CHAPTER 1

INTRODUCTION AND OVERVIEW

1.1 Research Motivation and Purpose

It is well known that the sliding-mode control (SMC) is an effective control algorithm for systems suffering from matched disturbances under the condition that their upper bounds are given [1-4]. Attracted by the robustness advantage, the SMC has been widely studied and applied in various fields of engineering applications over the last 30 years [5-17].

For the SMC design, the system trajectory is forced to reach a chosen hyper-surface, called sliding surface, by employing a discontinuous feedback control algorithm. When the system stays on this selected sliding surface, it is called that the system is in the sliding mode. In the sliding mode, the controlled system possesses excellent robustness and invariance properties to the matched disturbances. In general, the SMC requires m sliding surfaces for a system with m control inputs. However, these discontinuity surfaces divide the system space into 2^m sub-regions and 2^m distinct control vectors are generated correspondingly.

To minimize the number of control vectors, Baida and Izosimov [18] proposed the simplex sliding-mode control (SSMC) based on a simplex set, which consists of m+1 distinct control vectors. By utilizing the simplex set, the system space is only divided into m+1 sub-regions, which is much less than 2^m sub-regions caused by the traditional SMC. Attracted to this feature, some investigators have paid their attentions to the SSMC and applied successfully in various fields of engineering applications. Following the steps of Baida and Izosimov, Diong further extended the SSMC to linear multivariable systems [19] and Li et al. applied the SSMC to singular perturbation systems and discrete-time linear time-invariant systems [20-23]. Bartolini et al. developed the SSMC theory to deal with multi-input nonlinear uncertain systems [24-27]. In the practical engineering field, the SSMC was successfully applied to the underwater gripper [28] and the PWM converter [29].

However, some problems still exist in the SSMC. The first problem is how to suitably select the magnitude and direction of the simplex set. Traditionally, the SSMC designers usually select a sufficiently large magnitude of the simplex set to ensure the system trajectory could be forced to reach the sliding mode. Although the definition of the simplex set is explicitly given in the original literature [18], selecting an appropriate simplex set is not an easy task, especially for a system with control inputs more than three. One popular method for the selection of the magnitude and direction of the simplex is based on the trial and error method, but this approach may prevent the great potential of the SSMC from being realized. Consequently, how to suitably select the magnitude and direction of the simplex set is one of the most important topics for the researchers of the SSMC.

The second problem is how to easily determine the sub-region to which the current system trajectory belongs. Actually, it is an important step to determine the sub-region in the SSMC control algorithm. For a system with the number of control inputs less than three, it may be not so difficult to decide the sub-region where the system trajectory stays. However, it would become a thorny problem as the number of inputs is highly increased and makes the implementation of an SSMC more difficult and sometimes infeasible.

The third problem is how to completely eliminate the chattering which exists in the SSMC. Actually, it is inevitably faced with the chattering phenomenon for the SSMC due to the use of switching functions. However, the chattering caused by the SSMC happens not only in the sliding mode, but also during the approach mode. Some of the developed SSMCs attempt to utilize the concept of sliding layer around the sliding mode to get rid of the chattering, but do not consider the chattering excited during the approaching mode where the system trajectory switches from one sub-region to the other sub-region. As a result, their system performance still suffers from the chattering before the sliding mode.

In order to tackle the above problems, Bartolini et al. proposed an obtuse angle condition and a way to build the required simplex set [26]. In the work of Chen et al.

[30], an adaptive control rule was presented to obtain a suitable magnitude of the simplex set. On the other hand, some investigators attempt to solve these problems by employing the intelligent theory. For example, Lu et al. applied the chaos theory to seek the simplex set [31] and Li et al. adopted Fuzzy theory to avoid the chattering phenomenon caused by the SSMC [32].

In this dissertation, the above problems will be solved in an alternative way. First, we extend the simplex set to the uniformly distributed simplex set. With the use of the uniformly distributed simplex set, some important properties are obtained to benefit the solution of the chattering problem and the development of a concise strategy, which could quickly determine the sub-region where the system trajectory currently stays even when the number of inputs is more than three. In addition, two efficient approaches are proposed to efficiently select an appropriate uniformly distributed simplex set. Most precisely, a novel SSMC, called uniformly distributed simplex sliding-mode control (UDSSMC), is developed to theoretically determine the magnitudes of the uniformly distributed simplex set to suppress matched disturbances under the condition their upper bounds are given. Finally, in order to demonstrate the usefulness of the developed UDSSMC in the practical field, the UDSSMC is applied to robotic manipulators suffering from the system uncertainties and matched disturbances.

Although the UDSSMC could efficiently eliminate the matched disturbance, it must require the prior information concerning the upper bound of the disturbance in order to fulfill the UDSSMC algorithm. However, it is not an easy work to precisely estimate these upper bounds in practice. In order to get rid of the matched disturbances, their upper bounds are often over-estimated or too conservative. As a result, the magnitude of the control input has to be increased largely and maybe unreasonably. In case the upper bounds are not well estimated, the control algorithm could be inadequate to suppress the matched disturbances, which makes the control unsuccessful. Obviously, it is important to effectively predict the matched disturbances when the UDSSMC is applied.

Actually, the same problem also exists in the SMC theory. For improvement, many researchers have paid their attentions to the suppression of matched disturbances [56-61] and some of them adopt the grey theory for prediction [56,57]. The grey theory proposed by Professor Deng in 1982 was developed to deal with systems possessing poor and incomplete information [33,34]. Up to now, the grey prediction had been successfully applied to diverse fields, such as earthquakes, industry, economics, and control [35-40].

Attracted to the features of simplicity and effectiveness, Lin and Hung utilized the grey theory to predict the trend of the value of a Lyapunov function in their sliding-mode controller [56]. Chou proposed a variable structure control by using the grey theory for predicting the difference the controlled system and its nominal system [57]. In this dissertation, we will provide a novel UDSSMC controller, which uses a more efficient way to predict the matched disturbances via abstracting them directly from the derivative of the sliding vector. By means of grey prediction, the matched disturbances can be suppressed by the novel UDSSMC controller without any prior information concerning their upper bounds.

1.2 Organization of This Dissertation

This dissertation is organized into seven chapters. Chapter 2 introduces the basic concept of the conventional simplex sliding-mode control (SMC), including the definition and properties of the simplex set and the control algorithm of the SMC. In Chapter 3, a specific simplex set, named uniformly distributed simplex set, is presented and the corresponding properties are also derived. In addition, two approaches are presented to obtain a suitable uniformly distributed simplex set. Based on the uniformly distributed simplex set, a novel simplex sliding-mode control, uniformly distributed simplex sliding-mode control (UDSSMC), is developed in Chapter 4. Besides, a new smoothing strategy is proposed to solve the chattering problem caused by the SSMC. Chapter 5 proposes a novel design method of the UDSSMC combined with grey prediction, which is used to predict the matched disturbances. In Chapter 6, the UDSSMC algorithm is developed to deal with the position tracking control of the robotic manipulators suffering from the system uncertainty and external disturbances. Finally, the summary of this dissertation and suggestions for future research are given in Chapter 7.