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2 DOF Robot Experiment for LabVIEW™ Users

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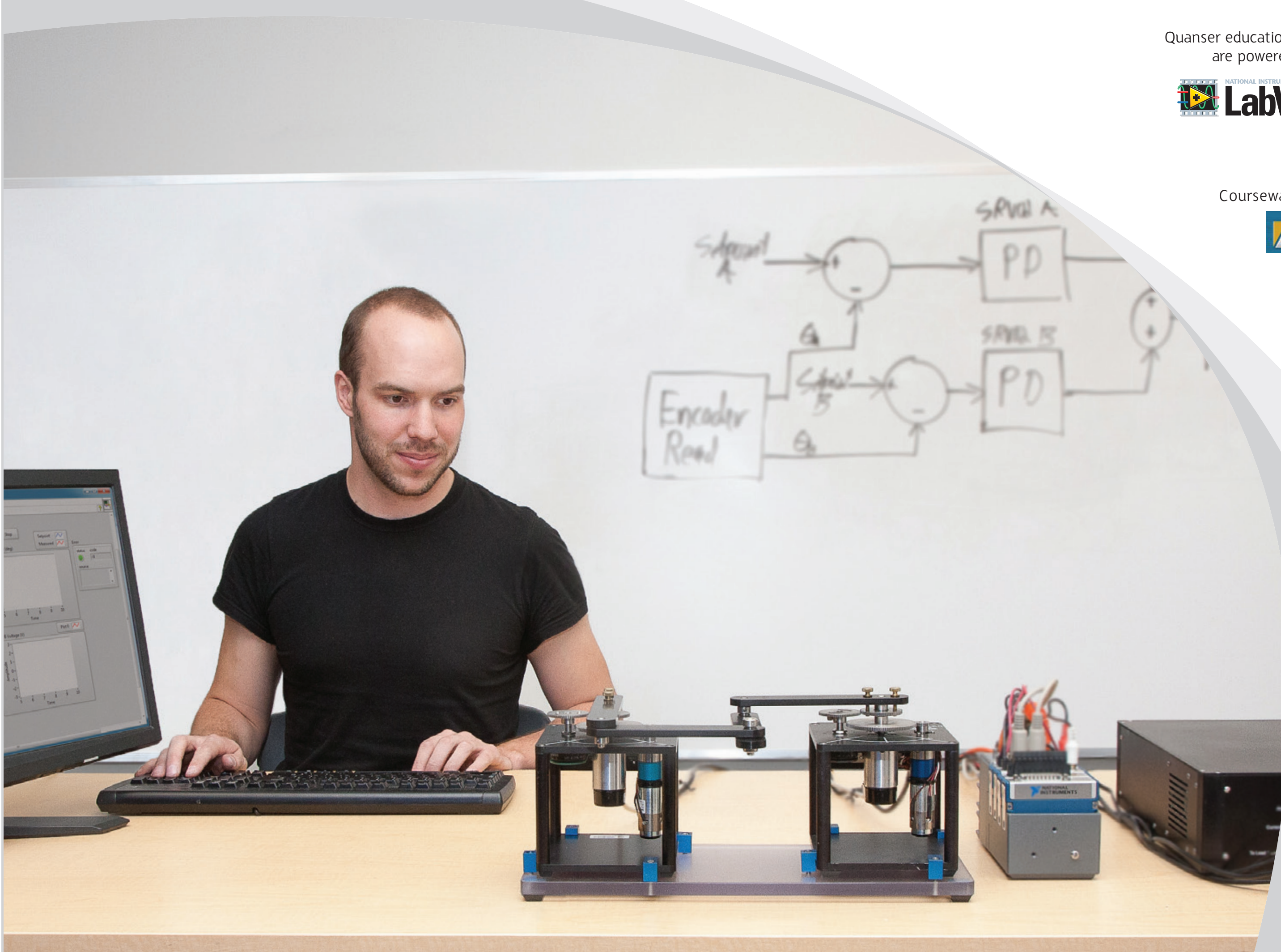

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CONTENTS

1 INTRODUCTION

The challenge in this experiment is to design a controller that manipulates the tip of a two degree of freedom (2 DOF) pantograph type robot. The Quanser 2 DOF Robot is composed of two Quanser Rotary Servo Base Units (SRV02) connected together with a four-bar linkage. See the 2 DOF Robot User Manual [2] for information about the system.

In order to control the X-Y position of the end-effector (i.e., the tip of the robot links), the direct and inverse kinematics of the mechanism must be derived. This is an experiment in kinematic control rather than dynamical control. The servo or joint space control is done using PD-based control.

Topics Covered

- Design PD-based control to position the servo (i.e., robot joint) angles according to certain specifications, i.e., the *joint space* control.
- Simulate the joint space control and ensure it meets the given specifications.
- Run the joint space control on the actual 2 DOF Robot system.
- Find direct (or forward) kinematics and inverse kinematics of a 2 DOF pantograph type robot.
- Using the two PD control loops on the servos with the kinematics, simulate the closed-loop X-Y positioning of the end-effector, i.e., simulate the *workspace* control.
- Implement the workspace controller on the 2 DOF Robot system.

Prerequisites

In order to successfully carry out this laboratory, the user should be familiar with the following:

1. See the system requirements in Section 5 for the required hardware and software.
2. Transfer function fundamentals, e.g., obtaining a transfer function from a differential equation.
3. Proportional-velocity control detailed in the *Position Control* lab in the SRV02 Workbook [1].
4. Basics of LabVIEW™ .
5. LabVIEW Integration lab detailed in Appendix A in the SRV02 Workbook [1].

2 SYSTEM REPRESENTATION

The 2 DOF planar manipulator is shown in Figure 2.1. As documented in the 2 DOF Robot User Manual [2], the two Quanser Rotary Servo units are named SRV02 A and SRV02 B. In Figure 2.1, the servos are represented by the actuated revolute joints A and B. All four bars comprising the manipulator linkage have the same length, denoted L_b. The 2 DOF robot end-effector is depicted by joint E. The two actuated angles are denoted θ_A and θ_B and they are the output shaft angles of SRV02 A and SRV02 B, respectively.

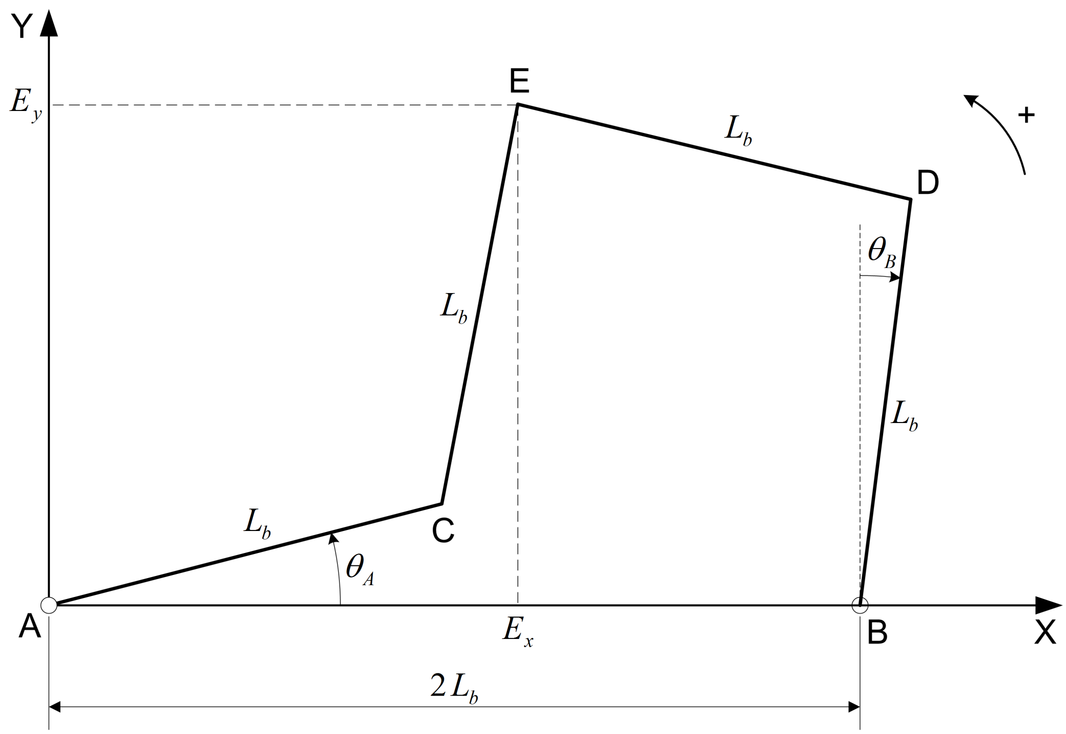


Figure 2.1: Angles and lengths in the 2 DOF Robot system

The positive direction of rotation is counter-clockwise when looking from the top of the 2 DOF planar manipulator. In Figure 2.1, the Cartesian coordinates of the actuated joints A and B are fixed. Joint A is at the origin of the reference frame with the positive X- and Y- directions defined as shown in Figure 2. The X-Y coordinates of joints A and B results in $(0, 0)$ and $(B_x, 0)$, respectively.

When the two SRV02 devices are mounted on the supplied base plate, the two servo output shafts are apart a distance of $B_x = 2L_b$.

2.1 Home Position

The home position of the 2 DOF manipulator is illustrated in Figure 2.2. The 2 DOF robot home defines the zero joint angles. Therefore, the angular position of both actuated joints results in $\theta_A = 0$ and $\theta_B = 0$. Assuming that joint A is at the origin of the reference frame, the X-Y global coordinates of the end effector joint E in the home position equals $(E_x, E_y) = (L_b, L_b)$. See the 2 DOF Robot [2] for more information on the home position.

When close to the home position, SRV02 B causes motion only in the X direction while SRV02 A causes motion only in the Y direction. Both actuated joints are thus decoupled.

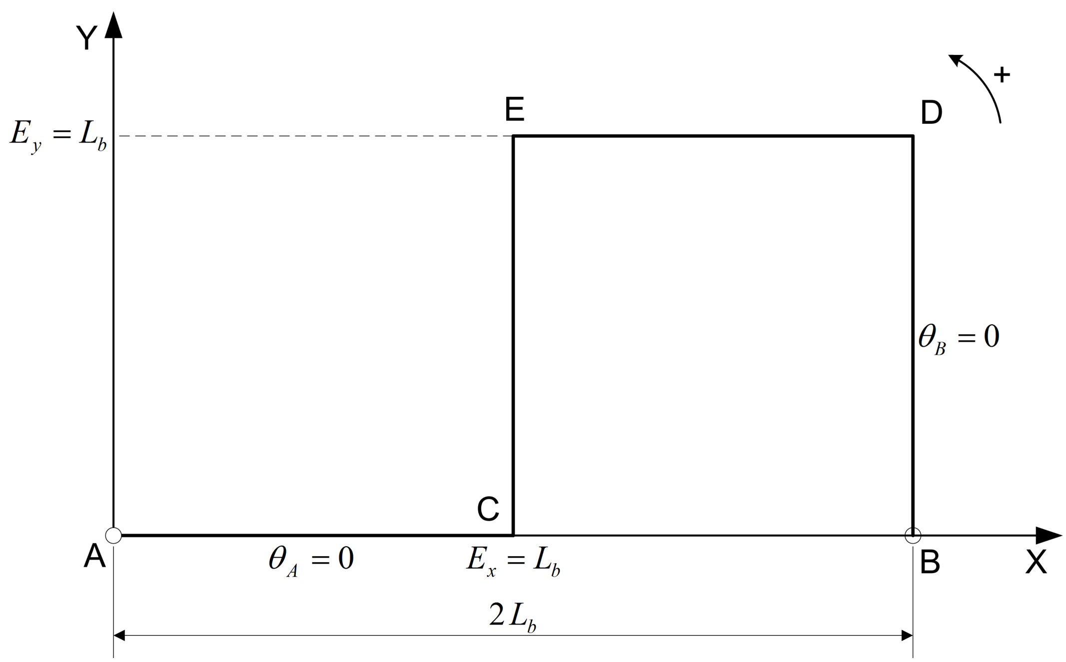


Figure 2.2: Home position of the 2 DOF Robot system

3 JOINT SPACE CONTROL

Joint space is the coordinate system describing the state of the robot based on its joints. In the 2 DOF Robot system, the joints are the two Rotary Servo units (i.e., Quanser SRV02). This section describes how to develop a PID-based control to manipulate the angular position of each robot joint, i.e., to control the position of each servo load gear.

3.1 Background

3.1.1 Model

Recall in the Modeling Laboratory in the SRV02 Workbook [1], the SRV02 voltage-to-speed transfer function was derived. To find the voltage-to-position transfer function, we can put an integrator $(1/s)$ in series with the speed transfer function (effectively integrating the speed output to get position). Then, the resulting open-loop voltage-to-load gear position transfer function becomes:

$$P(s) = \frac{K}{s(\tau s + 1)} \tag{3.1}$$

For this laboratory, you can use the following model parameters are:

$$K = 1.53 \text{ rad/(V-s)} \tag{3.2}$$

and

$$\tau = 0.0414 \text{ s} \tag{3.3}$$

These model parameters are slightly different than those derived in the Modeling Laboratory in [1] because it includes the additional inertia from the four-bar linkage attached to the load gear shaft of the servo.

3.1.2 Desired Position Control Response

The block diagram shown in Figure 3.1 is a general unity feedback system with compensator (controller) C(s) and a transfer function representing the plant, P(s). The measured output, Y(s), is supposed to track the reference signal R(s) and the tracking has to match to certain desired specifications.

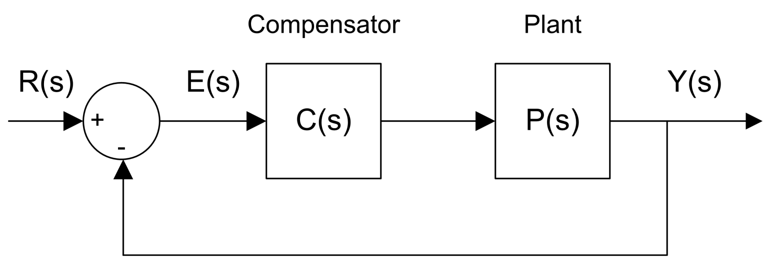


Figure 3.1: Unity feedback system.

The output of this system can be written as:

$$Y(s) = C(s)\,P(s)\,\left(R(s) - Y(s)\right) \tag{3.4}$$

By solving for $Y(s)$, we can find the closed-loop transfer function:

$$\frac{Y(s)}{R(s)} = \frac{C(s)\,P(s)}{1 + C(s)\,P(s)} \tag{3.5}$$

In fact, when a second order system is placed in series with a proportional compensator in the feedback loop as in Figure 3.1, the resulting closed-loop transfer function can be expressed as:

$$\frac{Y(s)}{R(s)} = \frac{\omega_n^2}{s^2 + 2\zeta\,\omega_n\,s + \omega_n^2} \tag{3.6}$$

where ω_n is the natural frequency and ζ is the damping ratio. This is called the *standard second-order* transfer function. Its response properties depend on the values of ω_n and ζ.

3.1.3 Peak Time and Overshoot

Consider a second-order system as shown in Equation 3.6 subjected to a step input given by

$$R(s) = \frac{R_0}{s} \tag{3.7}$$

with a step amplitude of $R_0 = 1.5$. The system response to this input is shown in Figure 3.2, where the red trace is the response (output), $y(t)$, and the blue trace is the step input $r(t)$.

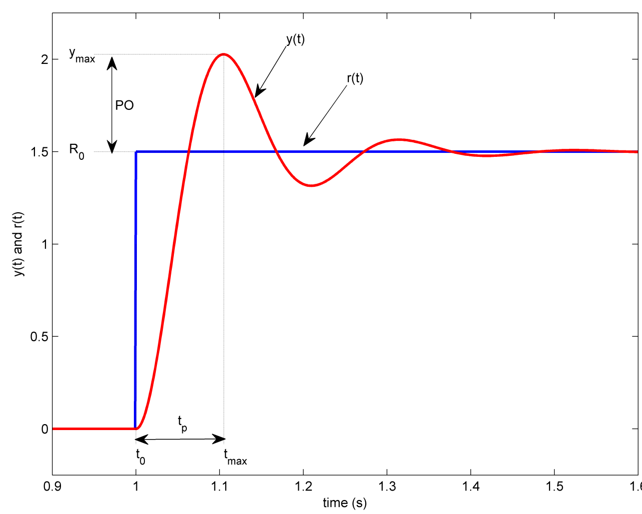


Figure 3.2: Standard second-order step response.

The maximum value of the response is denoted by the variable y_{max} and it occurs at a time t_{max}. For a response similar to Figure 3.2, the percent overshoot is found using

$$PO = \frac{100\,(y_{max} - R_0)}{R_0} \tag{3.8}$$

From the initial step time, t_0, the time it takes for the response to reach its maximum value is

$$t_p = t_{max} - t_0 \tag{3.9}$$

This is called the *peak time* of the system.

In a second-order system, the amount of overshoot depends solely on the damping ratio parameter and it can be calculated using the equation

$$PO = 100\,e^{\left(-\frac{\pi\,\zeta}{\sqrt{1-\zeta^2}}\right)} \tag{3.10}$$

The peak time depends on both the damping ratio and natural frequency of the system and it can be derived as:

$$t_p = \frac{\pi}{\omega_n\,\sqrt{1-\zeta^2}} \tag{3.11}$$

Generally speaking, the damping ratio affects the shape of the response while the natural frequency affects the speed of the response.

3.1.4 2 DOF Robot Specifications

The desired time-domain specifications for controlling the position of the load shaft on each SRV02 system are:

$$|e_{ss}| \leq 0.5 \text{ deg} \tag{3.12}$$

$$t_p = 0.15 \text{ s} \tag{3.13}$$

and

$$PO = 5.0 \text{ \%} \tag{3.14}$$

Thus, when tracking the load shaft reference, the transient response should have a peak time less than or equal to 0.10 seconds, an overshoot less than or equal to 5 %, and the steady-state response should have less than 5% error.

3.1.5 PV Controller Design

The proportional-velocity (PV) compensator to control the position of the SRV02 has the following structure

$$V_m(t) = k_p\,(\theta_d(t) - \theta_l(t)) - k_v\left(\frac{d}{dt}\,\theta_l(t)\right) \tag{3.15}$$

where k_p is the proportional control gain, k_v is the velocity control gain, $\theta_d(t)$ is the setpoint or reference load shaft angle, $\theta_l(t)$ is the measured load shaft angle, and $V_m(t)$ is the SRV02 motor input voltage. The block diagram of the PV control is given in Figure 3.3.

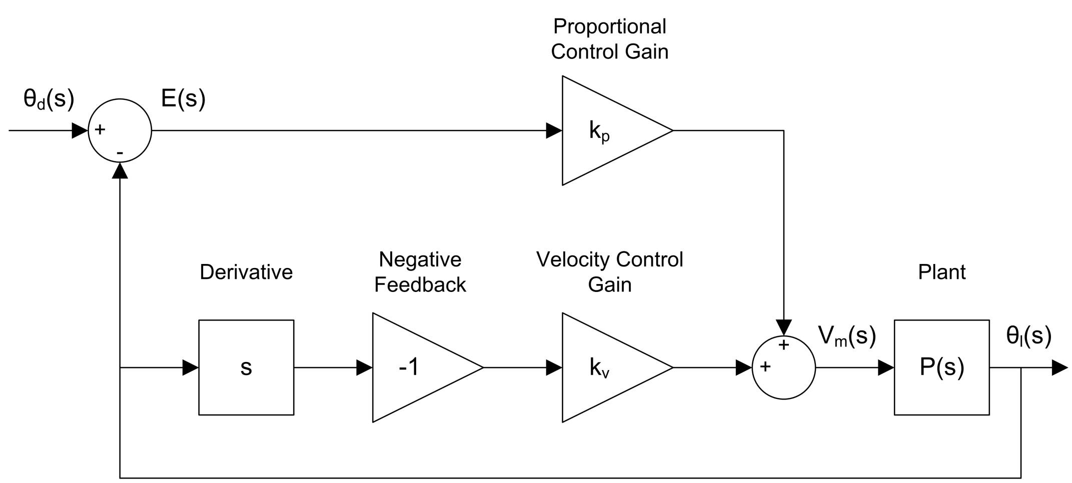


Figure 3.3: Block diagram of SRV02 PV position control.

We need to find the closed-loop transfer function $\Theta_l(s)/\Theta_d(s)$ for the closed-loop position control of the SRV02. Taking the Laplace transform of equation 3.15 gives

$$V_m(s) = k_p\,(\Theta_d(s) - \Theta_l(s)) - k_v\,s\,\Theta_l(s) \tag{3.16}$$

From the Plant block in Figure 3.3 and equation 3.1, we can write

$$\frac{\Theta_l(s)}{V_m(s)} = \frac{K}{s\,(\tau\,s+1)} \tag{3.17}$$

Substituting equation 3.16 into 3.17 and solving for $\Theta_l(s)/\Theta_d(s)$ gives the SRV02 position closed-loop transfer function as:

$$\frac{\Theta_l(s)}{\Theta_d(s)} = \frac{K\,k_p}{\tau\,s^2 + (1 + K\,k_v)\,s + K\,k_p} \tag{3.18}$$

For more information, see the Position Control lab in the SRV02 Workbook [1].

3.2 Pre-Lab Questions

1. The SRV02 closed-loop transfer function was derived in equation 3.18 in Section 3.1. Find the control gains k_p and k_v in terms of ω_n and ζ. **Hint:** Remember the standard second order system equation.

2. Calculate the minimum damping ratio and natural frequency required to meet the specifications given in Section 3.1.4.

3. Based on the K and τ model parameters given in Section 3.1.1, calculate the control gains needed to satisfy the time-domain response requirements given in Section 3.1.4. **Note:** Alternatively, you can find the K and τ of your SRV02 systems using one of the techniques outlined in the Modeling Laboratory in the SRV02 Workbook [1].

3.3 Lab Experiments

3.3.1 Simulation

In this section you will simulate the joint space control of the Rotary 2 DOF Robot system. Each SRV02 system is modeled using the first-order transfer function and controlled using the PV controller described in Section 3.1.5. Our goals are to confirm that the desired response specifications are satisfied and to verify that the motor is not saturated.

Experimental Setup

The *Joint Space Control Sim* VI shown in Figure 3.4 will be used to simulate the closed-loop position control response with the PV controller. The SRV02 Model uses a *Transfer Function* block from *Control Design and Simulation* palette. The *PV Control* sub-VI contains the PV controller detailed in Section 3.1.5.

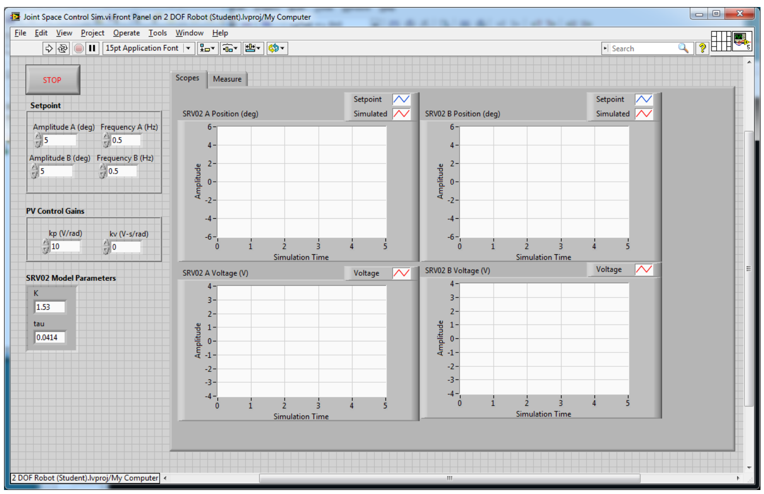


Figure 3.4: VI that simulates 2 DOF Robot joint space response.

IMPORTANT: Before you can conduct these experiments, you need to make sure that the lab files are configured according to your SRV02 setup. If they have not been configured already, then you need to go to Section 5 to configure the lab files first.

1. Enter the proportional and velocity control gains found in Pre-Lab question 3 in the VI front panel.
2. To generate a ± 5 degree square wave step reference, go to the *Setpoint* section ensure the amplitude and frequency of the signal generators are set to the following:
   - Amplitude A = 5 deg
   - Frequency A = 0.5 Hz
   - Amplitude B = 5 deg
   - Frequency B = 0.5 Hz
3. Run the simulation (i.e., click on the *Run* button). By default, the simulation runs for 5 seconds. The scopes should be displaying responses similar to Figure 3.5. Note that in the *SRV02 A Position* (deg) scopes, the blue trace is the setpoint position while the red trace is the simulated position (generated by the transfer function model).
4. Generate a figure showing the *Simulated Joint Space* position response and the input voltage.

   Exporting scope: After running the simulation, right-click on the scope and go to *Export* | *Export Simplified Image*. Choose the graphic file type and export it to the clipboard. The response can then be pasted.

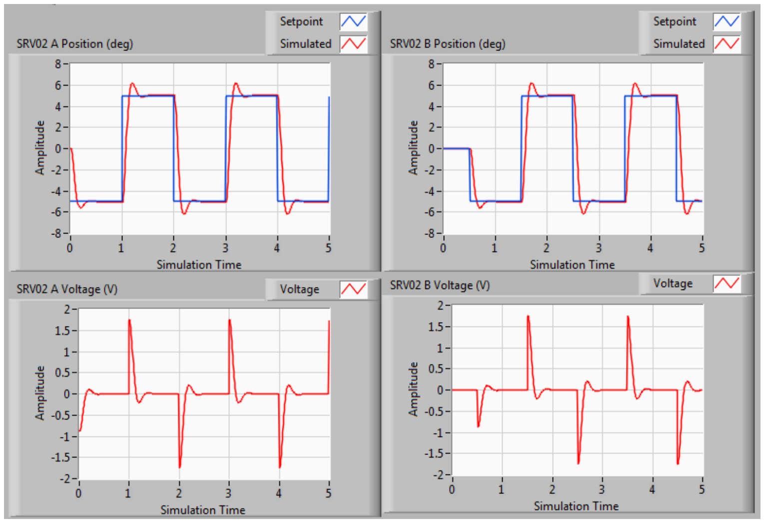


Figure 3.5: Simulated closed-loop response in joint space.

5. Measure the steady-state error, the percent overshoot and the peak time of the simulated response. Does the response satisfy the specifications given in Section 3.1.4? **Hint:** Go to the *Measure* tab and user the graph cursors to take the measurements.

3.3.2 Implementation

The *Joint Space Control* VI shown in Figure 3.6 is used to perform the position control exercises in this laboratory. This VI interfaces with the DC motor and sensors of the 2 DOF Robot system and implements the PV controller detailed in Section 3.1.5.

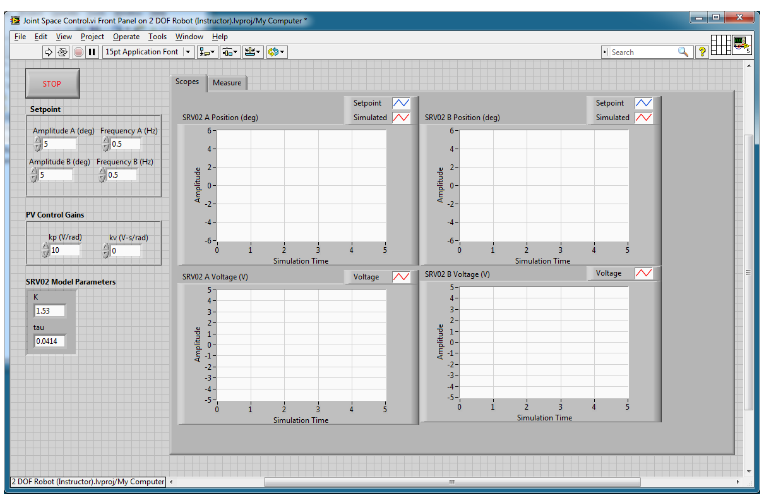


Figure 3.6: VI used to run joint space control on 2 DOF Robot device.

IMPORTANT: Before you can conduct these experiments, you need to make sure that the lab files are configured according to your SRV02 setup. If they have not been configured already, then you need to go to Section 5 to configure the lab files first.

Follow this procedure:

1. Enter the proportional and velocity control gains found in Pre-Lab question 3 in the VI.

2. To generate a ± 5 degree square wave step reference, go to the *Setpoint* section ensure the amplitude and frequency of the signal generators are set to the following:
    - Amplitude A = 5 deg
    - Frequency A = 0.5 Hz
    - Amplitude B = 5 deg
    - Frequency B = 0.5 Hz
3. Make sure the 2 DOF Robot is in the HOME position.
4. Run the VI. The scopes should be displaying responses similar to Figure 3.7. Note that in the *SRV02 A Position* (deg) scopes, the blue trace is the setpoint position while the red trace is the measured position.

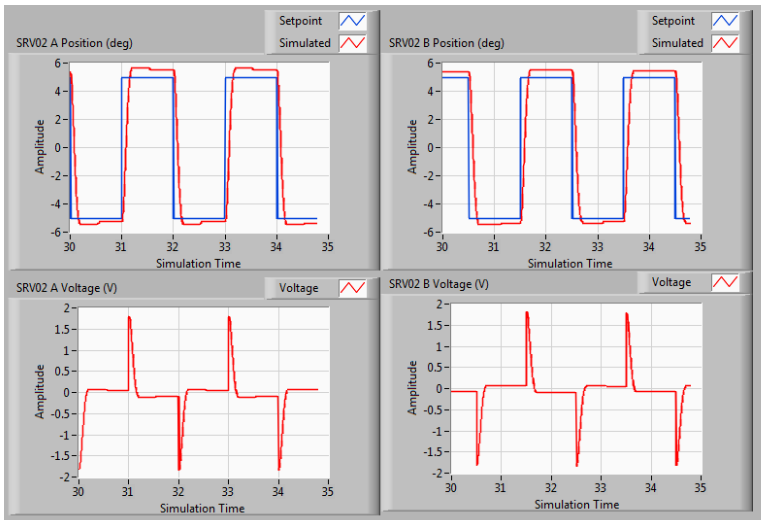


Figure 3.7: Running joint space control on 2 DOF Robot using $k_p = 10$ and $k_d = 0$

5. Generate figures showing the *Implemented Joint Space* position response and the input voltage.

6. Measure the steady-state error, the percent overshoot and the peak time of the simulated response. Does the response satisfy the specifications given in Section 3.1.4? **Hint:** Go to the *Measure* tab and user the graph cursors to take the measurements.

3.4 Results

Fill out Table 3.1 with your answers from your control lab results - both simulation and implementation.

Description	Symbol	Value	Units
Pre Lab Questions			
Proportional Control Gain	k_p		V/rad
Velocity Control Gain	k_v		V-s/rad
Simulation			
Steady-state error	e_{ss}		deg
Peak time	t_p		s
Percent overshoot	PO		%
Implementation			
Steady-state error	e_{ss}		deg
Peak time	t_p		s
Percent overshoot	PO		%

Table 3.1: Joint Space Results

4 WORKSPACE CONTROL

Workspace is the coordinate system describing the state of the end-effector. Using kinematics and joint space control, the planar position of the 2 DOF Robot end-effector can be controlled. This is called the *workspace control*.

4.1 Background

4.1.1 Direct Kinematics

The forward, or direct, kinematics computes the global Cartesian coordinates of the robot end-effector from the joint angles. The direct kinematics of the 2 DOF Robot is shown in Figure 4.1.

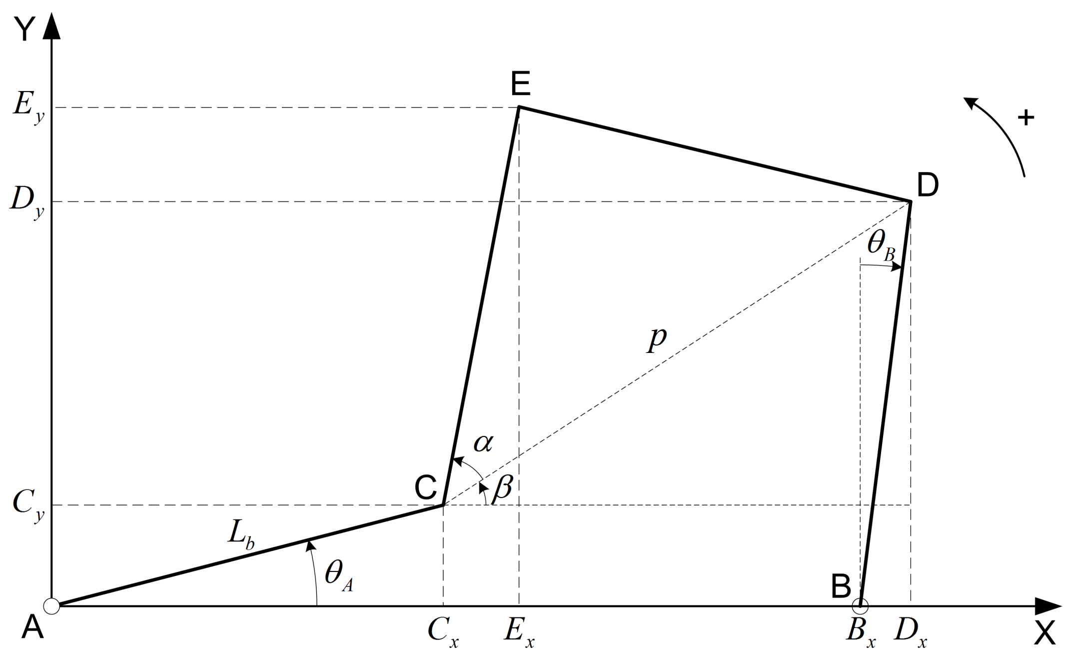


Figure 4.1: Direct kinematics of 2 DOF Robot system

Given the angles of the joints, θ_A and θ_B, located at points A and B the Cartesian coordinates of joint C are $C_x = L_b \cos\theta_A$ and $C_y = L_b \sin\theta_A$. Similarly, the Cartesian coordinate of D, are $D_x = B_x - L_b \cos\theta_B$ and $D_y = L_b \cos\theta_B$.

The distance p between points C and D, shown in Figure 4.1, can be found using the Pythagorean theorem. The x side of the triangle is $D_x - C_x$ long and the y length is $D_y - C_y$. The resulting length of the hypotenuse, i.e., the distance between C and D, is

$$p = \sqrt{(D_x - C_x)^2 + (D_y - C_y)^2}).$$

Because each manipulator link is of the same length, L_b, triangle ΔCDE is isosceles. You can express angle α in terms of L_b and p. In Figure 4.1, if you draw a line going from point E down to the middle of length p such that it is perpendicular to p, you have a right angle triangle (with hypotenuse L_b). Taking the cosine of angle α will then give the expression

$$\cos\alpha = \frac{p/2}{L_b}$$

which gives

$$\alpha = \arccos\frac{p}{2L_b}.$$

To obtain angle β at the C vertex, take the *tangent* of β to get

$$\tan\beta = \frac{D_y - C_y}{D_x - C_x}$$

and solve for β for

$$\beta = \arctan\frac{D_y - C_y}{D_x - C_x}.$$

The sum of angles α and β form the angle between link CE and the Cartesian coordinate X-axis. This leads directly to the X-Y position of E. The forward kinematics of the end-effector in the x-axis and y-axis is therefore

$$E_x = C_x + L_b\cos(\alpha+\beta)$$

and

$$E_y = C_y + L_b\sin(\alpha+\beta).$$

4.1.2 Inverse Kinematics

The backward, or inverse, kinematics calculates the joint angles from the X-Y Cartesian coordinates of the end-effector. The inverse kinematics of the 2 DOF Robot system is shown in Figure 4.2. The known quantities in the inverse kinematics are the X and Y coordinates of the end-effector location E, i.e., E_x and E_y. From this, we can obtain the angles of the motor joints A and B, i.e., θ_A and θ_B.

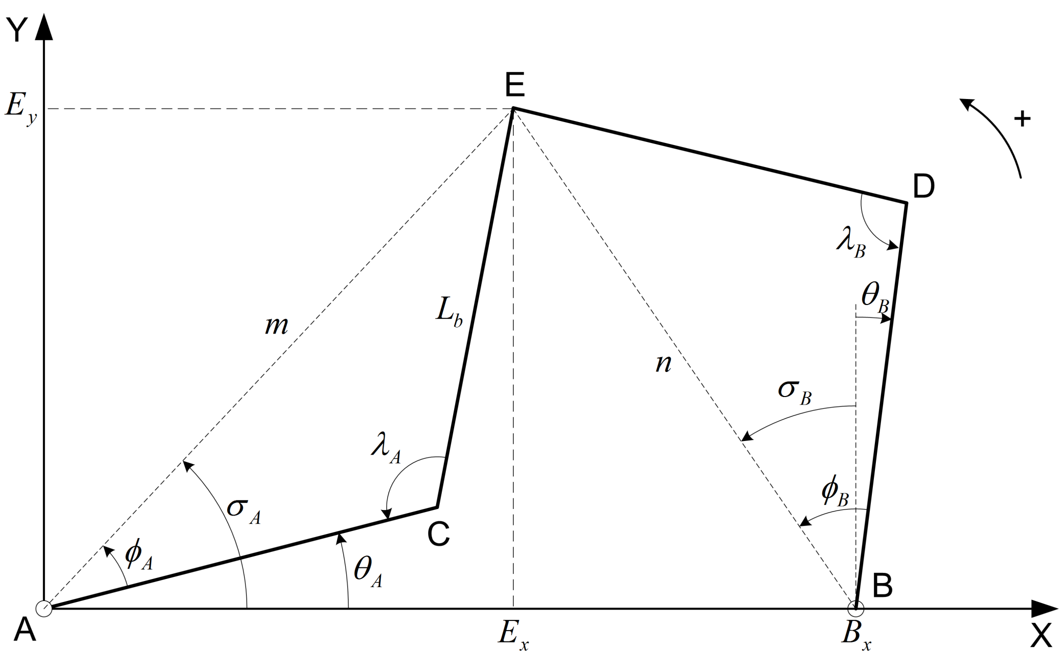


Figure 4.2: Inverse kinematics of 2 DOF Robot system

Consider ΔABE in Figure 4.2, i.e., the triangle with vertices A, B, and E. Its sides are denoted by the variables m and n. Assuming that vertex A is at the origin, the length of elements m and n in terms of the end-effector location and B_x is

$$m = \sqrt{E_x^2 + E_y^2}$$

and

$$n = \sqrt{(E_x - B_x)^2 + E_y^2}.$$

By using the Cosine Law on ΔACE and ΔBDE, we find

$$m^2 = 2L_b^2(1 - \cos\lambda_A)$$

and

$$n^2 = 2L_b^2(1 - \cos\lambda_B).$$

Solving for λ_A and λ_B

$$\lambda_A = \arccos\frac{2L_b^2 - m^2}{2L_b^2}$$

and

$$\lambda_B = \arccos\frac{2L_b^2 - n^2}{2L_b^2}.$$

The expressions that calculate the joint angles required for a certain X-Y end-effector position is left as an exercise in the *Pre-Lab Questions*.

4.2 Pre-Lab Questions

1. Recalling that ΔACE and ΔBDE are both isosceles, find the vertex angles ϕ_A and ϕ_B.
2. Find angles σ_A between the X-coordinate axis and AE, and σ_B between the Y-coordinate axis and BE relative to E_x, E_y, and B_x.
3. Give the inverse kinematics of the end effector - the joint angles θ_A and θ_B.

4.3 Lab Experiments

4.3.1 Simulation

In this section you will simulate the workspace control of the 2 DOF Robot system.

Experimental Setup

The *Workspace Control Sim* VI shown in Figure 4.3 will be used to simulate the workspace control for the 2 DOF Robot. **This file is not complete.** The direct and inverse kinematics must be completed.

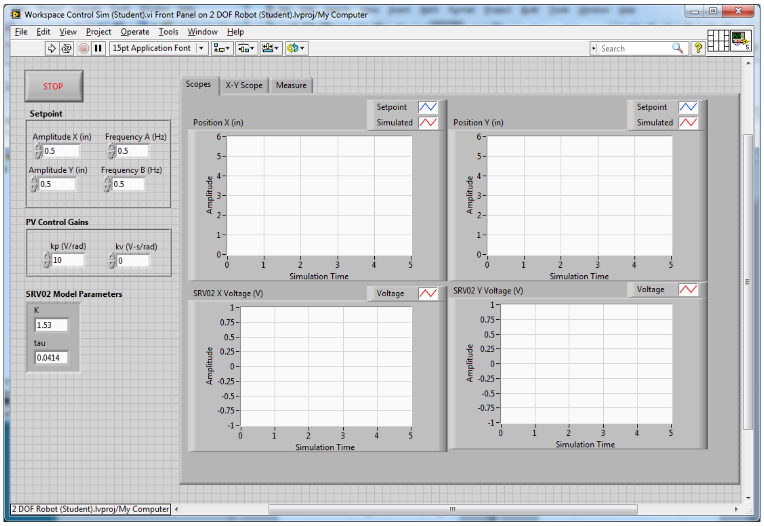


Figure 4.3: VI used to simulate 2 DOF Robot workspace response.

IMPORTANT: Before you can conduct these experiments, you need to make sure that the lab files are configured according to your SRV02 setup. If they have not been configured already, then you need to go to Section 5 to configure the lab files first.

The workspace control is implemented in the VI as shown in Figure 4.4. As illustrated, it includes the same servo-based controller used in Section 3 but in this case the servo commands are generated by MathScript Node called *Inverse Kinematics*. The servo angles required for the end-effector to be at a desired Cartesian X-Y location is computed by this block.

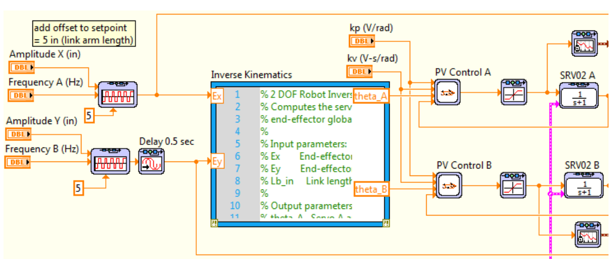


Figure 4.4: Inverse Kinematics

The direct (or forward) kinematics, on the other hand, are computed from the measured or simulated servo angles to give the resulting planar end-effector position. This is implemented in another MathScript Node called *Direct Kinematics*, as shown in Figure 4.5.

1. Enter the proportional and velocity control gains found in Pre-Lab question 3.
2. To generate a $\pm$0.5 inch square wave reference, ensure each *Signal Generator* is set to the following:

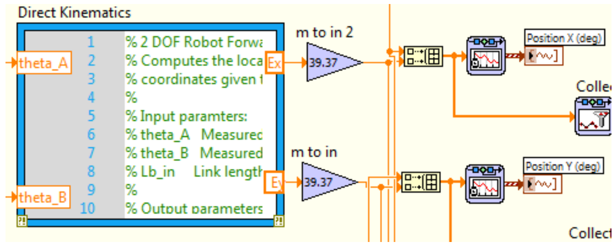


Figure 4.5: Direct Kinematics

- Amplitude A = 0.5 in
- Frequency A = 0.5 Hz
- Amplitude B = 0.5 in
- Frequency B = 0.5 Hz

3. Run the simulation. By default, the simulation runs for 5 seconds. The scopes should be displaying responses similar to Figure 4.6. In the *Position X (in)* and *Position y (in)* scopes, the blue trace is the setpoint position while the red trace is the simulated position. However, in this case **the simulated position is zero because the kinematics blocks have not been completed**.

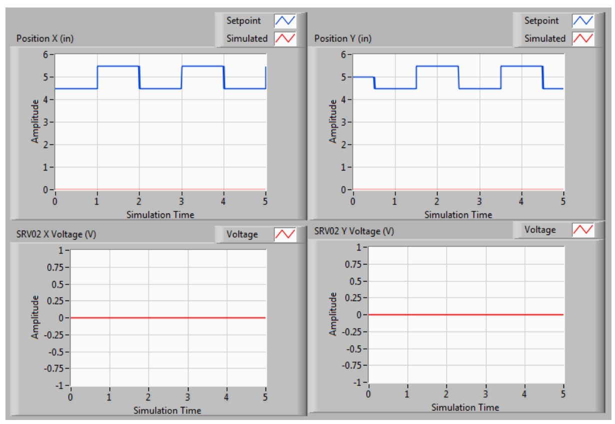


Figure 4.6: Initial simulated response

4. As shown below, the *Inverse Kinematics* MathScript node outputs 0 for both the SRV02 A and B angles. Complete the function using the equations found in Section 4.2.

```
function [theta_A,theta_B] = inv_kin_2d_robot(Ex, Ey, Lb_in)
% link length (in)
Lb = Lb_in;
%
theta_A = 0;
theta_B = 0;
```

5. The *Forward Kinematics* MathScript node script shown below. It outputs 0 for the *Ex* and *Ey* end-effector positions. Using the exercises in Section 4.2, complete this MathScript node so the end-effector position can be measured from the servo angles.

```
function [Ex,Ey] = fwrd_kin_2d_robot(theta_A, theta_B, Lb_in)
% Convert link length to meters.
Lb = 0.0254*Lb_in;
%
Ex = 0;
Ey = 0;
```

6. Run the simulation with the completed kinematic blocks. Attach a plot of the *X-Y End-Effector Position (in)* figure to your report showing the end-effector setpoint and simulated response in the X-Y plane.

7. Produce figures showing the time-based E_x and E_y response. Show both the setpoint and simulated positions in each response.

8. In terms of steady-state error, percentage overshoot, and peak time, the E_x and E_y responses should be similar to the servo angle responses, θ_A and θ_B. Do you notice any additional effects in the end-effector responses?

4.3.2 Implementation

The *Workspace Control* VI shown in Figure 4.7 implements the workspace control on the 2 DOF Robot system. It interfaces with the DC motor and sensors of the system.

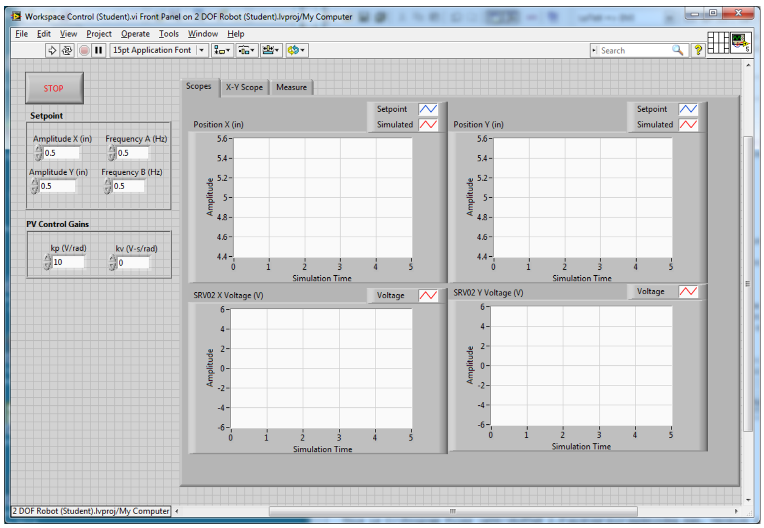


Figure 4.7: VI used to run workspace control on 2 DOF Robot

IMPORTANT: Before you can conduct these experiments, you need to make sure that the lab files are configured according to your SRV02 setup. If they have not been configured already, then you need to go to Section 5 to configure the lab files first.

Follow this procedure:

1. Enter the proportional and velocity control gains found in Pre-Lab question 3.

2. To generate a ± 0.5 inch square wave reference, ensure each *Signal Generator* is set to the following:

   - Amplitude A = 0.5 in
   - Frequency A = 0.5 Hz
   - Amplitude B = 0.5 in
   - Frequency B = 0.5 Hz

3. Copy the scripts from the direct and inverse kinematic MathScript nodes that were completed in the *Workspace Control Sim* VI in Section 4.3.1.

4. Run the VI. The scopes should be displaying responses similar to Figure 4.6. In the *Position X (in)* and *Position y (in)* scopes, the blue trace is the setpoint position while the red trace is the simulated position.

5. Attach a plot of the *X-Y End-Effector Position (in)* to your report showing the end-effector setpoint and measured response in the X-Y plane (in the X-Y Scope tab).

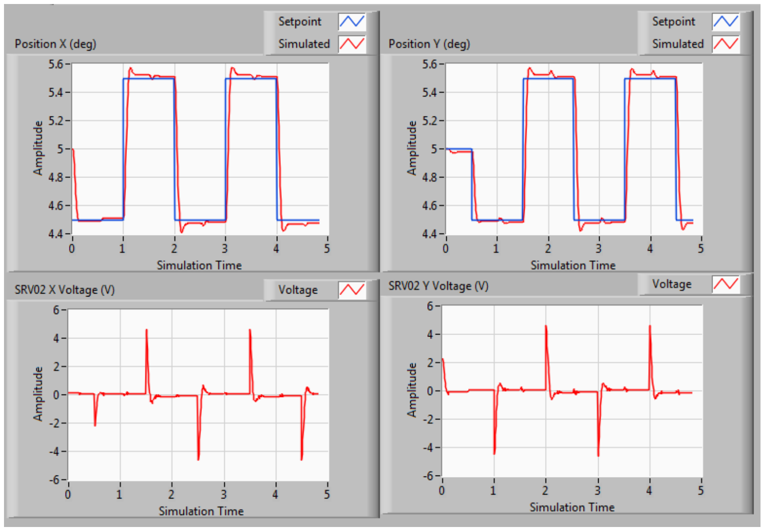


Figure 4.8: Implemented response

6. Produce a Matlab figure showing the time-based E_x and E_y response. Show both the setpoint and measured positions in each response..
7. Is the X-Y end-effector response comparable to the specifications (i.e., steady-state error, percentage overshoot, and peak time) given for the the servo angle responses, θ_A and θ_B. Besides this, do you witness the same effect in the measured signal as seen in the simulation? Explain.
8. Click on the *Stop* button.
9. Shut off the power of the amplifier if no more experiments will be performed on the SRV02 in this session.

5 SYSTEM REQUIREMENTS

Required Software

Make sure LabVIEW™ is installed with the following required add-ons:

1. LabVIEW™
2. NI-DAQmx
3. NI LabVIEW™ Control Design and Simulation Module
4. NI LabVIEW™ MathScript RT Module
5. Quanser Rapid Control Prototyping Toolkit®

Note: Make sure the Quanser Rapid Control Prototyping (RCP) Toolkit is installed after LabVIEW. See the RCP Toolkit Quick Start Guide for more information.

Required Hardware

- Data acquisition (DAQ) device that is compatible with Quanser Rapid Control Prototyping Toolkit®. This includes Quanser DAQ boards such as Q2-USB, Q8-USB, QPID, and QPIDe and some National Instruments DAQ devices.
- Quanser SRV02-ET rotary servo.
- Quanser SRV02 2 DOF Robot (attached to SRV02).
- Quanser VoltPAQ-X1 power amplifier, or equivalent.

Before Starting Lab

Before you begin this laboratory make sure:

- LabVIEW™ is installed on your PC.
- DAQ device has been successfully tested (e.g., using the test software in the Quick Start Guide).
- SRV02 2 DOF Robot and amplifier are connected to your DAQ board as described Reference [2].

5.1 Overview of Files

File Name	Description
2 DOF Robot User Manual.pdf	This manual describes the hardware of the 2 DOF Robot system and explains how to setup and wire the system for the experiments.
2 DOF Robot Workbook (Student).pdf	This laboratory guide contains pre-lab questions and lab experiments demonstrating how to design and implement controllers for both the joint space and work space on the 2 DOF Robot plant using LabVIEW™ .
Joint Space Control Sim.vi	VI that simulates a joint space, servo-based closed-loop PV controller for the 2 DOF Robot system.
Workspace Control Sim (Student).vi	VI that simulates controlling the X-Y Cartesian position of the end-effector, i.e., the *workspace* control. **To be completed by student.**
Joint Space Control.vi	VI that implements a local, servo-based closed-loop PV controller on the 2 DOF Robot system using LabVIEW™ .
Workspace Control (Student).vi	VI that controls the X-Y position of the end-effector on the actual 2 DOF Robot system using LabVIEW™ . **To be completed by student.**

Table 5.1: Files supplied with the 2 DOF Robot

5.2 Setup for Joint Space Simulation

Follow these steps before beginning the lab procedure outlined in Section 4.3.1:

1. Load the LabVIEW software.
2. Open the LabVIEW Project *2 DOF Robot (Student).lvproj*.
3. Open the *Joint Space Control Sim.vi* shown in Figure 3.4.

5.3 Setup for Implementing Joint Space Control

Follow these steps to get the system ready for this lab in Section 3.3.2:

1. Setup the SRV02 with the 2 DOF Robot module as detailed in the 2 DOF Robot User Manual [2].
2. Make sure the 2 DOF Robot is in the HOME position.
3. Open *2 DOF Robot (Student)* project as outlined in Section 5.2.
4. Open *Joint Space.vi* shown in Figure 3.6.
5. **Configure DAQ:** Ensure the HIL Initialize block is configured for the DAQ device that is installed in your system. To do this, go to the block diagram (CTRL-E) and double click on the **HIL Initialize** Express VI shown in Figure 5.1.
6. Under the Main tab, select the data acquisition device that is installed on your system in the *Board type* section. For example, in Figure 5.2 the Q2-USB is chosen.

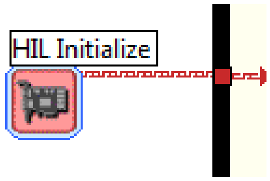


Figure 5.1: HIL Initialize Express VI

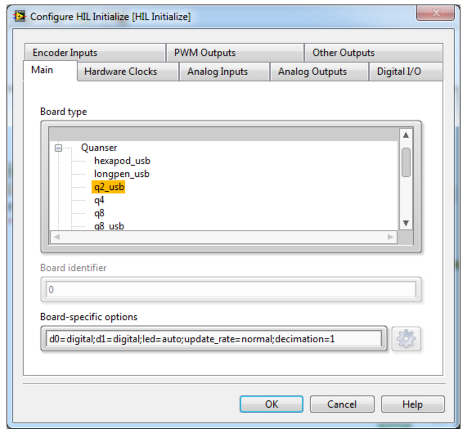


Figure 5.2: Select DAQ board that will be used to control system

5.4 Setup for Workspace Simulation

Follow these steps before beginning the lab procedure outlined in Section 4.3.1:

1. Load the LabVIEW software.
2. Open the LabVIEW Project *2 DOF Robot (Student).lvproj*.
3. Open the *Workspace Control Sim (Student).vi* shown in Figure 4.3.

5.5 Setup for Implementing Workspace Control

Follow these steps to get the system ready for the lab exercises in Section 4.3.2:

1. Setup the SRV02 with the 2 DOF Robot module as detailed in the 2 DOF Robot User Manual ([2]).
2. Make sure the 2 DOF Robot is in the HOME position.
3. Open *2 DOF Robot (Student)* project as outlined in Section 5.2.
4. Open *Workspace Control (Student).vi* shown in Figure 4.7.
5. **Configure DAQ:** Ensure the HIL Initialize Express VI is configured as explained in Section 5.3.
6. **Note: This VI is to be completed by the student.** Go through the exercises in Section 4.3.2.

6 LAB REPORT

This laboratory contains two groups of experiments, namely,

1. Joint space control, and
2. Workspace control.

For each experiment, follow the outline corresponding to that experiment to build the *content* of your report. Also, in Section 6.3 you can find some basic tips for the *format* of your report.

6.1 Template for Joint Space Control Report

I. PROCEDURE

1. *Simulation*
   - Briefly describe the main goal of the simulation.
   - Briefly describe the simulation procedure in Step 4 in Section 3.3.1.
2. *Implementation*
   - Briefly describe the main goal of this experiment.
   - Briefly describe the experimental procedure in Step 5 in Section 3.3.2.

II. RESULTS
Do not interpret or analyze the data in this section. Just provide the results.

1. Response plot from step 4 in Section 3.3.1, *Joint space simulation*.
2. Response plot from step 4 in Section 3.3.2, *Joint space implementation*.
3. Provide applicable data collected in this laboratory (from Table 3.1).

III. ANALYSIS
Provide details of your calculations (methods used) for analysis for each of the following:

1. Peak time, percent overshoot, steady-state error, and input voltage in Step 5 in Section 3.3.1.
2. Peak time, percent overshoot, steady-state error, and input voltage in Step 6 in Section 3.3.2.

IV. CONCLUSIONS
Interpret your results to arrive at logical conclusions for the following:

1. Whether the controller meets the specifications in Step 5 in Section 3.3.1, *Joint space controller simulation*.
2. Whether the controller meets the specifications in Step 6 in Section 3.3.2, *Joint space controller implementation*.

6.2 Template for Workspace Control Report

I. PROCEDURE

1. *Simulation*
   - Briefly describe the main goal of the simulation.
   - Briefly describe the simulation procedure in Step 6 in Section 4.3.1.
2. *Implementation*
   - Briefly describe the main goal of this experiment.
   - Briefly describe the experimental procedure in Step 5 in Section 4.3.2.

II. RESULTS
Do not interpret or analyze the data in this section. Just provide the results.

1. Response plot from step 7 in Section 4.3.1, *Workspace simulation*.
2. Completed inverse kinematics code, in Step 4 in Section 4.3.1.
3. Completed direct kinematics code, in Step 5 in Section 4.3.1.
4. Response plot from step 6 in Section 4.3.2, *Workspace implementation*.

III. ANALYSIS
Provide details of your calculations (methods used) for analysis for each of the following:

1. Examine the simulated workspace response in Step 8 in Section 4.3.1.
2. Examine the actual workspace response running on the 2 DOF Robotin Step 7 in Section 4.3.1.

IV. CONCLUSIONS
Interpret your results to arrive at logical conclusions for the following:

1. Whether the controller meets the specifications in Step 7 in Section 4.3.2, *Workspace controller implementation*.

6.3 Tips for Report Format

PROFESSIONAL APPEARANCE

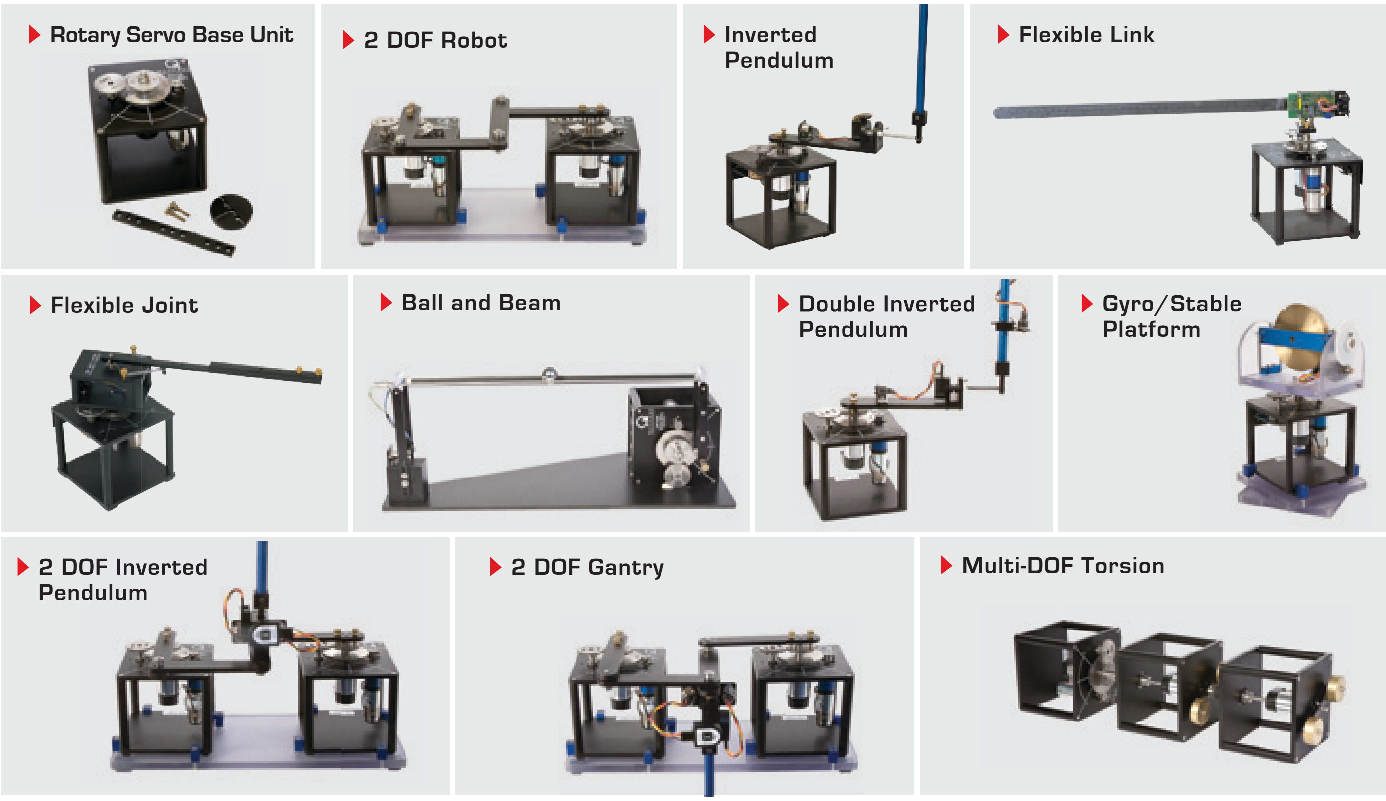
- Has cover page with all necessary details (title, course, student name(s), etc.)
- Each of the required sections is completed (Procedure, Results, Analysis and Conclusions).
- Typed.
- All grammar/spelling correct.
- Report layout is neat.
- Does not exceed specified maximum page limit, if any.
- Pages are numbered.
- Equations are consecutively numbered.
- Figures are numbered, axes have labels, each figure has a descriptive caption.
- Tables are numbered, they include labels, each table has a descriptive caption.
- Data are presented in a useful format (graphs, numerical, table, charts, diagrams).
- No hand drawn sketches/diagrams.
- References are cited using correct format.

REFERENCES

[1] Quanser Inc. SRV02 lab manual. 2011.

[2] Quanser Inc. *2 DOF Robot User Manual*, 2012.

Over ten rotary experiments for teaching fundamental and advanced controls concepts



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