Single, Double and Triple Inverted Pendulum – ENGT 481 Team 45

The Inverted Pendulum Problem

PURDUE POLYTECHNIC

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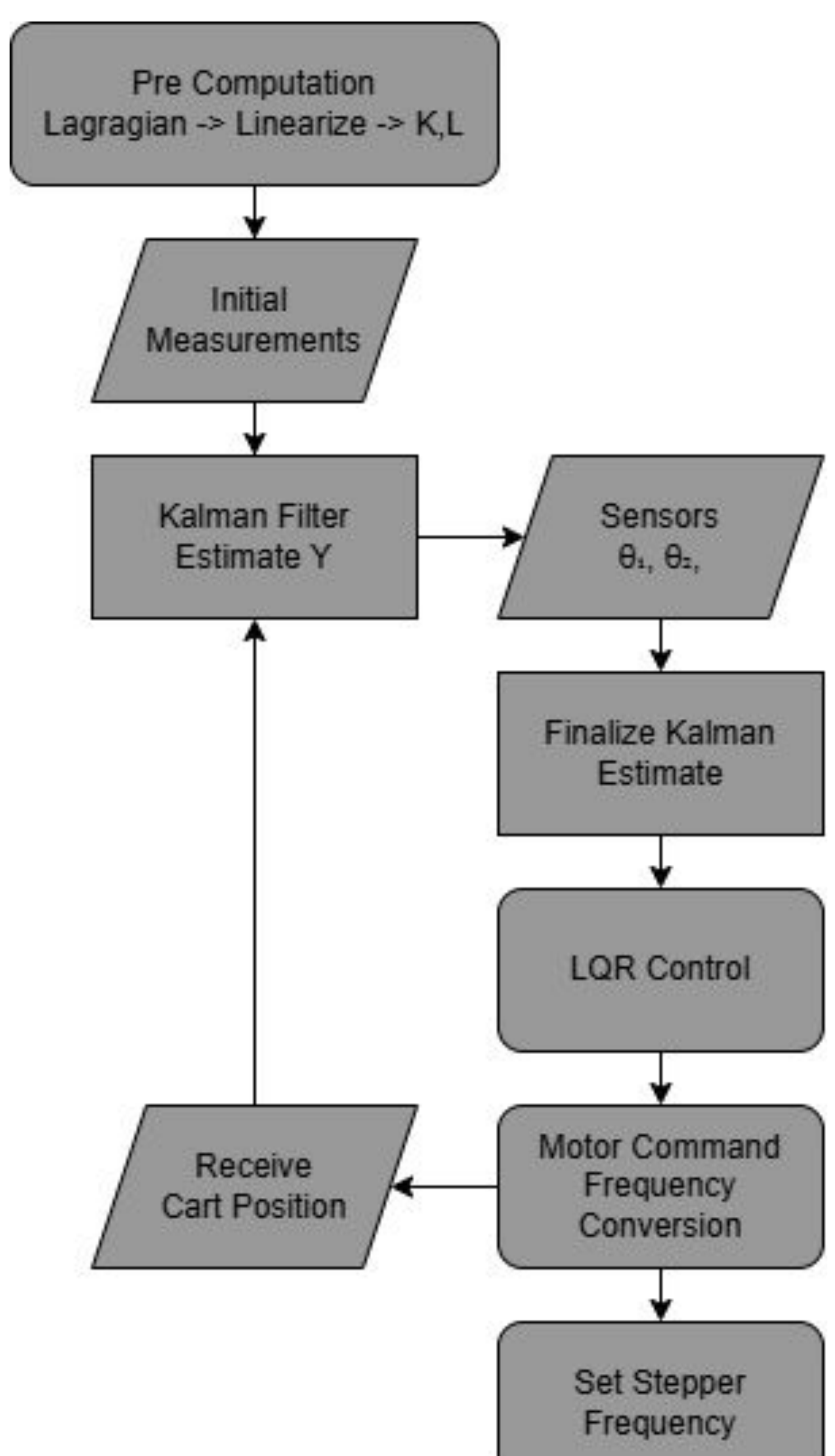
Problem Statement

The goal of this project is to design and build a modular single, double, and triple inverted pendulum system for Purdue Polytechnic. The system must balance increasingly unstable pendulum configurations using a single cart-driven input while remaining within rail limits and operating safely. This project serves as both a control theory benchmark and an educational platform for future students studying dynamic systems and advanced controls.

Customer Background

Our customer is Purdue Polytechnic, with the intent of creating a hands-on demonstration platform for control systems education and experimentation. Inverted pendulums are a classic benchmark problem because they are a naturally unstable, nonlinear and highly sensitive to sensing and control quality. A successful build would provide students and researchers with a physical system for testing classical and modern control strategies in a safe repeatable environment.

Control Schema



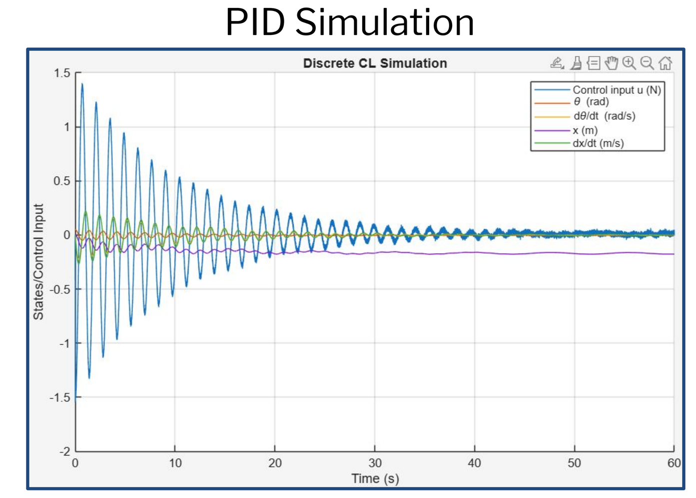
Experimentation and Concepts

Our test bench was designed for other groups to easily pick up core concepts on controls experimentation with 8 different major revisions made to improve the systems reliability. Most of these changes came after issues shown in physical testing.

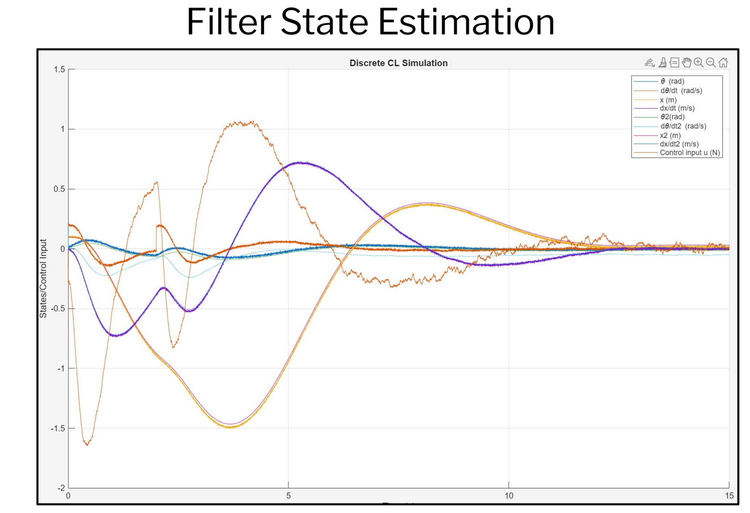
Our controls system and test programs ran through a series of changes as we continued to progress with our project. Our test algorithms included:

- Single Pendulum
  - PID
  - LQG
  - LQG with angle tuning
- Double Pendulum
  - LQG
  - LQG with angle tuning
- Communications Test
- Frequency Sweep Test

PID Simulation



Simulation of LQG with Kalman Filter State Estimation



Final Design

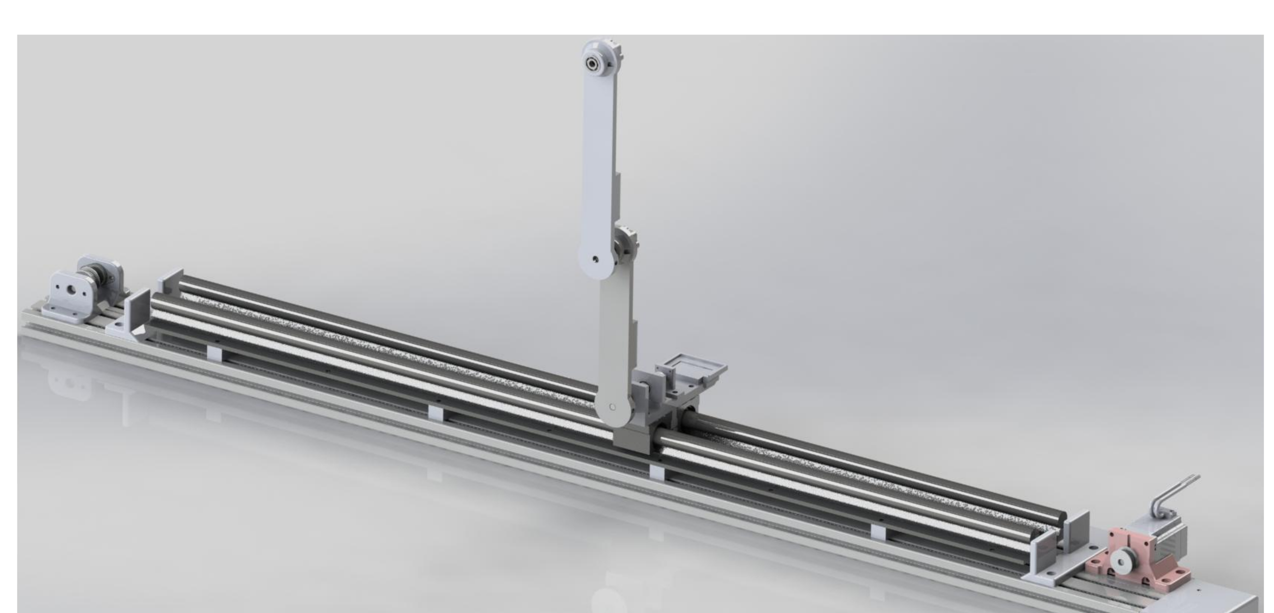
MATLAB SOLIDWORKS

Mechanical Components

- 2 Linear tracks for the cart to move on
- 4 Linear bearings to hold the cart
- NEMA 23 Stepper motor with a belt for controlling the movement

Electronics

- 2 MT6701 magnetic encoders to read the angles of the pendulum arms
- 2 ESP-32 Xiao Seed's with batteries connected to the encoders to wirelessly send angle readings
- 1 ESP-32 WROOM Dev Board for encoder data polling
- 1 Raspberry Pi is given the angle readings and performs computations for our control program
- 1 Arduino MEGA 2560 is given a frequency from the Pi which then controls the motor



Testing and Results

We tested our pendulum by running it repeatedly and making adjustments to the tuning values. There was very little hard data involved in our adjustments, just a visual assessment of the performance of the system. When close comparisons of changes were needed, we would take videos to compare the results. Our results from early simulations matched well with the actual performance of the system when it was implemented.

Single Pendulum LQG Testing

Double Pendulum LQG Testing