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Control of a Two-Wheeled Inverted Pendulum using Integral Sliding Mode

Ravindra K. Munje
K. K. Wagh Institute of Engineering Education and Research, Nashik 422003, India, ravimunje@yahoo.co.in

Deepak M. Sonje
R. H. Sapat College of Engineering, Management Studies and Research, Nashik 422009, India, deepaksonje123@gmail.com

Deepak P. Kadam
MET's Institute of Engineering, Nashik 422003, India, dpkadam@gmail.com

Abstract -

Modelling and control of two-wheeled inverted pendulum (TWIP) are gaining much interest due to the advancements in hardware and computing technologies. TWIP system has many advantages and applications. However, it is still having many challenges to control when faced with tasks of positioning, disturbance rejection, parameter uncertainties, etc. In this paper, a control scheme based on modern control techniques is presented to overcome these issues. In this, a robust integral sliding mode controller (ISMC) is proposed for the nonlinear system of TWIP. First of all, a robust integral sliding mode controller is designed to tackle short-term and long-term constant and time-varying disturbances and issues related to parameter variations. Then, it is applied to the nonlinear model of TWIP and performance is observed under different transient conditions. A comparison with prevalent controllers in the literature is carried out. From this, a significant improvement is seen with the proposed controller for all types of transients. This paper also discusses the software Simulink realization of modelling and control of TWIP, which can be valuable for novices working in this area.

Index Terms - Integral Sliding Mode, Simulink Modeling, Sliding Mode Control, Two-Wheeled Inverted Pendulum.

INTRODUCTION

The two-wheeled inverted pendulum (TWIP) is a highly nonlinear and naturally unstable system. It is an underactuated system having three degree-of-freedom with pitch, yaw and straight-line movements merely with two wheels [1]. This interesting system has attracted the attention of many researchers worldwide over the last three decades. However, there are some challenges. Challenges associated with this system are mathematical modelling, controller design and its implementation. Although the modelling is difficult due to nonlinear and complex dynamics, uncertain environmental conditions, parameter uncertainties, etc. several research groups have proposed mathematical models for TWIP. An exact and accurate nonlinear model of the TWIP system is proposed in [2]. This model overcomes the drawbacks of the earlier models such as inappropriate assumptions, improper terms, missing some important terms, etc. Followed by modelling, control design plays an important role. In literature, the controllers for TWIP are designed using the linear quadratic regulator (LQR) [3], feedback linearization [4], fuzzy logic [5, 6], sliding mode control [7], optimal control [8], etc.

In [9], a gray box modelling of a TWIP robot using the Lagrange equation is proposed, in which a closed-loop parameter identification method is used. Further, in this, the design and software implementations of PID and LQR are demonstrated. In another research, the model of TWIP is obtained using differential equations, and then PID, LQR and linear quadratic Gaussian (LQG) controllers are designed. It is also shown that the performance of LQG is superior to LQR [10]. In [11], an optimal controller based on model predictive control is designed to show the performance improvement over PID for the self-balancing two-wheeled robot system. In [12], an integral sliding