Sliding Mode Control in Dynamic Systems (Editorial)

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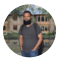
3 authors:


Ali Arshad
COMSATS University Islamabad


Rizwan Azam
COMSATS University Islamabad


Jamshed Iqbal
University of Hull

electronics

Editorial

Sliding Mode Control in Dynamic Systems

Ali Arshad Uppal [1], Muhammad Rizwan Azam [1] and Jamshed Iqbal [2,*]

[1] Department of Electrical and Computer Engineering, COMSATS University Islamabad, Islamabad 45550, Pakistan
[2] School of Computer Science, University of Hull, Hull HU6 7RX, UK
* Correspondence: j.iqbal@hull.ac.uk

1. Introduction

Due to its inherent robustness and finite time convergence, sliding mode control (SMC) is extensively used for the control of nonlinear uncertain systems. Apart from robustness against parametric variations and external disturbances, it also provides model order reduction. It has been employed in a large range of dynamic systems, including but not limited to; electric drives, power converters, power systems, aircrafts, autonomous vehicles, a wide range of mechanical systems, and industrial processes. The discontinuous control law in SMC is the reason behind its robustness. However, it also suffers from for the so-called chattering problem. Much of the research in SMC is carried out to address the chattering phenomenon, which gives rise to higher order SMC, adaptive SMC and chattering free SMC. Another important research topic pertaining to SMC is the finite-time convergence of the error dynamics, which leads to the advent of finite time convergent SMC (FTSMC). Contrary to conventional SMC, the sliding variable in FTSMC is nonlinear which results in finite time convergence of the sliding mode.

The objective of this special issue is to bring together an articulate set of papers that advance understanding of the theory and practice behind SMC and its variants. The special issue is timely since recent years have witnessed the notable experimental realisation of SMC-based control laws in applications of immense importance. It is anticipated that the wider dissemination of recent research trends in SMC and its variants will stimulate more exchanges and collaborations among the control community and contribute to further advancements from an applied perspective.

The topics of interest are as follows:

- Sliding mode control-Theory and practice
- Sliding mode observers
- Higher-order sliding mode controllers
- Fast integral terminal sliding mode controller
- Fixed-time nonlinear homogeneous sliding mode controller
- Adaptive or Neuro-adaptive global sliding mode controller
- Role of SMC in Industry 4.0 cyber physical systems

2. Review of Published Papers

Asif et al. in [1] propose a two-stage maximum power point tracking (MPPT) approach for photovoltaic (PV) systems with partial shading conditions. The proposed method combines machine learning (ML) and terminal sliding mode control (TSMC) to improve MPPT algorithm accuracy. The first stage generates the reference voltage for MPPT by employing a neuro fuzzy network (NFN), whereas, the second stage tracks the maximum power point (MPP) voltage by employing a TSMC. The proposed method is validated through simulations as well as experiments. The results indicate that it outperforms traditional MPPT algorithms in generating higher power and ensuring finite time convergence of the MPP voltage tracking. Moreover, it effectively handles shading-induced multiple peaks and

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performs well under irradiance, temperature and load variations. The proposed two-stage approach offers a promising and robust solution for enhancing PV system performance in PSCs.

In [2], Yao, G. et al. have designed a sliding mode based observer to reconstruct the q-axis current of the permanent magnet synchronous motor (PMSM), provided that the d-axis current is measurable. The authors have employed the 2-phase model of the PMSM in a static reference frame for observer synthesis. Apart from robustness, the proposed technique also eliminates the blind area of current reconstruction. The estimated current is used to control the speed of the PMSM using a cascaded control system. The inner loop controls the currents of d and q axes of synchronously rotating reference frame, whereas the outer loop is responsible for maintaining a desired speed. The performance of the control system is tested for nominal and perturbed systems, which shows that the proposed method is robust.

In [3], Vennemann, J. et al. have developed a cascaded control system for active magnetic bearings (AMBs) with large air gaps. The aim of the control strategy is to regulate the positions of x and y axes AMBs, which is attained by two independent position controllers in the outer loop. The inner current control loop employs the super-twisting algorithm (STA) for maintaining the desired trajectories of currents produced by the outer loop controllers. The use of STA is motivated due to the fact that it only requires the measurement of the output signal, yields reduced chattering and improved tracking performance. Furthermore, the proposed methodology is implemented on a physical system. The results show that the designed methodology with STA is superior as compared to conventional control techniques.

The authors in [4] have designed a model-based, chattering free sliding mode controller (CFSMC) to track the desired trajectory of the calorific value of the exit gas mixture for an underground coal gasification process. The design of the CFSMC employs a nonlinear mathematical model of the UCG process. In order to estimate the unmeasurable states of the system involved in the controller synthesis, a state dependent Kalman Filter (SDKF) is also designed. The structure and algorithm of the SDKF is similar to a discrete time Kalman Filter, however, it utilizes the quasi-linear model of the UCG process to estimate the states on the entire operating range. The advantage of using a quasi-linear model is that it decomposes the system in the form of state space representation, with state dependent matrices, retaining the original nonlinear dynamics of the process. The simulation results of the designed technique are compared with dynamic integral sliding mode control and a conventional sliding mode control, which show that the tracking performance of the CFSMC is superior as compared to its counterparts.

Riaz S. et al. in [5] propose a robust predefined time convergent sliding mode controller (PreDSMC) algorithm for precise position control of permanent magnet linear motor (PMLM) systems for industrial applications. The proposed algorithm eliminates the position tracking error within a predefined time. Moreover, PreDSMC effectively handles external disturbances and model parameter variations with bounded convergence error and constrained control input. Numerical simulations demonstrate current research work's effectiveness in reducing the impacts of friction and external disturbances compared to traditional control methods (i.e., PID and linear SMC). The proposed algorithm has potential applications in trajectory tracking control of a wide range of industrial nonlinear systems.

In [6], the authors have proposed a hybrid backstepping based super-twisting algorithm for speed control of a 3-phase induction machine (IM) with squirrel cage rotor. The discontinuities in the input are minimized using exact differentiator. The simulations are performed in MATLAB and the IM is operated in three different modes: start and stop mode, normal operation mode and disturbance rejection mode. A comprehensive simulation study is carried out in which the proposed technique is compared with conventional sliding mode control, super-twisting control and backstepping control. The quantitative comparison in terms of integral squared error, integral absolute error and integral time absolute error shows that the proposed methodology has superior disturbance rejection and tracking performances.

Alvaro J. P. et al. in [7] address the windup phenomenon by proposing and experimentally realizing two SMC-based control algorithms to improve the response of integral controllers, which are common in industrial setups. The algorithms, named as ‘windup conditional reset’ and ‘windup instantaneous reset’, rely on resetting the integral control action while maintaining the disturbance rejection capability of the system. An anti-saturation function is used for anticipating and steering the error in trajectory tracking onto the manifold origin. This is complemented by an action to compensate for robustness. The algorithmic efficiency of the anti-windup techniques is characterized by applying them to two chemical processes; a stirred tank reactor and a mixing tank, which respectively feature the systems with variable longtime delay and with variable height. Different reference signals are applied considering various disturbances and relevant error benchmarks like integral time square error (ITSE) and integral square error (ISE) are observed. Experimental results evidence that the proposed algorithms circumvent actuators’ saturation and offer adequate tracking accuracy despite application of disturbances as demonstrated by the reduced overshoot and settling time achieved in the response. It is shown that robustness is achieved without deteriorating stability of the system. Also, the original schemes of controllers do not need to be changed for realizing the proposed algorithms.

R. Hu et al. in [8] investigate coupling effects and nonlinearity in manipulators by realizing multi-joints coordination in the robot. The main objective here is to exploit the benefits offered by dynamically combining two control techniques namely; super-twisting SMC and fractional-order non-singular terminal SMC. The former control offers fast system response with suppressed chattering while the latter exhibits superior steady-state tracking accuracy. The proposed controller named ‘Dynamic Fractional-Order Non-singular Terminal Super-Twisting SMC’ gets benefit from these remarkable features and allows the position of the sliding surface to dynamically change. The controller design is based on the derived model of a four degree of freedom low-cost humanoid manipulator. Kinematics is derived using Denavit–Hartenberg (DH) parameters while the derivation of manipulator dynamics considers friction effects. Lyapunov theory is used to prove stability of the manipulator. The higher order term hiding the sign function suppresses chattering phenomenon in SMC. Simulation and experimental results demonstrate that the proposed control law permits accurate tracking accuracy, chattering mitigation and improved error convergence.

In [9], Jnayah, S. et al. have designed a robust direct torque control (DTC) strategy of an induction machine (IM) with a three-level inverter. The speed, flux and torque controllers employ sliding mode control theory, which proves to be more robust as compared to conventional hysteresis and PI based control algorithms. The simulation results show that the proposed control strategy is robust against sudden changes in load torque. Furthermore, the proposed SMC based DTC approach is implemented on a field programmable gate array (FPGA) using the Xilinx system generator. The parallel processing of the FPGA has been demonstrated through hardware co-simulation results.

Liang, Y. et al. in [10] propose a novel sliding mode controller for trajectory tracking in systems with unknown uncertainties. The proposed controller combines a PID type sliding surface with a variable gain hyperbolic reaching law, resulting in improved control performance. This choice of reaching law combines the benefits of integral sliding mode (ISM) and terminal sliding mode (TSM) control algorithms, and provides global finite-time convergence. Utilizing a variable gain hyperbolic term instead of conventional switching term eliminates chattering and ensures variable approaching velocities to the sliding surface for different initial positions. Simulation studies using a two-link robot validate the effectiveness of the proposed controller, demonstrating fast response, and high tracking accuracy even in the presence of time-varying uncertain external disturbances and load variations.

The authors in [11] have designed a dynamic integral sliding mode control (DISMC) strategy to boost and regulate the output voltage of proton exchange membrane fuel cell (PEMFC) system operating under varying loads. The voltage control problem is solved using a 2-loop control strategy, with a PI controller in the outer loop for voltage regulation and the inner current control loop employs the DISMC algorithm. The DISMC offers increased robustness due to the elimination of the reaching phase and it also yields a continuous control effort. The efficacy of the designed technique is validated on a hardware setup in which a portable PEMFC is connected to a boost power converter. The results of voltage regulation are compared for the DISMC and PI controllers in simulation and hardware settings, which show that the proposed scheme exhibits a better transient response and demonstrates superior robustness against sudden changes in load.

Li, Z. et al. in [12] present a sensorless control algorithm for permanent magnet linear synchronous motors (PMLSMs) that enhances tracking capability and estimation accuracy. The system combines a continuous terminal sliding mode controller (CTSMC) with a fuzzy super twisting sliding mode observer (FSTSMO). The CTSMC enables fast and continuous control, achieving rapid tracking of desired speed, while the FSTSMO algorithm improves sensorless estimation accuracy by using adaptive gains instead of fixed gains (as used in conventional SMO). Simulation as well as experimental results demonstrate the effectiveness of the proposed system, with reduced position tracking errors and improved dynamic performance. This research offers a promising solution for high-precision operation in sensorless PMLSM systems, with potential applications in various industries.

Conflicts of Interest: The authors declare no conflict of interest.

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