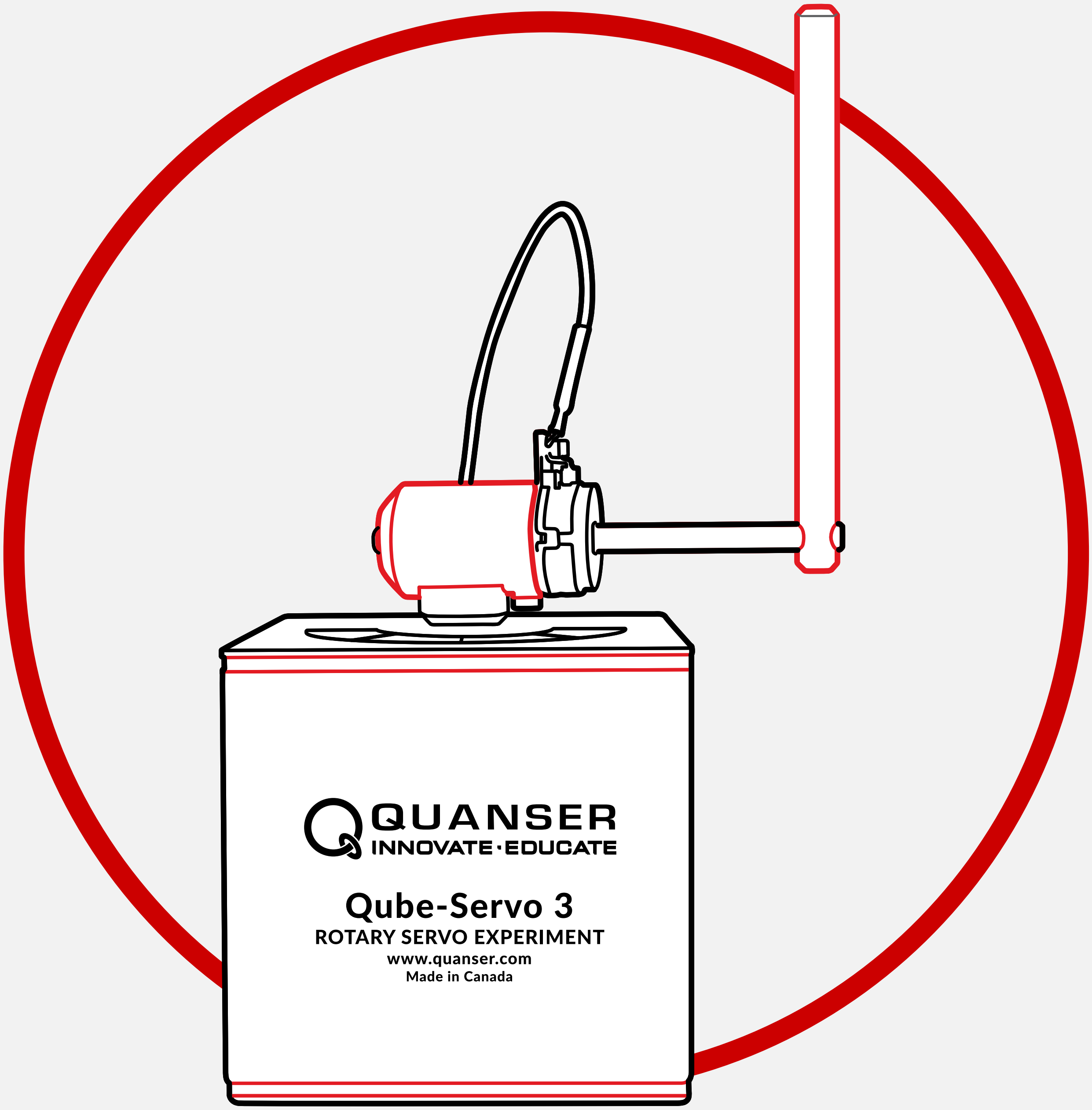

Qube-Servo 3

Curriculum Pipelines

V1.0 – 1st September 2024

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Qube-Servo 3

Curriculum Pipelines

Why pipeline driven content?

The curriculum provided with the Qube Servo 3 is broken down by pipelines for various module attachments for the device (disc and pendulum). Each pipeline includes a series of labs to walk students through aspects of that pipeline. As an instructor, you will find that the pipelines typically suit the needs of your courses, and serve to guide you towards meeting your teaching goals and learning outcomes.

Background

Every lab consists of the following documentation,

- Concept Reviews:
  Independent reference material for student use that serves as a means for them to refresh the most important concepts and equations for any lab. These exist in a separate concept_reviews folder in the downloaded files.

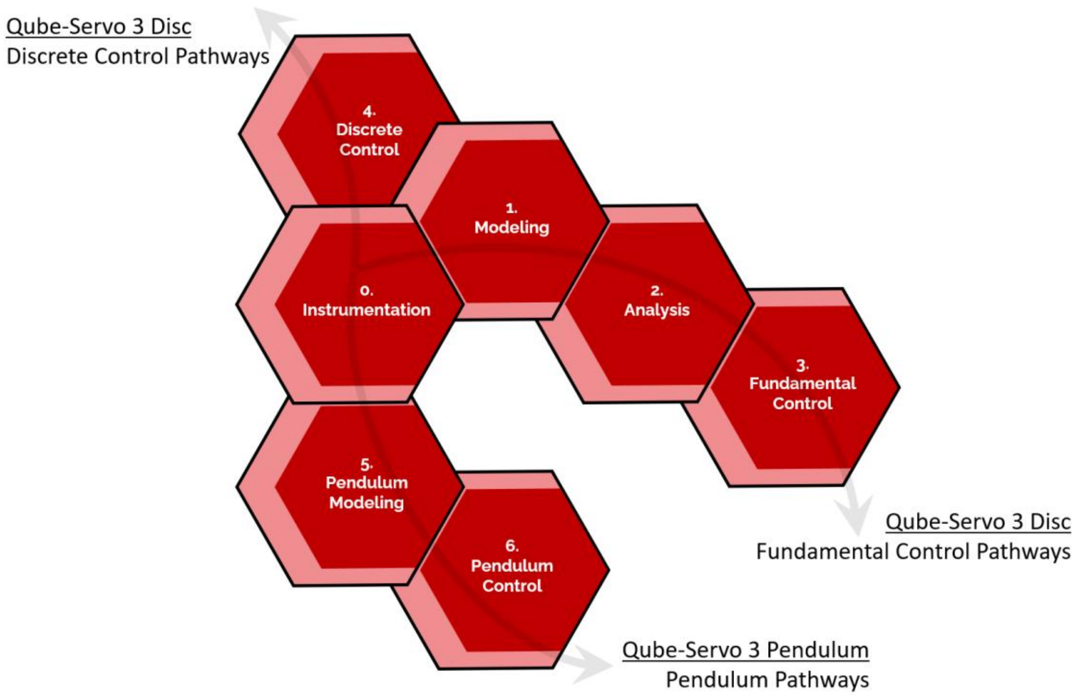
- Application Guides:
  Lab specific introduction that guides students towards why the lab is important and what they will learn as well as things they need to know before starting the lab.

- Lab Procedures:
  Lab specific instruction manuals with guided steps to walk students through the lab, reflect on important considerations and take notes or screenshots and capture results.

- Recommended Assessments:
  Lab specific take home questionnaire that requires critical thinking and further analysis of lab results. The results from the lab procedure will be analyzed here by the student.

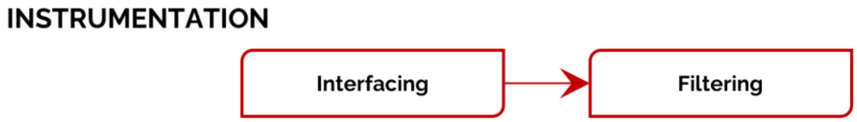
Getting started

The Qube Servo 3 curriculum is broken down into a list of 7 pipelines in total, with 3 recommended pathways as shown below. For introductory modeling, analysis and controls, we recommend the pathway from pipelines 0 through to 3.



Pipeline 0 - Instrumentation

We recommend every course using the Qube-Servo 3 to start with this pipeline. The two fundamental labs in this pipeline introduce the device to students in a user-friendly manner. If your students have not used hardware before, or need a refresher on using hardware, this is a must have that sets students up for success with other learning outcomes.

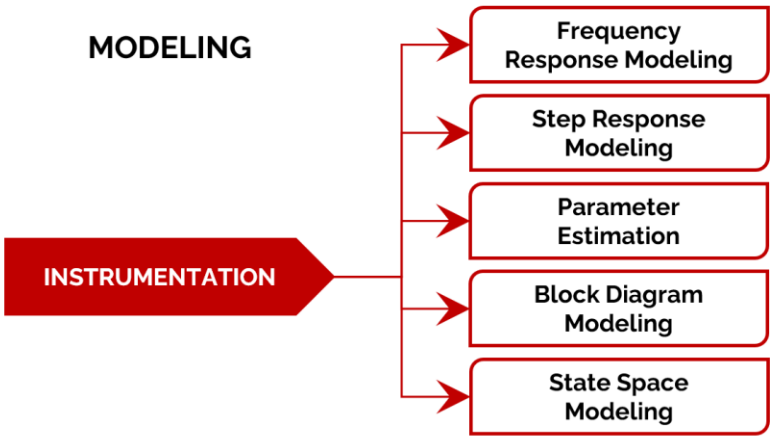


Lab 1 – Hardware Interfacing

Lab 2 – Filtering

Pipeline 1 - Modeling

This pipeline introduces various methods and concepts related to modeling physical plants. You can tackle learning outcomes ranging from understanding and using transfer functions to represent plant functions, estimating hardware parameters experimentally, etc. to using analytical first principles modeling and state space methods. Depending on your course, you can choose 1 modeling lab to introduce students to understanding a DC motor or go through all of them for students to get a general understanding of different ways to model a system. These labs are not numbered since they can be done in any order. The instrumentation labs should be done first to get a general idea on how to interface with the system.



Lab – Frequency Response Modeling

Lab – Step Response Modeling

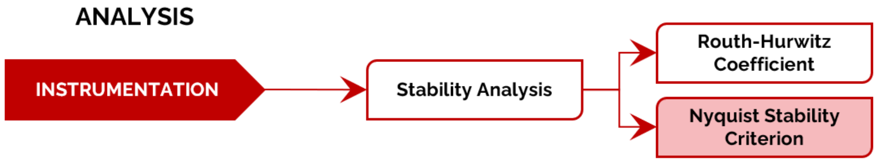
Lab – Parameter Estimation

Lab – Block Diagram Modeling

Lab – State Space Modeling

Pipeline 2 - Analysis

The analysis pipeline focuses on fundamental control theory concepts applied to the Qube-Servo 3 DC motor system. This includes labs on stability analysis using methods like the Routh-Hurwitz criterion and Nyquist stability criterion, response analysis of the system's rise time, settling time and overshoot, and frequency response analysis to measure bandwidth. You can choose these labs when students are learning about stability of a system and how to interpret those results.
Note: The labs marked in red are not yet published.



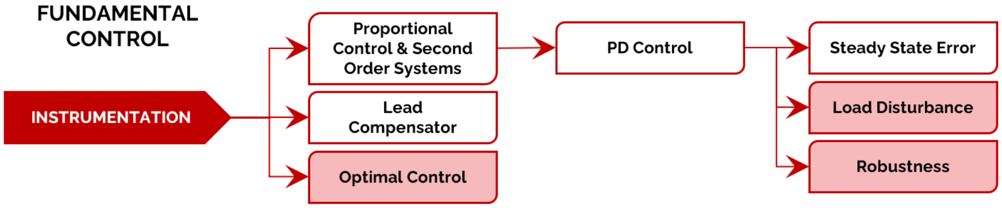
Lab 1 – Stability Analysis

Lab 2a – Routh-Hurwitz Coefficient

Lab 2b – Nyquist Stability Criterion

Pipeline 3 – Fundamental Control

The Fundamental Control pipeline of the Qube-Servo 3 curriculum covers the essential control theory concepts required to effectively manipulate the DC motor system. This includes labs focused on designing proportional and second-order control systems, implementing PD control to achieve desired transient responses, and analyzing techniques to minimize steady-state errors, such as incorporating integral control. By understanding these control theory skills, students gain a robust understanding that supports their development of increasingly sophisticated control strategies for the system.
Note: The labs marked in red are not yet published.



Lab 1a – Proportional Control and Second Order Systems

Lab – Lead Compensator

Lab – Optimal Control

Lab 2 – PD Control

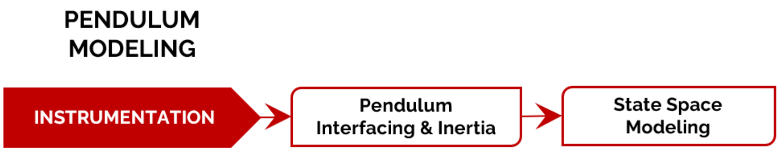
Lab 3a – Steady State Error

Lab 3b – Load Disturbance

Lab 3c - Robustness

Pipeline 5 – Pendulum Modeling

The pendulum modeling pipeline introduces the dynamics and modeling of the Qube-Servo 3's inverted pendulum attachment. Students will learn how to interface with the pendulum hardware, measure its physical parameters, and derive the state-space representation of the inverted pendulum system. These modeling skills provide the groundwork for advanced control design to keep the pendulum balanced in the pendulum control pipeline.
Note: The labs marked in red are not yet published.

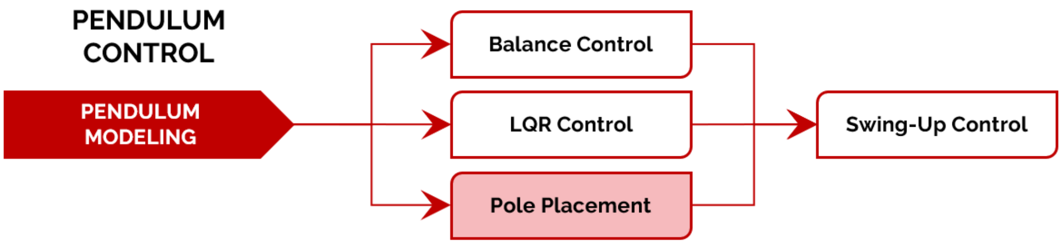


Lab 1 – Pendulum Interfacing and Inertia

Lab 2 – State Space Modeling

Pipeline 6 – Pendulum Control

When students are ready for more advanced control applications, the pendulum control pipeline will focus on stabilizing and manipulating the inverted pendulum. Labs cover implementing feedback controllers for balance, designing optimal LQR controllers, using pole placement techniques, and developing strategies to swing the pendulum up from the hanging equilibrium. These labs allow students to leverage the modeling and analysis skills from previous pipelines to showcase the Qube-Servo 3's full capabilities. Students can do any lab to understand balancing a pendulum using 3 different control techniques and finally they can learn to do an energy-based swing up controller. Students will have to have completed pipeline 5 to be able to understand how to interface with the pendulum as well as the position conventions.
Note: The labs marked in red are not yet published.



Lab 1a – Balance Control

Lab 1b – LQR Control

Lab 1c – Pole Placement

Lab 2 – Swing-Up Control