ME155C Final Project Report
Inverted Pendulum Control: Swing-up, Balance, and Catching

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Abstract

This project focuses on the identification, modeling, and control of an inverted pendulum on a cart system. Through experimental identification, control design, and closed-loop testing, we implemented robust swing-up, balancing, and catching controllers. System identification methods included logarithmic sine sweeps and parametric identification with MATLAB's tfest. Controller design employed energy-based swing-up methods and robust LQR/LQG balancing strategies. Experimental validations confirm effective performance, achieving stable equilibrium transitions and pendulum catching.

1 Introduction

This project investigates the control of an inverted pendulum on a cart, specifically targeting swing-up, balancing, and catching tasks. The inverted pendulum, a classic control problem, requires precise and robust feedback control strategies due to its inherent instability. Previous literature includes methods involving energy-based swing-up and state-space feedback stabilization. The report is structured with system identification in Section 2, controller design in Section 3, closed-loop results in Section 4, and conclusions in Section 5.

2 System Identification

2.1 Process Description

The experimental setup consists of an asymmetric metal rod mounted to a motor-driven cart, with encoders providing measurements of pendulum angle (θ) and cart position. The control input is the motor voltage (u), and the primary controlled outputs are cart position and pendulum angle.

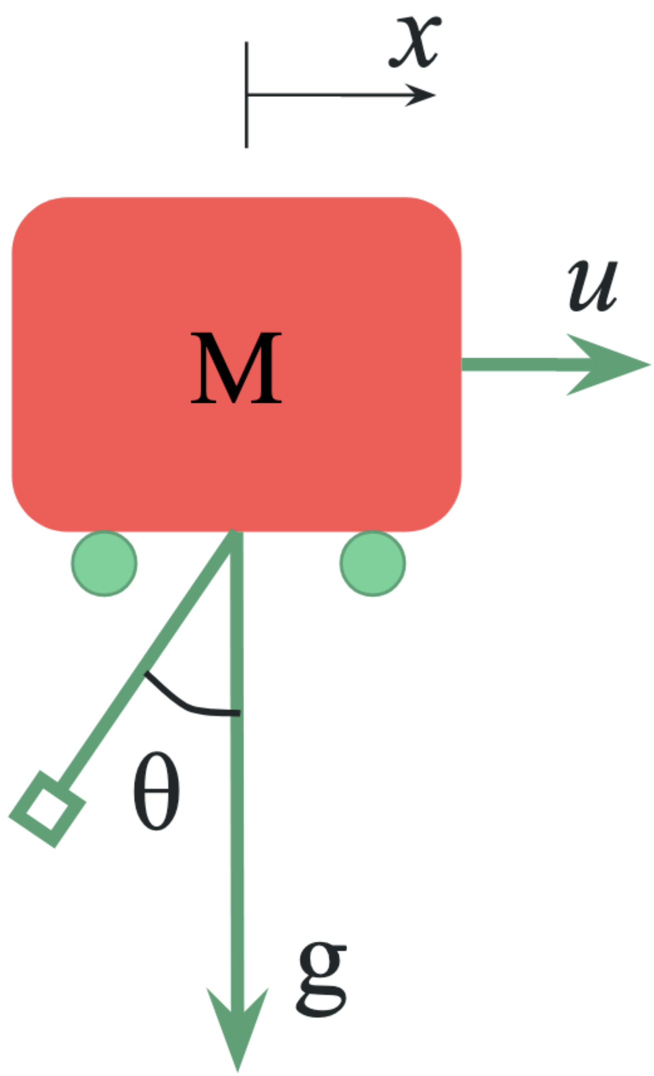

Figure 1: Experimental setup: Cart-pendulum system.

2.2 Identification Methods

Non-parametric identification utilized a logarithmic sine sweep ($0.3 - 3$ Hz). Parametric identification was done using MATLAB's `tfest` function, performing 30 experimental trials.

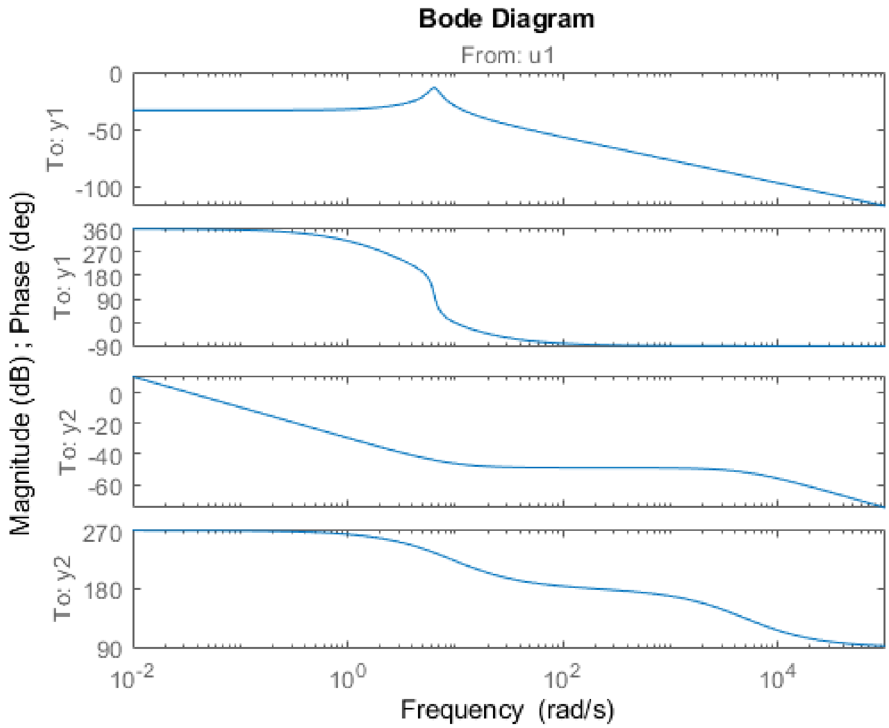

Figure 2: Bode plot: Identified frequency response for cart dynamics and pendulum dynamics downwards.

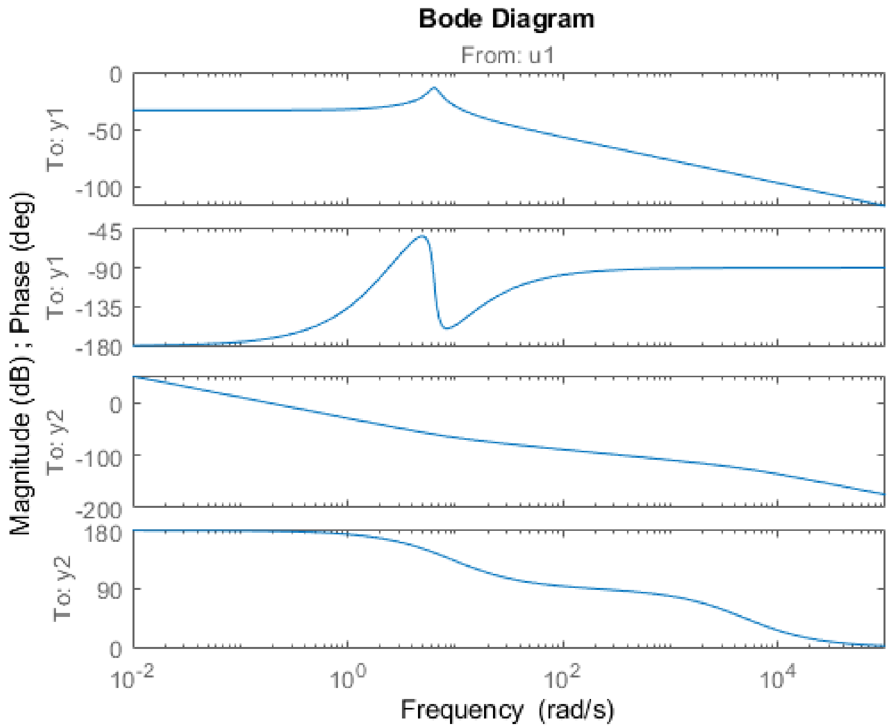

Figure 3: Bode plot: Identified frequency response for cart dynamics and pendulum dynamics upwards.

3 Controller Design

3.1 Swing-Up Controller

An energy addition method drives the pendulum toward the upright position by strategically applying force near zero crossings of θ, boosting the system's mechanical energy.

Figure 4: Swing-up controller activation.

3.2 Balancing Controller

The balancing controller employs LQR/LQG methods to stabilize the pendulum in the inverted (unstable) equilibrium within a narrow angular region.

3.3 Catching Controller

Similar to balancing, catching employs LQR/LQG but aims to return the pendulum reliably to the stable downward equilibrium.

3.4 State Machine

Control modes transition between swing-up, balancing, and catching using a robust state machine architecture.

Figure 5: State machine for mode switching between controllers.

4 Closed-Loop Performance

Closed-loop experiments validated the controllers' performance. The step response showed quick stabilization and effective handling of mode transitions.

Figure 6: Closed-loop step response for cart and pendulum positions.

5 Conclusions and Future Work

The controllers successfully addressed swing-up, balancing, and catching objectives, validating theoretical designs with robust experimental performance. Further work includes enhancing failure logic and addressing steady-state error.