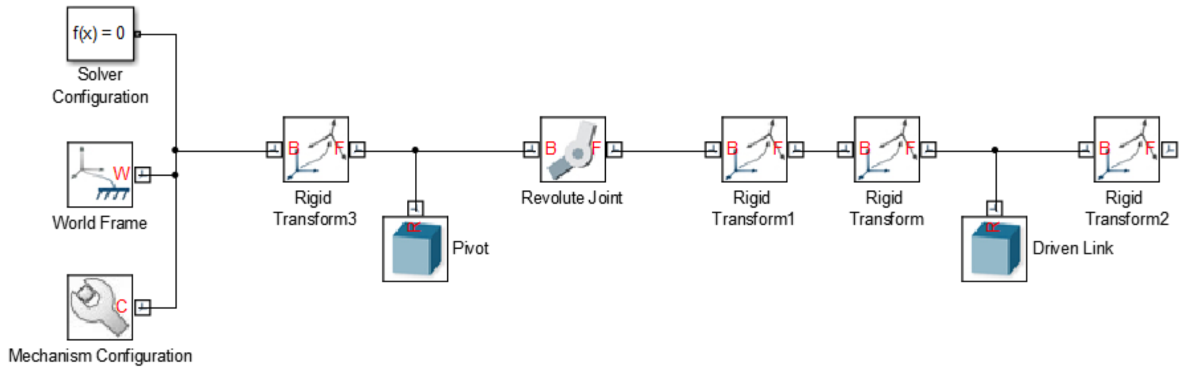
1. At the MATLAB® command line, enter `smnew`. The SimscapeMultibody block library and a model template with commonly used blocks open up.
2. Make a copy of the Rigid Transform block and paste it in the model. The Rigid Transform blocks enable you to create new frames to which you can connect joints during multibody assembly.
3. Delete the blocks Simulink-PS Converter, PS-Simulink Converter, and Scope. These blocks are required in this task.
4. Connect the remaining blocks as shown in the figure. Ensure that the base frame ports (B) of the Rigid Transform blocks both face the Solid block frame port. Since each Rigid Transform block applies a spatial transformation with respect to its base frame, switching port connections generally changes the spatial relationship between the two frames.



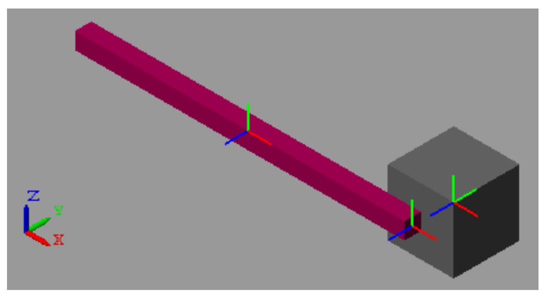
Parameter	Rigid Transform	Rigid Transform2	Units
Translation > **Method**	Standard Axis	Standard Axis	Not applicable
Translation > **Axis**	-X	+X	Not applicable
Translation > **Offset**	Length/2 = 10	Length/2 = 10	Change to cm

Task 2: Modelling of a Mechanism in SimMechanics

- Model a planar mechanism consisting of the pivot link and the driven link connected by a revolute joint.Choose all the dimensions as per the details given in the table.
- Connect the blocks as shown in the figure below



- Choose the rigid configurations such that the mechanism after modelling must look something similar the figure below:



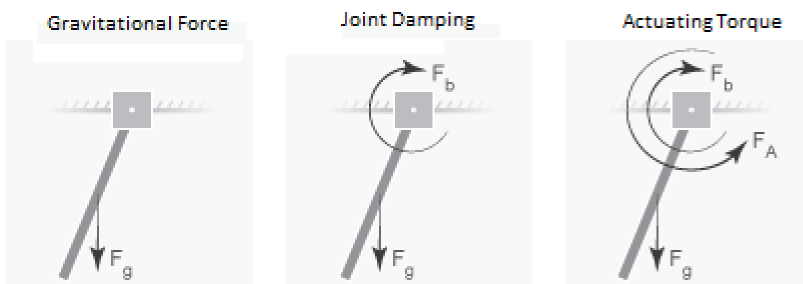
Task 3: Analysis of the Dynamic Response of the Model

The forces and torques applicable to this system under consideration are as follows which are indicated in the figure below:

Gravitational force (F_g) — Global force, acting on every rigid body in direct proportion to its mass, that you specify in terms of the acceleration vector g. You specify this vector using the Mechanism Configuration block.

Joint damping (F_b) — Internal torque, between the pendulum and the joint fixture, that you parameterize in terms of a linear damping coefficient. You specify this parameter using the Revolute Joint block that connects the pendulum to the joint fixture.

Actuation torque (F_A) — Driving torque, between the pendulum and the joint fixture, that you prescribe directly as a Simscape physical signal. You prescribe this signal using the Revolute Joint block that connects the pendulum to the joint fixture.



- Sense pendulum motion under three different operating conditions such as
  - Undamped
    - Plot the joint position and velocity with respect to time.
    - Plot the joint angular velocity with respect to the angular position.
    - The phase plot of the joint corresponding to a starting position of zero degrees with respect to the horizontal plane.
  - Damped (add a damping of 8e-5 (N*m)/(deg/s))
    - The damping coefficient causes energy dissipation during motion, resulting in a gradual decay of the pendulum oscillation amplitude.
    - Ensure that State Targets → Position → Value is set to 0 deg.
    - Plot the joint position and velocity with respect to time.
    - Plot the joint phase plot.
  - Driven
    - In the Sine Wave block dialog box, set Amplitude to 0.06. This amplitude corresponds to an actuation torque oscillating between -0.06 N and 0.06 N.
    - In the Revolute Joint block dialog box, ensure that State Targets → Position → Value is set to 0 deg.
    - Plot the joint position and velocity with respect to time.
    - Plot the joint phase plot.
  - Use MATLAB to plot all the data by transferring the required variables to workspace.

Task 4: Actuation to Mechanism (Practice Exercise)

- Add a DC motor as a torque source to the joint with suitable specification.
- Add an H-bridge drive to motor which can switch directions and take PWM command signal which switches direction.
- Observe the effect of changing PWM duty cycle and motor specifications on the link's motion.

Note the benefit of Model-Based Design: It is possible to model the entire system from multi disciplines without any approximation and observe the interactions in one platform.

DELIVERABLES

Task 1

- Image of the SimMechanics explorer window showing the developed link and all the coordinate frames

Task 2

- Image of the SimMechanics explorer window showing the developed link with the pivot block connected with a revolute joint and all the coordinate frames

Task 3

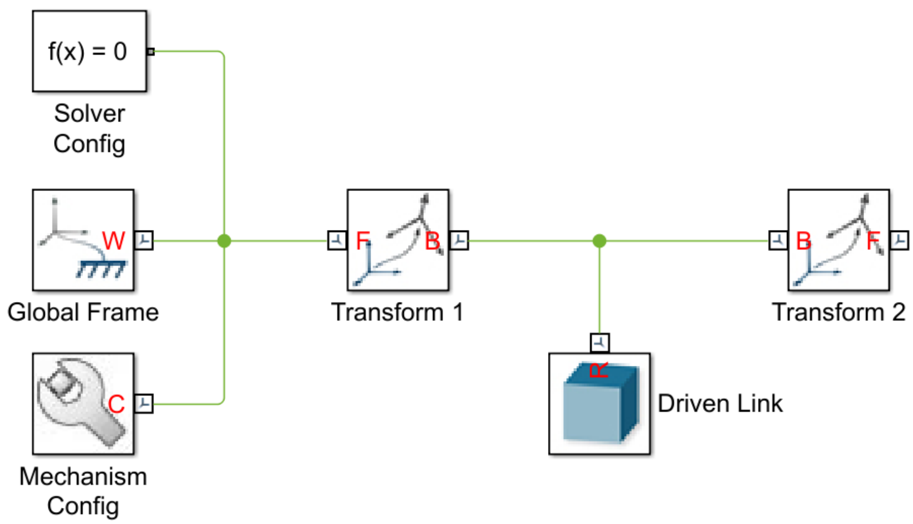
- Plot of joint angle and joint velocity vs. time on the same figure for all the following cases
  - Undamped
  - Damped
  - Driven
- Plot of joint angle vs. joint velocity for all the following cases
  - Undamped
  - Damped
  - Driven

Task 4

- Plot of link's velocity vs. time for at least two different motor specifications.
- Plot of link's velocity vs. time for atleast two different PWM duty signals.

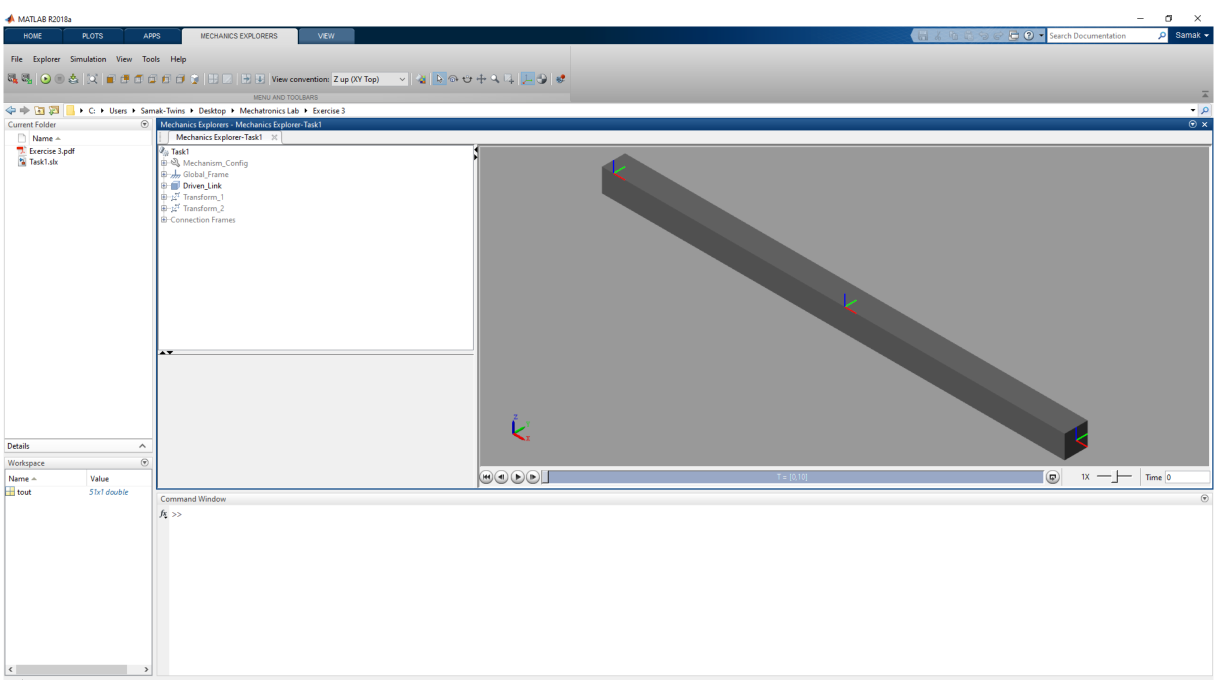
TASK 1: Modelling of a Link in SimMechanics

Block Diagram:



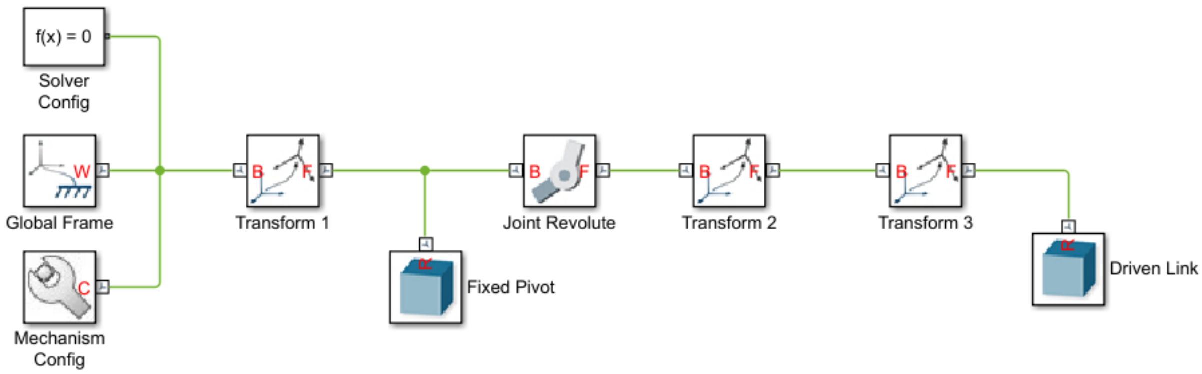
Deliverables:

1. Following is the image of the SimMechanics explorer window showing the developed link and all the coordinate frames.



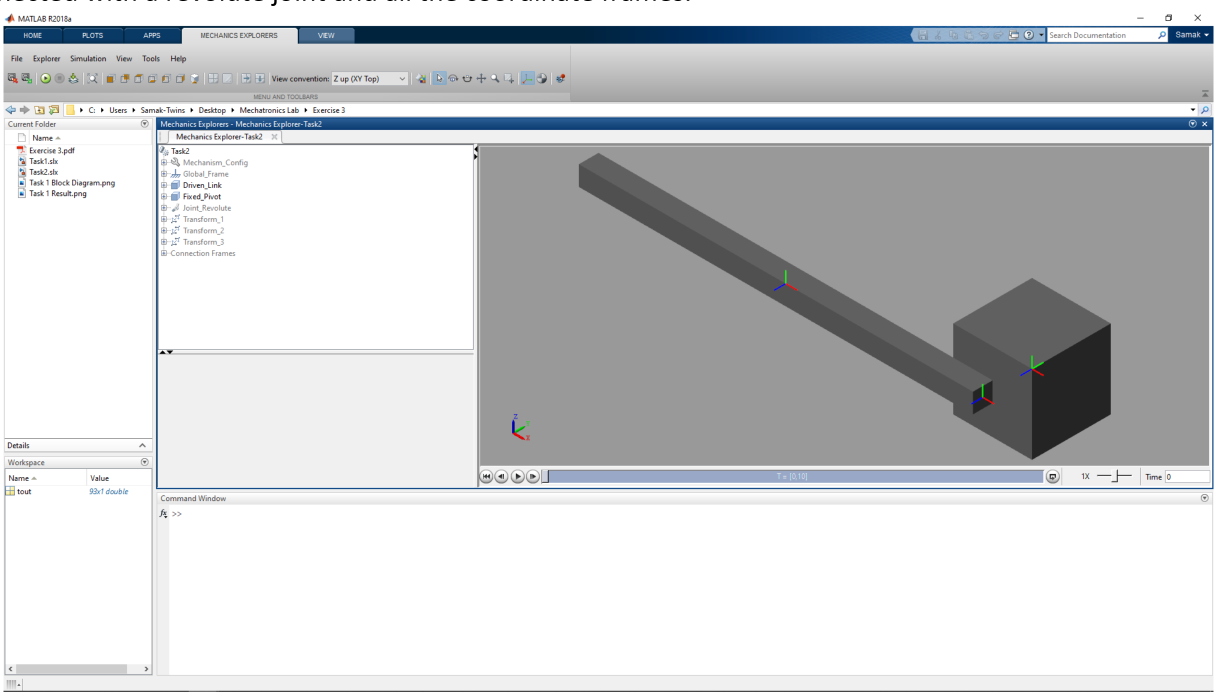
TASK 2: Modelling of a Mechanism in SimMechanics

Block Diagram:



Deliverables:

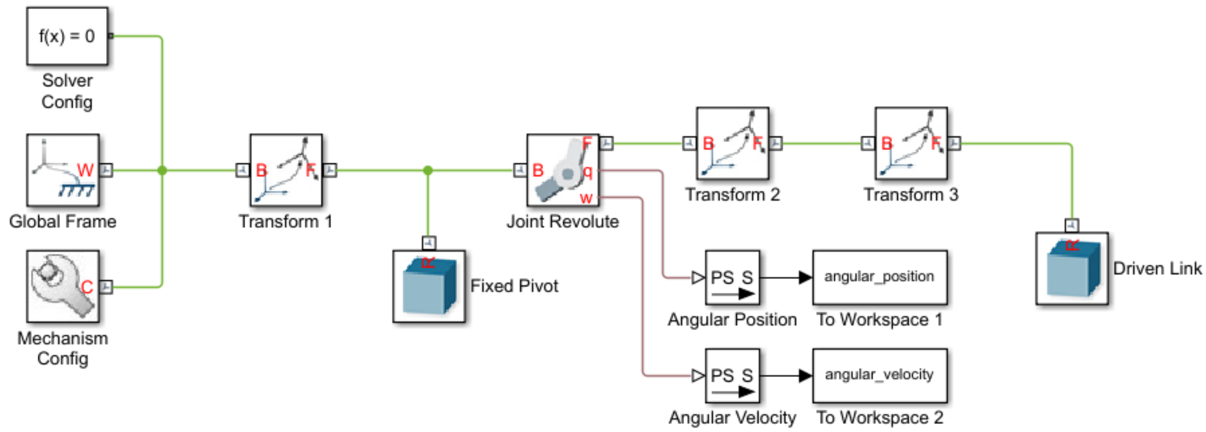
1. Following is the image of the SimMechanics explorer window showing the developed link with the pivot block connected with a revolute joint and all the coordinate frames.



TASK 3: Analysis of the Dynamic Response of the Model

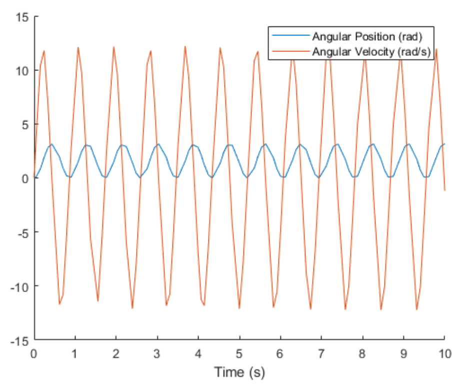
3.1: Undamped Revolute Joint

Block Diagram:

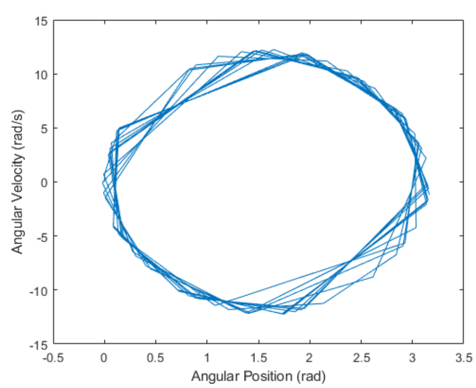


Deliverables:

1. Following is the plot of joint angle (rad) and joint velocity (rad/s) w.r.t. time (s) for undamped revolute joint

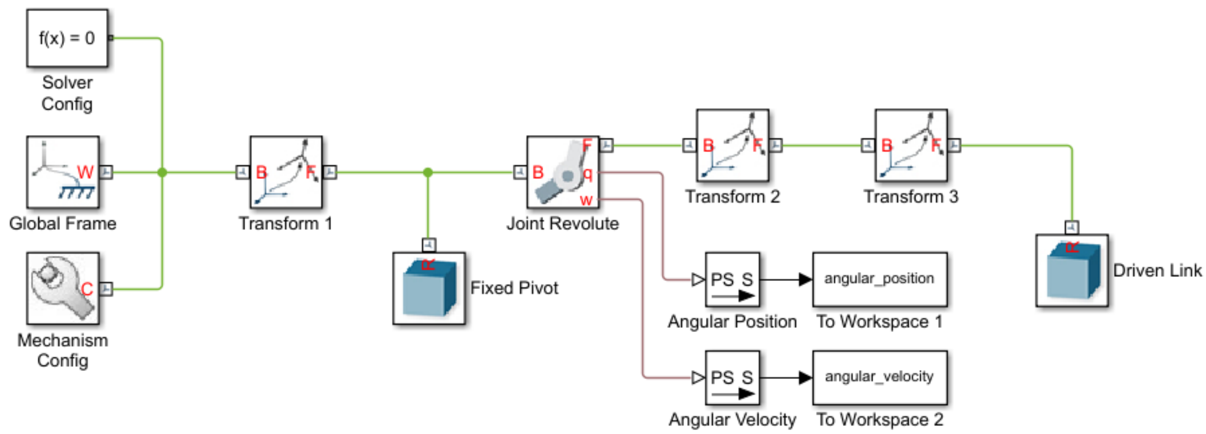


2. Following is the plot of joint angle (rad) vs. joint velocity (rad/s) for undamped revolute joint



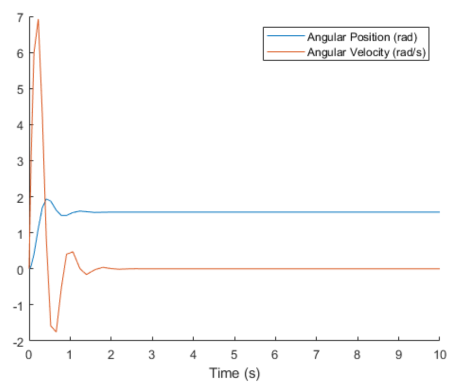
3.2: Damped Revolute Joint

Block Diagram:

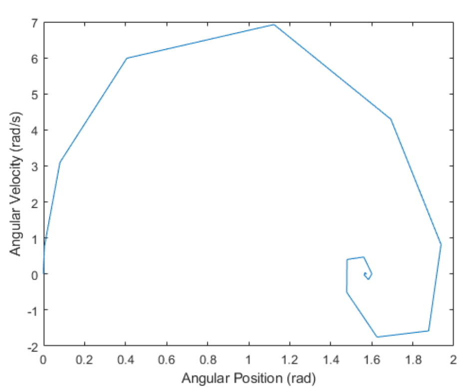


Deliverables:

1. Following is the plot of joint angle (rad) and joint velocity (rad/s) w.r.t. time (s) for damped revolute joint

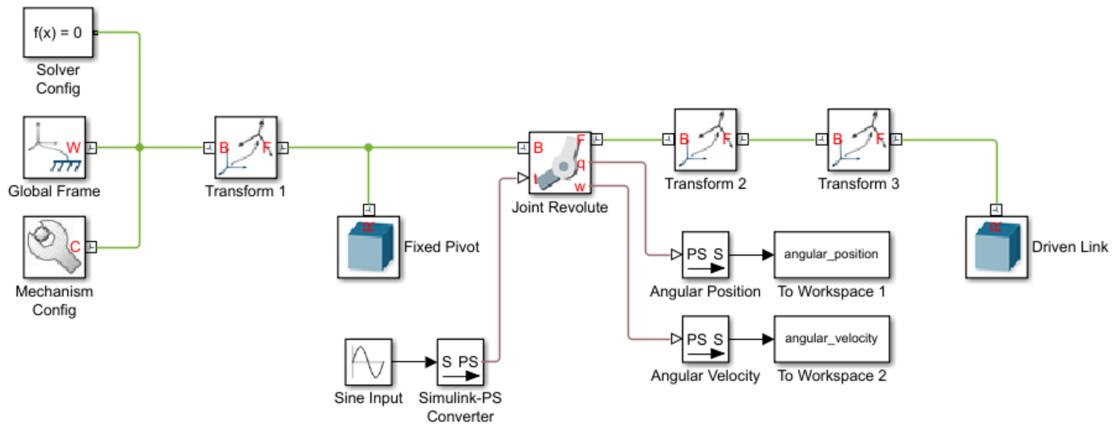


2. Following is the plot of joint angle (rad) vs. joint velocity (rad/s) for damped revolute joint



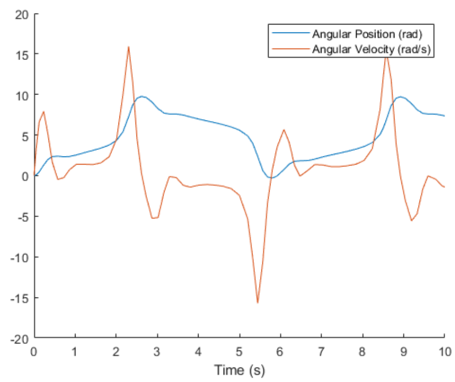
3.3: Driven Revolute Joint

Block Diagram:

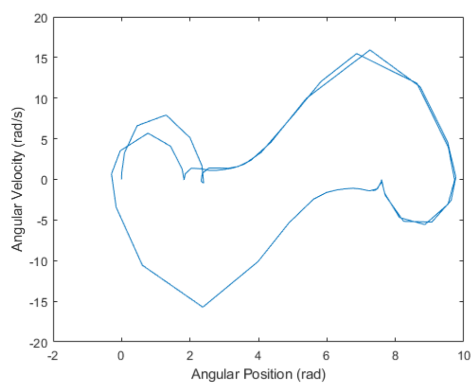


Deliverables:

1. Following is the plot of joint angle (rad) and joint velocity (rad/s) w.r.t. time (s) for driven revolute joint

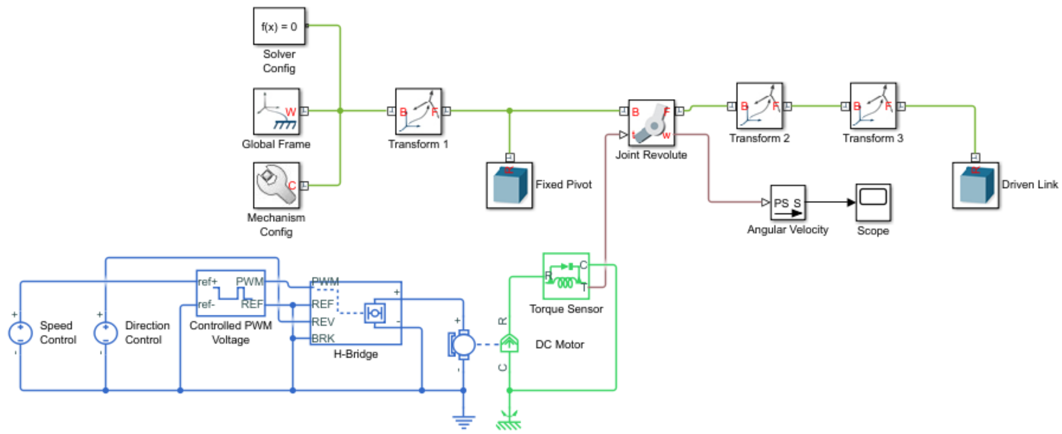


2. Following is the plot of joint angle (rad) vs. joint velocity (rad/s) for driven revolute joint



TASK 4: Actuation to Mechanism

Block Diagram:



PWM Specifications:

- **Voltage Range:** 0-5 V (0-100% Duty Cycle)
- **Switching Frequency:** 1000 Hz

H-Bridge Specifications:

- **Enable Threshold Voltage:** 2.5 V
- **PWM Signal Amplitude:** 5 V
- **Reverse Threshold Voltage:** 2.5V
- **Braking Threshold Voltage:** 2.5V
- **Output Voltage Amplitude:** 12 V
- **Total Bridge Resistance:** 0.1 Ohm
- **Freewheeling Diode Resistance:** 0.05 Ohm

Control Voltage Specifications:

- **Speed Control Voltage:** 0-5 V DC
- **Direction Control Voltage:** 5 V AC (0.05 Hz)

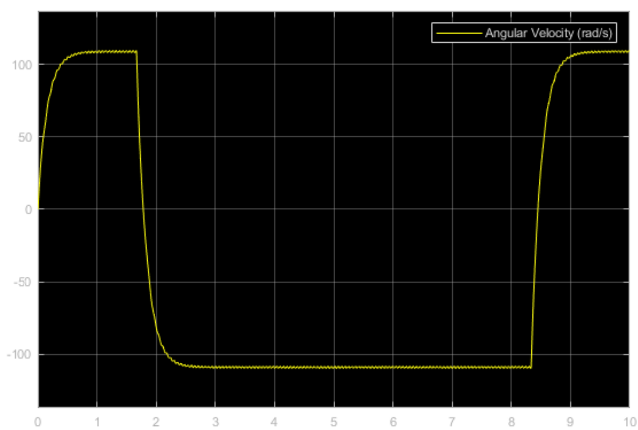
Motor Specifications:

- **Motor 1:**
  - **Armature Resistance:** 0.5 Ohm
  - **Armature Inductance:** 0.002 H
  - **Torque Constant:** 0.05 N*m/A
  - **Rotor Inertia:** 9e-5 kg*m^2
  - **Rotor Damping:** 0 N*m/(rad/s)
  - **Initial Rotor Speed:** 0 rpm

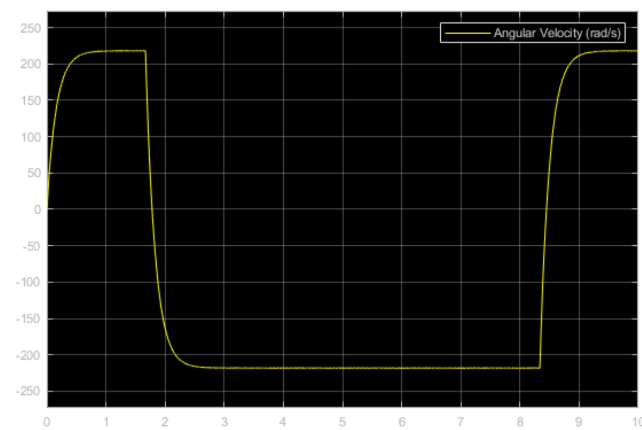
- **Motor 2:**
    - **Armature Resistance:** 0.2 Ohm
    - **Armature Inductance:** 0.005 H
    - **Torque Constant:** 0.1 N*m/A
    - **Rotor Inertia:** 5e-4 kg*m^2
    - **Rotor Damping:** 0 N*m/(rad/s)
    - **Initial Rotor Speed:** 0 rpm

Deliverables:

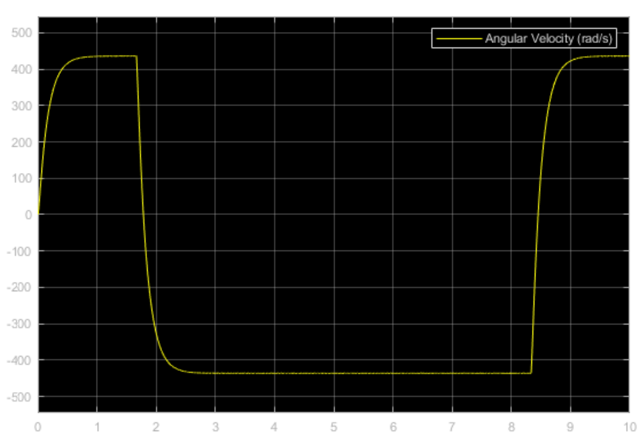
1. Following are the plots of joint velocity (rad/s) w.r.t. time (s) for 2 different motor specifications and 2 different PWM duty cycles



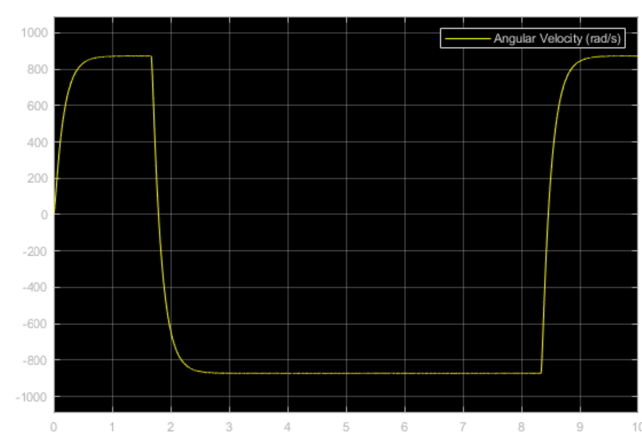
Motor 1 – 50% Duty Cycle



Motor 1 – 100% Duty Cycle

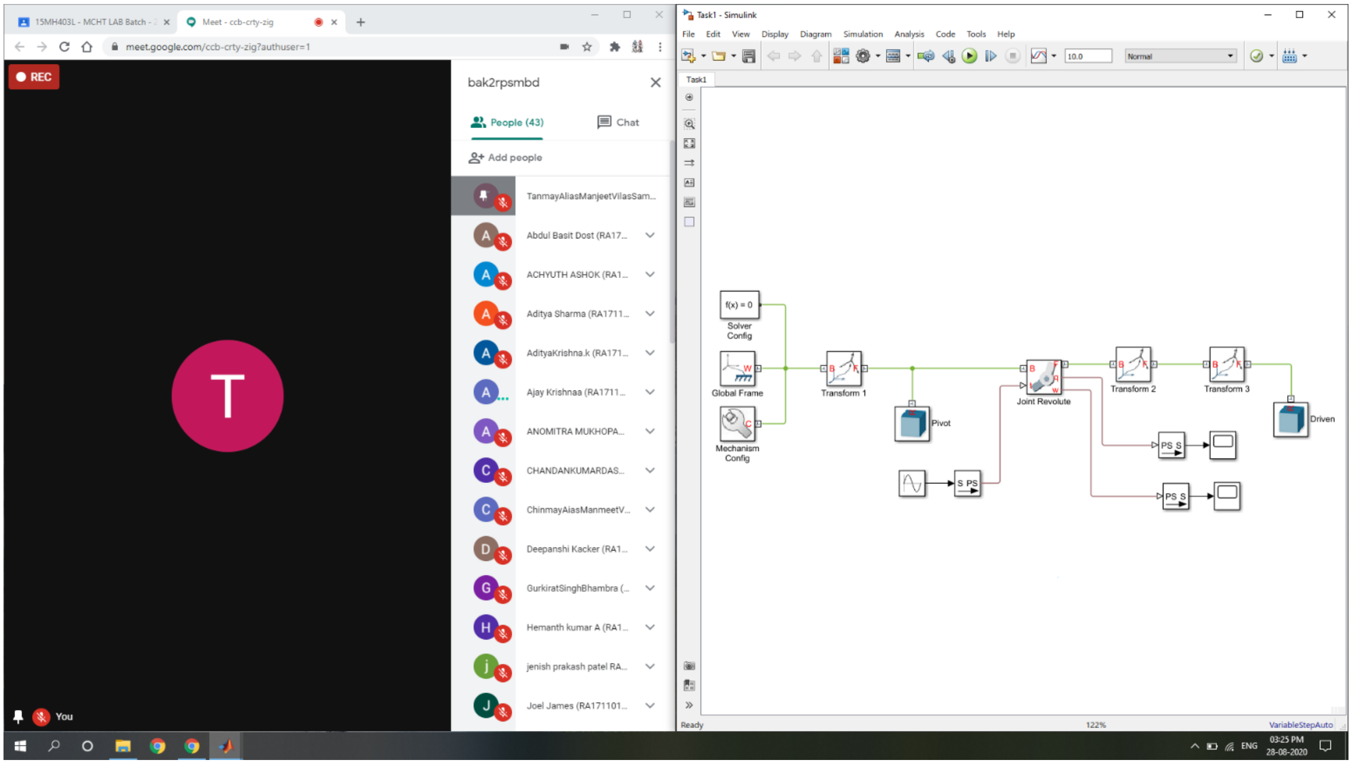


Motor 2 – 50% Duty Cycle



Motor 2 – 100% Duty Cycle

LAB SESSION SCREENSHOT



INFERENCE

This experiment gave a deeper understanding about physical modeling using SimMechanics (a simplified yet powerful approach to dynamic system modelling) and simulation of dynamic systems using a case study of a simple 1 DOF (rotational) mechanism, which is a typical mechatronics-based design approach. Moreover, the various tasks in this exercise helped gain a step by step knowledge about physical modeling of the said mechanism starting with minimal required components (Driven Link with appropriate Coordinate Transforms w.r.t. World Frame and gravity along negative z-axis configured using Mechanism Configuration block) and then gradually adding more (Pivot, Revolute Joint, Voltage Sources, Controlled PWM Voltage, H-Bridge, DC Motor, etc.) in the subsequent tasks to get a more detailed physical model. That being said, there is still a room for adding physical aspects such as gearbox, friction, damping, drag, actuator saturation limits, etc. in order to obtain a more realistic physical model of the system.

From this experiment, it is evident that MATLAB - Simulink is a very powerful tool when it comes to modelling and simulation of dynamic systems ranging from simple 1-DOF mechanisms (as modeled and simulated in this exercise) to highly complex multi-disciplinary systems. It provides a range of built-in functions and toolboxes for rapid system analysis across multiple representation types (including Simulink as well as Physical System blocks – it is an important inference that Simulink blocks represent only numerical data whereas Physical System blocks represent a specific physical quantity along with its associated unit/dimension).