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# Adaptive fractional order sliding mode controller with neural estimator

Juntao Fei [a,*], Cheng Lu [b]

[a] College of IoT Engineering, Hohai University, Changzhou 213022, China
[b] School of Electrical Engineering, Nantong University, Nantong 226019, China

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**Abstract**

In this study, an adaptive fractional order sliding mode controller with a neural estimator is proposed for a class of systems with nonlinear disturbances. Compared with traditional sliding mode controller, the new proposed fractional order sliding mode controller contains a fractional order term in the sliding surface. The fractional order sliding surface is used in adaptive laws which are derived in the framework of Lyapunov stability theory. The bound of the disturbances is estimated by a radial basis function neural network to relax the requirement of disturbance bound. To investigate the effectiveness of the proposed adaptive neural fractional order sliding mode controller, the methodology is applied to a *Z*-axis Micro-Electro-Mechanical System (MEMS) gyroscope to control the vibrating dynamics of the proof mass. Simulation results demonstrate that the proposed control system can improve tracking performance as well as parameter identification performance.
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## 1. Introduction

In recent years, fractional calculus has attracted much attention of scientists and engineers. As a branch of mathematics, fractional calculus is a generalization and extension of integer differentiation and integration to fractional orders. It is found that, by using fractional calculus in modeling, system models in fractional order format can more accurately describe the dynamics or behaviors of real systems. Thus, fractional calculus has been widely used

* Corresponding author.
*E-mail addresses:* jtfei@hhu.edu.cn, johnfei123@163.com (J. Fei).

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in chaos systems, economic systems, modeling and control applications [1–9], drawing more and more attention.

Sliding mode control (SMC) is a powerful robust control scheme which has been widely used in many areas. The concept of SMC is based on variable structure control where the SMC makes use of a designed manifold in the state space and a robust term will switch the SMC control law to force system states into a sliding state on the designed manifold. Due to the fact that the design of the sliding manifold is based on the dynamics of the system, SMC has many outstanding features such as robustness to parameters variation, insensitivity to external disturbances. In actual situations, adaptive control technique is usually used in sliding mode control because adaptive sliding mode control (ASMC) combines the merits of adaptive control and sliding mode control. In [10], a robust adaptive sliding mode controller is proposed for Takagi–Sugeno (T–S) fuzzy systems. A robust controller is proposed in [11] to obtain output voltage regulation in a quadratic boost converter where the inner loop of the robust controller is based on SMC method. An adaptive sliding mode position control of a coupled-phase linear variable reluctance (LVR) motor is developed for high-precision applications in [12]. ASMC can be used in control of integer order systems [11,12] and fractional order systems [3,5]. An adaptive sliding mode controller is proposed for fractional order uncertain linear systems in [3]. A sliding mode control is proposed in [5] to realize the synchronization of fractional order chaotic systems.

Some other advanced control methods have also been developed by adopting fractional order operators [13–21]. In [15], a fractional order controller named frequency adaptive selective harmonic control scheme is used to deal with the harmonics in the presence of grid frequency variations. A frequency adaptive fractional order repetitive control method is proposed in [16] for the shunt active power filters. In [18], a fractional order controller is proposed to control spacecraft attitudes for flexible spacecrafts. A fractional order PD motion controller is proposed in [21] where tuning rules and experiments are also provided and investigated. Thus, fractional order operator can also be used in ASMC and new sliding surface structures are worthy of concentration and investigation; meanwhile, the effects of fractional order terms shall also be studied in detail. Although ASMC can compensate model uncertainties and external disturbances, the bound of the lumped disturbance shall be known in advance. Actually, the bound of disturbances is varying all the time and it is hard or even impossible to get the actual value of disturbance bound. This will make the ASMC controller hard to be implemented and a conservative method to solve the problem is to choose a large robust gain so that all the disturbances can be compensated. However, the robust term in the ASMC controller contains a discontinuous part of sign function; a large robust gain will lead to severe chattering phenomena [22, 23]. Neural networks [24, 25, 28] have a capacity to approximate any smooth systems to arbitrary closeness and this merit makes neural network a good tool in adaptive application.

So it is necessary to design a compound fractional order sliding mode controller with upper bound neural estimate in the control of systems. The effectiveness of fractional order terms on the behaviors of systems under proposed control scheme shall be studied in detail. In this paper, a Lyapunov based adaptive fractional order sliding mode controller with upper bound neural estimation is proposed for a class of integer order systems with nonlinear disturbances. The main contribution is the design of a compound fractional order sliding manifold together with the corresponding ASMC controller using fractional order adaptive laws. The control strategy combines the adaptive fractional sliding mode control method with the Lyapunov stability theory. The proposed adaptive neural network fractional order sliding mode control

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