



Balancing an Inverted Pendulum on a Two-Wheeled Cart Under Low Sensor Sample Rate

A.W.B.I. Annasiwaththa^{1}, R.M.A.S. Wijerathna¹, S.M.S. Dinendra¹*

¹ Faculty of Engineering, University of Ruhuna

**Corresponding author: annasi@mme.ruh.ac.lk*

Balancing an inverted pendulum mounted on a two-wheeled cart presents a challenging nonlinear control problem due to its inherent open-loop instability and the coupled dynamics of the cart and pendulum. Furthermore, the system is underactuated and includes nonlinearities in both mechanical and electrical domains. The system investigated in this work is a two-degree-of-freedom platform where both the cart and the pendulum are free to rotate, each contributing to the instability. The cart itself cannot balance without continuous wheel actuation, while the pendulum adds an additional unstable mode, making the configuration similar to a simplified double-pendulum system, but in a more uncontrolled environment as it must operate on ground that is not perfectly smooth and flat, experiencing wheel slip and mechanical dead zones. This study examines whether effective stabilization can be achieved under a low sensor sampling rate and control rate of 200 Hz, which is intentionally selected to allow implementation on a low-cost microcontroller (STM32F103). Such constraints limit the bandwidth of the controller and increase sensitivity to measurement noise. Furthermore, they introduce processing limitations due to limited CPU power. Similar work presented in the literature uses sample rates beyond 500 Hz for simple control and over 1 kHz for advanced optimal or robust controller implementation. Advanced optimal control strategies were implemented with a 200 Hz sample and control rate, including a Linear Quadratic Regulator (LQR) combined with a Kalman state estimator, and incremental PI motor controllers are utilized to maintain stability. Despite low sampling rates and the use of the cheapest available IMU (\$1.50 USD), the proposed approach achieves reliable balancing and smooth recovery from disturbances. In this study, velocity estimation near the operating point of the implemented system is challenging due to the zero responses at the operating point, particularly under low sample rates. The Kalman estimator compensates for these limitations by fusing encoder, accelerometer, and gyro data.

Keywords: 2 DOF inverted pendulum, Pendulum on cart, Low sample rate control, Underactuated control