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An Introduction to Sliding Mode Controllers

1.1 Introduction

In the world of control systems, sliding-mode controller (SMC) is a nonlinear control strategy that uses a control signal with a variable structure to change the dynamics of a nonlinear system that forces the system to “slide” along a predetermined path. It is called the sliding surface, and the curved movement of the system path on this surface will guarantee the stability of the system in the presence of parametric and structural uncertainties with a limited bound. The state feedback control law in sliding mode controllers is not a continuous function in terms of time, and, in other words, the position of the system path curve in the state space is dependent. Hence, sliding mode control is a variable structure control method. This variable structure controller is designed in such a way that the system trajectories always converge toward the sliding surface, and by sliding on this path, the tracking error of the desired behavior in the control system tends to zero. The movement of the system during sliding along the neighborhood of the sliding surface is called sliding mode. In the framework of modern control theory, the SMC variable structure system is considered as a subset of hybrid dynamic control systems, because the path curve of the system moves continuously through different and discrete control laws.

Sliding-mode control has two main advantages. The first advantage is that by choosing the appropriate sliding function, the desired dynamic behavior of the system can be achieved. And secondly, the closed-loop response of the system has no sensitivity to uncertainties (model parameters, disturbances, and non-linearity). As a result, from a practical point of view, nonlinear processes are controlled by using sliding-mode control in the presence of model disturbances and uncertainties. Unique features such as accuracy, consistency, and easy setup and implementation have made sliding controllers very popular.

Methods of Developing Sliding Mode Controllers: Design and MATLAB Simulation, First Edition.
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Published 2025 by John Wiley & Sons, Inc.

Sliding-mode control is especially useful for systems that are highly nonlinear and have uncertain dynamics. It can also be used for systems with external disturbances that need to be rejected. This technique is widely used in aerospace, automotive, and robotics applications.

1.2 Advantages and Limitations of Sliding Mode Controllers

Sliding-mode control is a variable structure controller that was first introduced by Vadim Utkin [1]. Sliding-mode control is a robust control method that is widely used to control and stabilize nonlinear systems. Its most important features are simple design and resistance to uncertainty in the model, i.e. parametric uncertainties and unmodeled dynamics, as well as rejection of external disturbances. Uncertainties have destructive effects on nonlinear systems and strongly affect the design of closed-loop control system [2]. The SMC design is based on the definition of an arbitrary linear slip surface in order to guarantee the optimal performance of the closed-loop control system and asymptotic stability based on the concept of the Lyapunov stability theorem. As SMC does not result in the convergence of system states to zero in finite time, it is developed to Terminal Sliding-Mode Control (TSMC) in order to achieve the finite time convergence. In this method, a non-linear sliding surface is used instead of the linear one applied in conventional SMC methods. Nonlinear sliding surfaces in TSMC have improved the transient-mode performance and, compared to conventional SMC, TSMC provides features such as fast convergence, finite time stability, increased accuracy of steady-state response, and in addition enhanced robustness [3]. However, the conventional TSMC faces two major problems that need to be solved: the singularity problem and the chattering phenomenon. To solve the first problem in [4], a switching method between non-linear sliding surface in TSMC and linear sliding surface in SMC is proposed. Also, in [5], the method of transferring the system path to a specific area inorder to singularity avoidance, is used. However, in these methods, the singularity problem is solved indirectly. Therefore, a Non-singular Terminal Sliding-mode Control method (NTSMC) has been introduced in [6], which directly solves the singularity problem by proposing a non-singular non-linear sliding surface.

Regarding the second problem, in techniques based on sliding mode control, when the system states are close to the sliding level, the existence of the discontinuous term in the control law causes chattering phenomenon. Chattering is an undesirable phenomenon as the vibration of the control signal causes energy loss, and, on the other hand, due to its high frequency, it may stimulate the high-frequency modes of the system which could potentially lead to instability. Also, chattering can cause wear in mechanical parts and electromechanical systems, and possible damage to various system components. To overcome this problem, various techniques are used in different articles such as high-order sliding-mode control [7, 8], fuzzy sliding mode control [9–11], and using neural networks [12, 13].

Although, as stated, the supplementary topics of the sliding controllers, which are provided to solve the limitations of this controller, are very extensive, in this book, an attempt has been made to the basic part of these supplementary topics, i.e. chattering removal methods, terminal, fuzzy, adaptive, and super-twisting SMC. It is also combined with feedback linearization and back stepping and at the end of each chapter a MATLAB programming is presented on the inverted pendulum to investigate the results.

1.3 An Overview of Book Contents

This book contains 12 chapters. In the first chapter, sliding mode controllers and their challenges are introduced in general. In the second chapter, the basic issues and definitions of classic sliding mode controllers and how to program and simulate these controllers in MATLAB have been discussed. The third chapter deals with the terminal sliding controllers that use the non-linear sliding surface to increase the convergence speed. In addition, its complementary topics, including fast and non-singular sliding-mode controllers, have been introduced and simulated. The fourth chapter deals with the dynamic sliding controllers, and the fifth chapter introduces the fuzzy sliding controllers for the uncertain dynamic estimation of the system with fuzzy structure and its sliding control. In the sixth chapter, adaptive sliding controllers with indeterminate parameters in system dynamics are presented along with parameter adaptation rules and MATLAB programming. The seventh chapter, includes super-twisting sliding-mode controllers. In chapter eight, the combination of sliding and backstepping control, which is of great interest due to its advantages such as the ability to design subsystems step by step, has been introduced and simulated. In the ninth chapter, the phenomenon of chattering and the effective solutions to reduce drawbacks have been reviewed along with providing suitable examples and analytical tables of the results. Chapter 10 indicates the supplementary topics of using sliding controllers with feedback linearization. In chapter 11, the design and stability analysis of fixed-time sliding mode controllers is discussed and finally the last chapter is related to design and MATLAB programming of event triggered sliding mode controllers.

The purpose of the authors of this book is to introduce basic techniques of SMC improvement to students and researchers who are interested in design and simulation of sliding-mode controllers and control of nonlinear systems, quickly and easily. We hope that this book can be an effective guide for researchers in this field.

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