BALANCE CONTROL

Topics Covered

- Control enabling logic.
- PD-based balance control.

Prerequisites

- Filtering laboratory experiment.
- PD Control laboratory experiment.
- Rotary Pendulum Modeling laboratory experiment.

1 Background

Balancing is a common control task. In this experiment we will find control strategies that balance the pendulum in the upright position while maintaining a desired position of the arm. When balancing the system, the pendulum angle α is small and balancing can be accomplished with a simple PD controller, as shown in Figure 1.1. If we are further interested in keeping the arm in a desired position, a feedback loop from the arm position will also be introduced. The control law can then be expressed as

$$u = k_{p,\theta}(\theta_r - \theta) - k_{p,\alpha}\alpha - k_{d,\theta}\dot{\theta} - k_{d,\alpha}\dot{\alpha} \tag{1.1}$$

where $k_{p,\theta}$ is the arm angle proportional gain, $k_{p,\alpha}$ is the pendulum angle proportional gain, $k_{d,\theta}$ is the arm angle derivative gain, and $k_{d,\alpha}$ is the pendulum angle derivative gain. The desired, or reference, angle of the rotary arm is denoted by θ_r. The reference for the pendulum angle is zero (i.e. upright position).

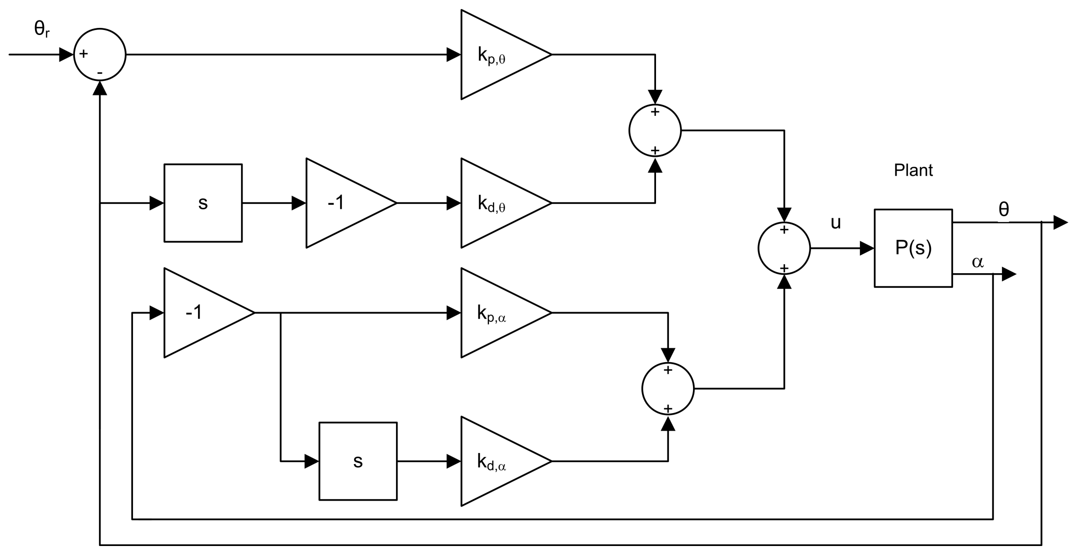


Figure 1.1: Block diagram of balance PD control for rotary pendulum

There are many different ways to find the controller parameters. The two most common ones are explored in the Pole-Placement Control and Optimal LQR Control laboratory experiments. Initially, however, the behavior of the system will be explored using default parameters.

Recall that the pendulum angle α is defined as zero when the pendulum is about its upright vertical position and expressed mathematically using $\alpha = \alpha_{full} \bmod 2\pi - \pi$, as defined in the Rotary Pendulum Modeling Lab as

$$\alpha = \alpha_{full} \bmod 2\pi - \pi.$$

The balance control is to be enabled when the pendulum is within the following range:

$$|\alpha| \leq 10^\circ. \tag{1.2}$$

Given that the pendulum starts in the downward vertical position, it needs to be manually brought up to its upright vertical position. Once the pendulum is within $\pm 10^\circ$, the balance controller is engaged. It remains in balance mode until the pendulum goes beyond $\pm 10^\circ$.

If desired, you can integrate this with an algorithm that swings-up the pendulum automatically. See the Pole-Placement Control laboratory experiment for details.

2 In-Lab Exercises

Construct a QUARC® controller similarly as shown in Figure 2.1 that balances the pendulum on the QUBE-Servo 2 rotary pendulum using the PD control detailed in Section 1.

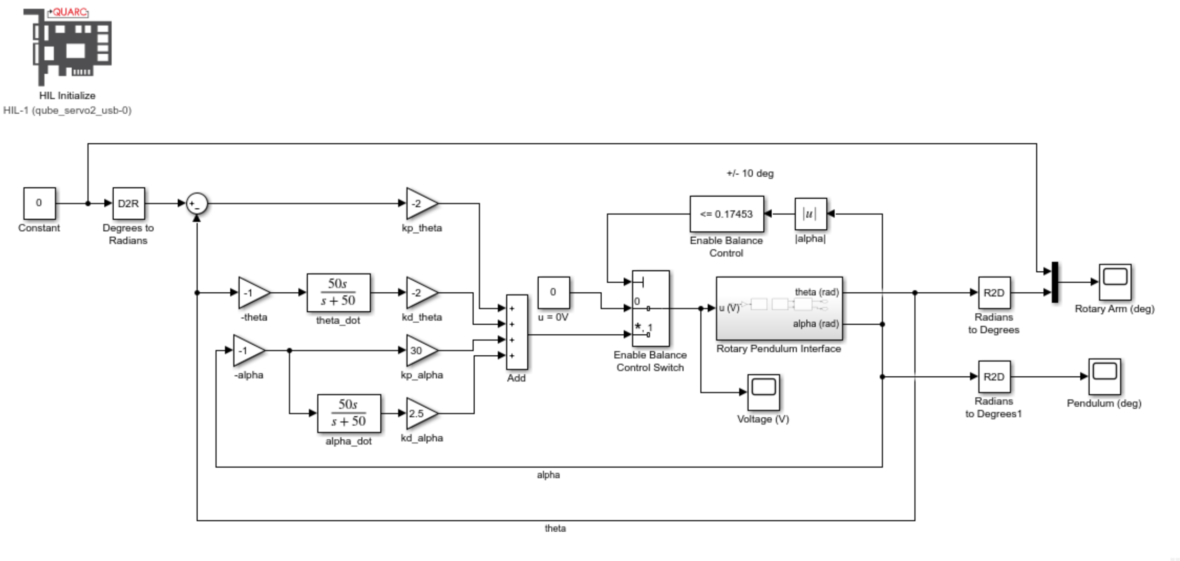
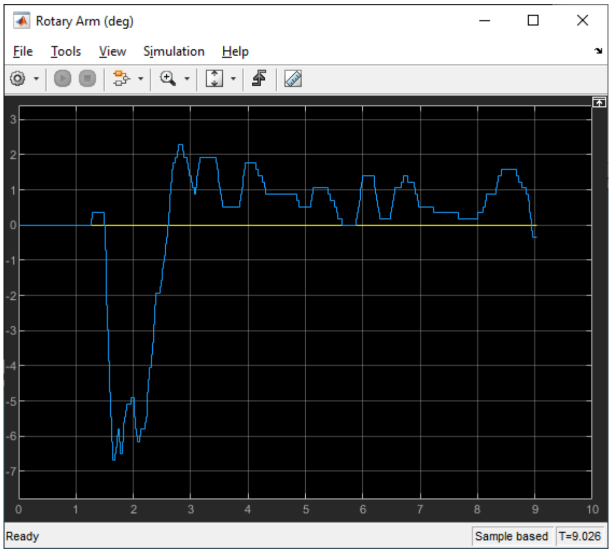
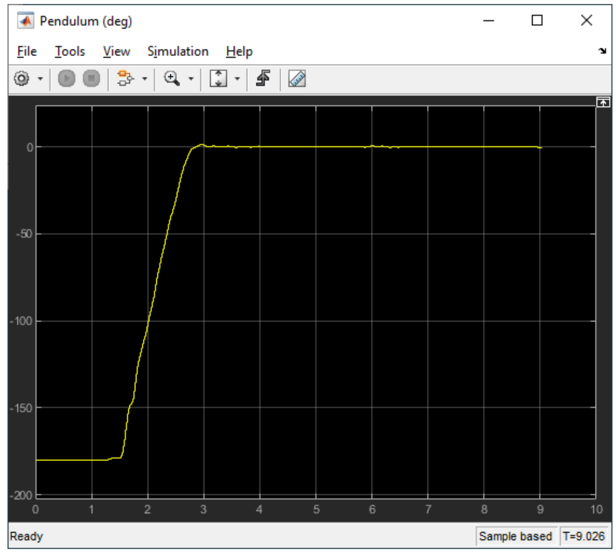


Figure 2.1: SIMULINK® model used with QUARC® run balance controller

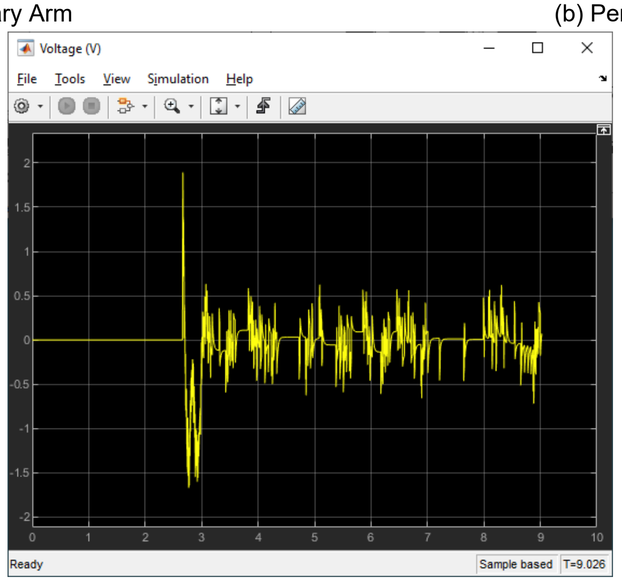
1. Using the SIMULINK® model you made in the *Rotary Pendulum Model* lab, construct the controller shown in Figure 2.1:
   - The Rotary Pendulum Interface subsystem includes the QUARC® HIL blocks to interface to the encoders and motor of the QUBE-Servo 2 pendulum system and the Counts to Angles subsystem contains the same blocks used in the Stability Analysis laboratory experiment to convert encoder counts to radians. *Make sure you use the inverted pendulum angle*.
   - Similarly as done in Filtering laboratory experiment, add the derivative and low-pass filter transfer function blocks $50s/(s+50)$ to find the velocity of the rotary arm and pendulum.
   - Add the necessary Sum and Gain blocks to implement the PD control given in Equation 1.1 and illustrated in Figure 1.1.
   - The controller should only be enabled when the pendulum is $\pm 10°$ about the upright vertical position (or ± 0.175 rad). Add the absolute value, constant comparison, and selector blocks to implement this.
2. Set the PD gains as follows: $k_{p,\theta} = -2$, $k_{p,\alpha} = 30$, $k_{d,\theta} = -2$, and $k_{d,\alpha} = 2.5$.
3. Build and run the QUARC® controller.
4. Manually rotate the pendulum in the upright position until the controller engages. The scopes should read something similar as shown in Figure 2.2. Attach response of the rotary arm, pendulum, and controller voltage.



(a) Rotary Arm



(b) Pendulum



(c) Motor Voltage

Figure 2.2: QUBE-Servo 2 rotary pendulum response

5. As the pendulum is being balanced, describe the responses in the *Rotary Arm (deg)* and the *Pendulum Angle (deg)* scopes.
6. Vary the `Constant` block that is connected to the positive input of the summer block in the PD control. Observe the response in the *Arm Angle (deg)* scope. **Do not set the value too high, keep it within $\pm 45°$ to start.** What variable does this represent in the balance control? Attach representative screen captures of the response.
7. Stop the QUARC® controller.

Quanser Inc.
119 Spy Court
Markham, Ontario
L3R 5H6
Canada
info@quanser.com
Phone: 1-905-940-3575
Fax: 1-905-940-3576

Printed in Markham, Ontario.

For more information on the solutions Quanser Inc. offers, please visit the web site at:
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