

**SLIDING MODE VARIABLE STRUCTURE CONTROL DESIGN
PRINCIPLES AND APPLICATION TO DC DRIVES**

AUZANI BIN JIDIN

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Universiti Teknologi Malaysia

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ABSTRACT

Interests in the application of sliding mode control technique in variable speed drives have increased in recent years. It is well known that a distinguished property of a sliding mode control technique is its insensitivity to system uncertainties and external disturbances. Compared to the conventional PI controller, the system is sensitive to the parameter variations and inadequate rejection of external disturbances or load variations. Furthermore in order to design PI controller, the challenge faced by the researchers due to multi loop system structure and trial and error design approach which make the control design time consuming and expensive. This has lead to the development of the sliding modes control technique, which is very attractive for its excellent performance, easy to implement with simple control algorithm. It is desirable to achieve robust performance against external disturbances especially sudden or step load applications. In this thesis, a control system of DC motor for speed and torque control based on variable structure systems with sliding mode control approach is discussed. The choice of switching functions for different control goals using a method of the switching function estimation based on control error and armature current information is presented. The current limiter mechanism to limit the current during startup, acceleration and deceleration for speed control loop is proposed and the external torque observer is constructed. The simulations of the performance comparisons between sliding mode control and PI control show that variable structure system with sliding mode control approach is less sensitive to parameter variations, produce faster dynamic response, eliminates overshoot and performs better in rejecting disturbance. The excellent features of the sliding mode control based on variable structure system are mainly due to the high gain effect, which suppresses influence of disturbances and uncertainties in system behavior.

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CHAPTER 1

INTRODUCTION

1.1 Background of the Variable Structure Control

Variable structure system (VSS) with sliding mode control was first proposed and elaborated in the early 1950's in the Soviet Union by Emelyanov and several co researchers. At the very beginning, VSS is well known as special class of nonlinear systems for solving several specific control tasks in second order linear and nonlinear systems. However VSS did not receive wide acceptance among engineering professionals until the first survey paper that is IEEE Transactions on Automatic Control in 1977 was published by Utkin. The most interesting fact is that robustness has becomes a major requirement in modern control application [1].

1.2 Variable Structure System with Sliding Mode Approach

The most distinguishing property of VSS is its ability to result in very robust control systems. In other words, the system is completely insensitive to parametric uncertainty and external disturbances. Due to its excellent invariance and robustness properties, the VSS concepts have been developed into practical application mainly in the field of control of DC servo motors [2][3], robotic manipulators [4][5], PM synchronous servomotors, induction motors, aircraft control, spacecraft control and flexible space structure control [6]. These experiments confirm the theoretical results regarding robustness of VSS with sliding modes.

However, in some of these experimental results [2][4][5], it was found that the resulting control is discontinuous and the chattering phenomenon which can lead to low accuracy in control system. These problems can be solved by replacing a continuous control [4][5] into the computation of the control input (a sign function). As a result, the large error behavior of a system is identical to that with discontinuous control. It can be assumed that, the behavior of the system in small error region as a high gain system and this is similar to that of system with discontinuous control. Hence, this high gain effect of sliding mode control based on VSS, suppressed the uncertainties due to parametric variations, external disturbances and variable payloads [5]. Besides that the proper selection of the switching functions will avoid chattering problem in the DC drive systems, hence result in high accuracy control. The choice of switching functions to control the system states, such that current, speed or position has been discussed and examined in detail in literature [7]. In [8], the control of a permanent magnet synchronous motor under sliding mode controller has been presented which uses a hyperbolic tangent switching function in order to overcome the chattering problem. Under this control strategy, the dynamic performance of the system can be shaped according to the system specification by an appropriate choice of switching function.

It is well known, that the sliding mode control is a popular robust control method. However it has a reaching phase problem and an input chattering problem (as discussed above). These problems cause the sliding mode control (SMC) is very conservative to be used with other controller design methods because the state trajectory of the sliding mode control system is determined by sliding mode dynamics, which cannot have the same order dynamics of the original system. This leads to the introduction of robust controller design with novel sliding surface. To overcome the conservatism of the SMC, the novel sliding surface has been used which has the same dynamics of the nominal original system controlled by a nominal controller. The reaching phase problem, can be eliminated, by using an initial virtual state that makes the initial sliding function equal to zero. Therefore, it is possible to use the SMC technique with various types of controller. The proposed controller design with novel sliding surface is discussed in detail in [9].

Besides that, as discussed in [10], although SMC systems are qualitatively well known for possessing robust performance, the quantitative analysis of the robustness and synthesis of the control system to enhance the robust performance, especially against a step load disturbance for DC drive is necessary. The reason why the quantitative analysis is necessary, because of the step load application may vary due to certain factors such as an integral action and smooth control algorithms which are often incorporated in the practical system. In [10], the analysis in terms of the time domain expressions of the transient speed deviation and its maximum value due to a step load application under sliding mode control was performed. As a result, the fast response speed and robust performances can be achieved.

In recent years the automation in manufacturing industries has becomes popular and shown significant interest in automation in order to increase the productivity as well as increases in intelligence of the process. In this context, the automated Guided Vehicle (AGV) system is the important part in a computer integrated manufacturing (CIM) facility. The comparison of various VSS techniques based on sliding mode control including a novel approach for the control of AGV has been proposed in [11]. There are three types of approach proposed. The first approach is classical SMC based on Lyapunov design. The second approach is classical SMC with the estimation of the equivalent control, and the third one is a novel approach to eliminate the chattering. As investigated in this literature, it was concluded that the novel approach is most powerful method and easily applicable in real systems. Furthermore this approach is capable of achieving a good chatter free trajectory following performance without an exact knowledge of plant parameters.

An advanced discrete time chattering free SMC scheme is presented in [12]. By using this scheme the chattering of control input can be eliminated and the excitation of the dynamic system without high frequency oscillations can be achieved. It is different with other techniques, especially the algorithm used to avoid chattering problem. This approach uses only the information about the distance from the sliding mode manifold to derive the control. The advantage of this approach prevails over those conventional control schemes, since no precise knowledge of mathematical model is necessary.

1.3 Comparison with Classical Linear Approach

Many papers [8][10][13] discussed about the comparison between the SMC and classical linear approach that is proportional integral (PI) control.

In [8], the performance comparisons between the sliding mode and PI controllers have been analyzed. A simple SMC is applied to a permanent magnet synchronous motor. The comparisons of the performance responses for both control schemes are analyzed in terms of which technique results an excellent robustness in responses to system parameter uncertainties, load disturbances and in case of noisy measurement. The simulation results show that the SMC performs better compared to the classical PI control.

As discussed in literature [10], the PI control is subject to limitations due to the intrinsic conflict between the steady state accuracy and dynamic response speed. In PI control, the dynamic performance specification can be achieved only if the compromise has been made to solve the conflict between excessive oscillation or overshoot and long settling time. Besides that, to meet higher system specification, the challenge faced by the design engineers due to multi loop system structure and trial and error design approach which lead to the control design time consuming and expensive. It was concluded that the principal weakness of the PI control is its sensitivity to parameter system variations and also not capable of rejecting any external disturbances or load variations.

In [13], the experimental comparison between second-order SMC of DC drives (a novel class of SMC algorithm) and PI control has been reported. The major drawback for linear control system design in order to get proper design of PI controllers was stated. Some adjustment or tuning process is necessary, in order to achieve the desired tradeoff between precision, bandwidth and disturbance rejection. These required precise knowledge of motor parameters. Therefore the robust control techniques such that second order SMC has been proposed to overcome these problems. Furthermore, this approach does not require current feedback, and demands only rough information about actual motor parameters. The experimental

results for the comparison was performed, it is shown that the proposed control scheme that is characterized by the absence of current loop, is more robust against parameter and load variations, compare to results obtained for the PI control. In addition, the results of the proposed control scheme show improvements with regard to robustness, dynamic response and chattering reduction.

1.3 Thesis Objectives and Scope of Work

The objectives of this thesis are listed as follows:

- i. To study and understand Variable Structure System (VSS) approach to control system design.
- ii. To simulate and design the VSS with SMC that shows good steady state and dynamic behavior in the presence of plant parameters variation and disturbances.
- iii. To make the performance comparisons of controller responses between classical method (PI control) and sliding mode technique.
- iv. To implement hardware of DC drives that is torque control, using SMC and PI control.

In this thesis project the scope of work will be undertaken in the following five developmental stages:

- i. Study of the control system of DC motor for speed and torque control based on VSS with SMC approach.
- ii. Design the current limiter mechanism to limit the current during startup, acceleration or deceleration for speed control loop and construct the external torque observer in order to estimate the load torque.

- iii. Perform simulation of SMC and PI control. This simulation work will be carried out on MATLAB platform with Simulink as its user interface.
- iv. The comparisons between PI control and sliding mode techniques are investigated.
- v. Development of the algorithm using C programming and implements the hardware of torque control of DC drives for SMC and PI control using TMS320C31 Digital Signal Processor (DSP).

1.4 Thesis Organisation

The rest of the thesis is organized as follows:

Chapter 2 describes the basic theory of DC motor such as the model and related equations of the permanent magnet DC motor. The chapter also briefly discusses 4 quadrant operations using full bridge DC-DC converter.

Chapter 3 discusses the basic of VSS with sliding mode to the control system and mathematical formulation of the control system requirements. The design process of VSS with sliding mode approach to control torque and speed are also presented.

Chapter 4 presents the performance comparisons of speed control between SMC and PI control. Simulation and experimental results of torque control using SMC and PI control are presented. In this chapter, the design procedures of the PI, speed and current controllers for a DC drive are also described.

Chapter 5 describes each the hardware components used in the experimental set-up. Some constraints of the hardware implementation in this project especially to control speed, are described.

Chapter 6 gives the conclusions to the thesis and recommendations to improve and further research in this work.