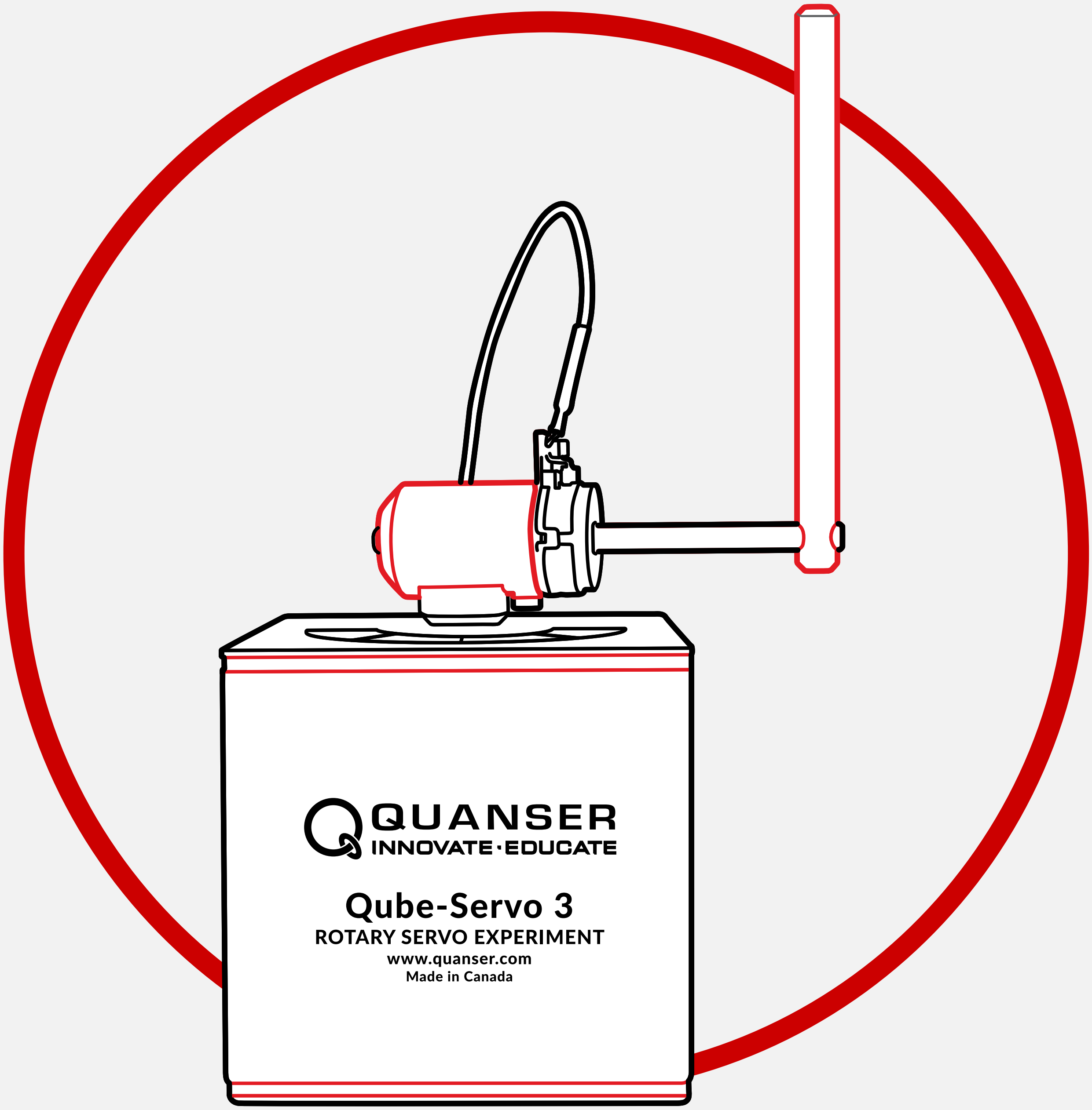

Qube-Servo 3

Balance Control

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QUANSER
INNOVATE·EDUCATE

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Qube-Servo 3 – Application Guide
Balance Control

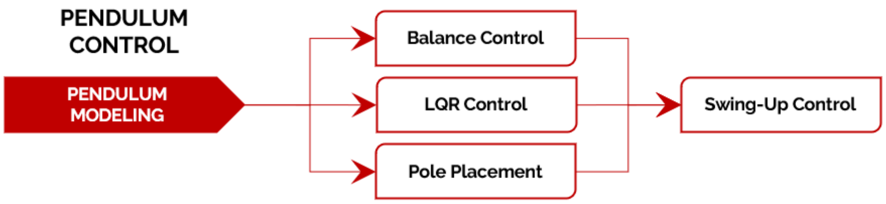
Why explore Balance Control?

The inverted pendulum is a harder challenge than controlling a simple motor position or velocity. An inverted pendulum represents an unstable equilibrium - the slightest disturbance will cause it to fall away. Based on the Qube's system, the state cannot be directly controlled; instead, the pendulum angle must be influenced indirectly through the rotation of the motor in the base, introducing nonlinearities that complicate the analysis and control design. This provides a challenging yet insightful platform to investigate the principles of proportional-derivative (PD) control. By analyzing the dynamic behavior of this inherently unstable system, students can gain a deeper understanding of feedback control, system identification, and the practical implementation of control algorithms.

Background

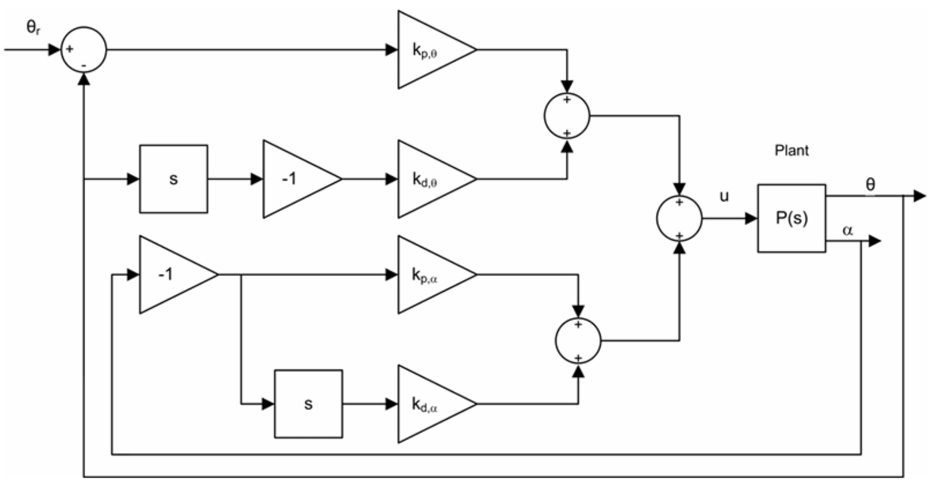
This lab is part of the Pendulum Control skills progression of the Qube-Servo 3. These labs are focused on understanding different ways to maintain balance of an inverted pendulum and finish off with creating an energy based controller to swing it up and then maintain the balance.

The lab progression is as follows:



PD Balance Control

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 here



If we are further interested in keeping the arm in a desired position, a feedback loop from the arm position will also be introduced. Notice in the figure above that there is no error term for the reference angle for the pendulum, since it is always zero (i.e. upright position). The control law can then be expressed as

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

Where:

- θ_r is the desired, or reference, angle of the base.

- $k_{p,\theta}$ is the is the base angle proportional gain

- $k_{d,\theta}$ is the base angle derivative gain

- $k_{p,\alpha}$ the pendulum angle proportional gain

- $k_{d,\alpha}$ is the pendulum angle derivative gain

We will use default parameters to explore balance control.

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. The balance control is to be enabled when the pendulum is within the following range: $|\alpha| \leq 10°$.

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

Getting started

In this lab, you will construct a Simulink model that uses two feedback PD loops to balance the pendulum once it is in the upright position. The goal of this lab is to explore the behavior of the balanced pendulum, so pre-determined control gains will be used.

Ensure you have completed the following labs

- SP0 _ Instrumentation Labs
- SP5_ Pendulum Modeling Labs

Before you begin this lab, ensure that the following criteria are met.

- If using a physical Qube-Servo 3, make sure it has been setup and tested. See the Qube-Servo 3 Quick Start Guide for details on this step.
- Make sure the pendulum attachment is set up and connected to the Qube-Servo 3 using the cable to the Encoder 1 port. Turn the plug to make sure the pendulum is centered around the front of the Qube at 0˚. The resistance from the cable will help keep it in the desired position.
- If using the virtual Qube-Servo 3, make sure you have Quanser Interactive Labs open in the Qube 3 - Pendulum → Pendulum Workspace.
- You are familiar with the basics of Simulink. See the Simulink Onramp for more help with getting started with Simulink.