Rotary Pendulum Modeling

Topics Covered

- Interact with the QUANSER® QUBE-Servo 2 Rotary Pendulum system.
- Configure sensor and actuator gains to match model conventions.

Prerequisites

- Integration laboratory experiment.
- Rotary pendulum module is attached to the QUBE-Servo 2.

1 Background

The rotary pendulum system, also known as the Furuta Pendulum, is a classic system often used to teach modeling and control in physics and engineering. The free-body diagram of a basic rotary pendulum is depicted in Figure 1.1.

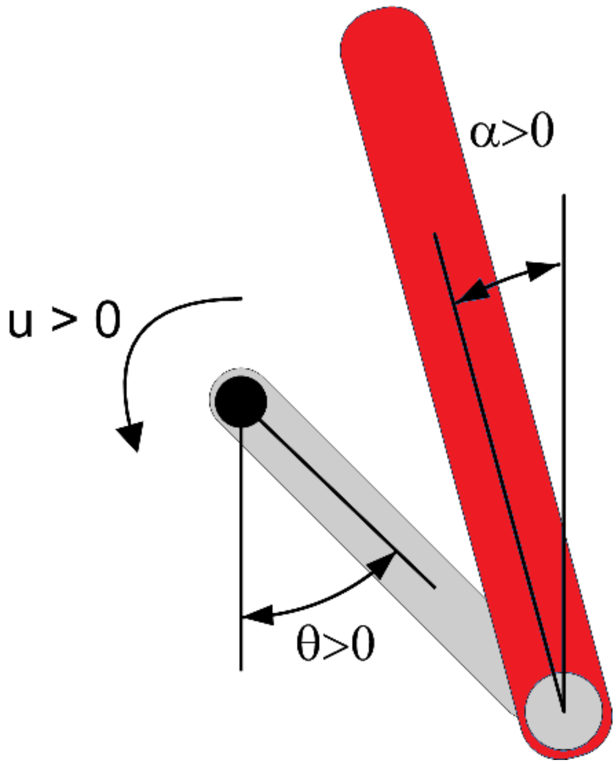


Figure 1.1: Free-body diagram of rotary pendulum

The rotary arm, which is attached to the motor pivot, is denoted by the variable θ and the pendulum angle, attached to the end of the rotary arm, is denoted by α. Note the following conventions:

- Angle α is defined as the *inverted pendulum angle*, i.e. the angle with respect to the upright vertical position where $\alpha = 0$ means the pendulum is perfectly upright. It is expressed mathematically using

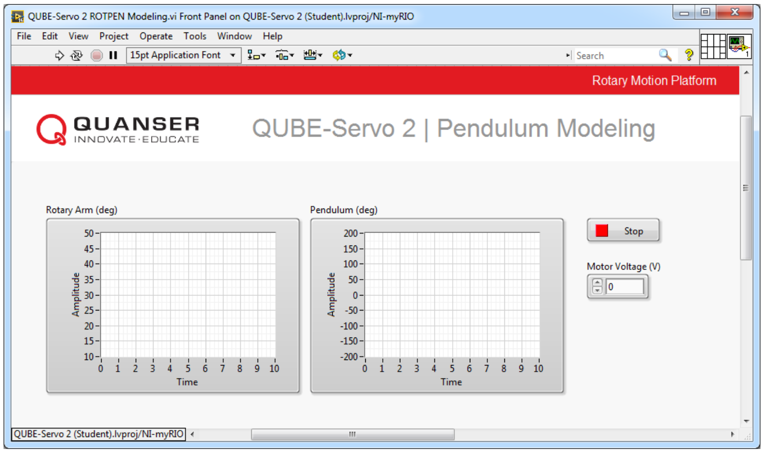
$$\alpha = (\alpha_{full} \text{ mod } 2\pi) - \pi. \tag{1.1}$$

  where α_{full} is the pendulum angle measured by the encoder, i.e. the continuous angle measurement defined as zero when pendulum is in the downward configuration.
- Both angles are defined as positive when rotated in the counter-clockwise (CCW) direction.
- When a positive voltage is applied to the motor, the rotary arm moves in the positive CCW direction.

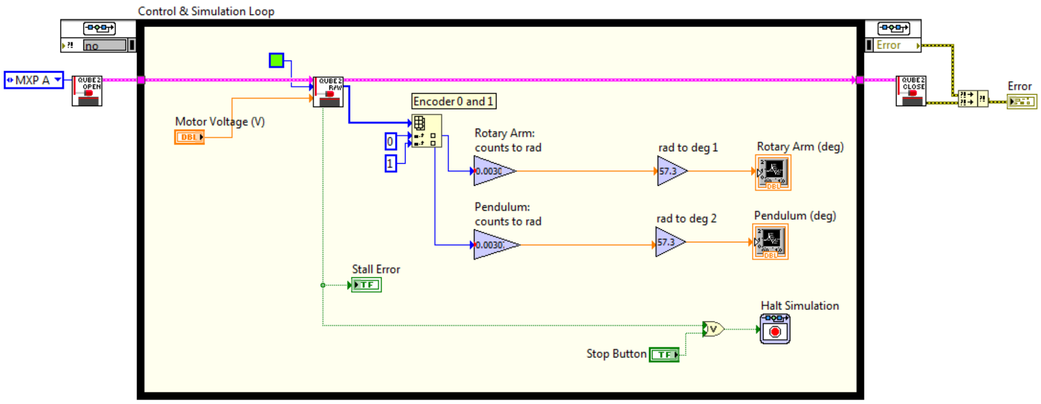
The goal is to design a system model that follows these conventions. The QUBE-Servo 2 Integration laboratory experiment introduced the DC motor and encoders on the QUBE-Servo 2 system. The pendulum angle is also measured using an encoder.

2 In-Lab Exercises

In this lab, we will create a LABVIEW™ Virtual Instrument (VI) to drive to the DC motor and measure both the rotary arm and pendulum angles - similarly as shown in Figure 2.1.



(a) Front Panel



(b) Block Diagram

Figure 2.1: VI used to drive motor and read angles on QUBE-Servo 2 Rotary Pendulum system

1. Based on the VI developed in the Integration laboratory experiment, do the following:
   - The QUBE 2 R/W block outputs both the arm and pendulum raw encoder counts. To read the pendulum encoder, expand the input terminals of the Index Array block and wire a Constant block with the value set to 1.
   - Setup the encoder gains on each channel to read the angles in radians (instead of degrees).
   - Connect the the measured angles to waveform charts, but display them in degrees (usually more intuitive). You can do this by adding Gain blocks that convert radians to degrees.
   - Connect a Numeric Control to the *Motor Voltage* terminal of the QUBE 2 R/W block to control the motor voltage.
2. Run the VI.
3. Rotate the rotary arm and pendulum counter-clockwise and examine the response on the waveform charts. Example responses are shown in Figure 2.2. Do the measured angles follow the modeling conventions given in Section 1?
4. Apply a small voltage (0.5 V) to the motor. Does your VI follow the modeling conventions?

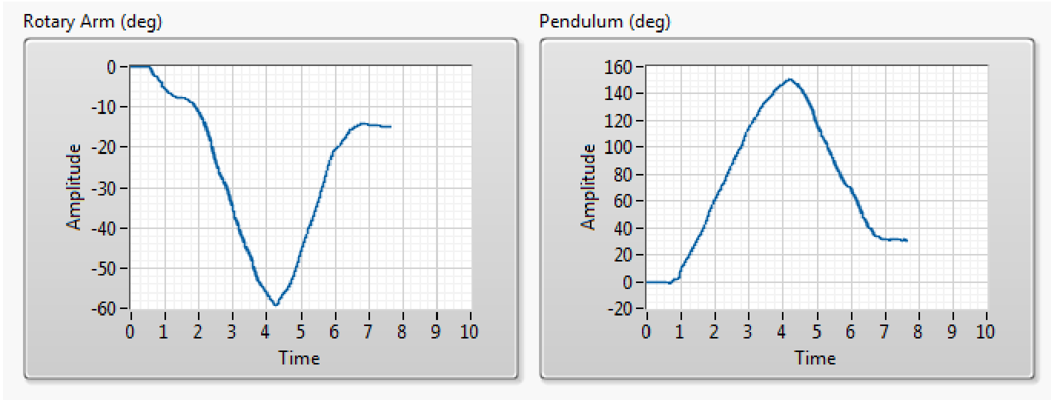


Figure 2.2: Measured rotary arm and pendulum angles

5. Modify the VI such that the measured angles and applied voltage follow by the modeling conventions. Briefly list any changes made.
6. Add modulus and bias blocks, as shown in Figure 2.3, to measure *inverted pendulum angle*, defined as Equation 1.1.

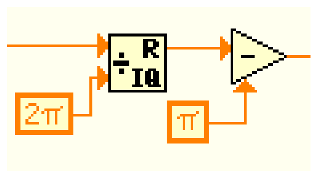


Figure 2.3: LabVIEW modulus and bias blocks

7. Make sure the pendulum is unperturbed in the downward position before starting the controller. Run the VI.
8. Rotate the pendulum to the upright vertical position and ensure the angle is measured correctly and it follows the free-body diagram in Figure 1.1. Capture the response of the pendulum being raise to the inverted position. Explain what the bias and modulus functions do.
9. Click on the Stop button to stop the VI.

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