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Comparative Analysis of Sliding Mode Control Variants for Double-Inverted Pendulum Systems: Performance, Stability, and Robustness

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Abstract

This paper presents a comprehensive comparative analysis of seven sliding mode control (SMC) variants for stabilization of a double-inverted pendulum (DIP) system. We evaluate Classical SMC, Super-Twisting Algorithm (STA), Adaptive SMC, Hybrid Adaptive STA-SMC, Swing-Up SMC, Model Predictive Control (MPC), and their combinations across multiple performance dimensions: computational efficiency, transient response, chattering reduction, energy consumption, and robustness to model uncertainty and external disturbances. Through rigorous Lyapunov stability analysis, we establish theoretical convergence guarantees for each controller variant. Performance benchmarking with 400+ Monte Carlo simulations reveals that STA-SMC achieves superior overall performance (1.82s settling time, 2.3

Keywords: Sliding mode control, double-inverted pendulum, super-twisting algorithm, adaptive control, Lyapunov stability, particle swarm optimization, robust control, chattering reduction