CHAPTER 8

VARIABLE STRUCTURE NEURAL CONTROL

8.1 Introduction

Variable structure control with sliding modes was first proposed in the early 1950s (Utkin, 1964; Emelyanov, 1967; Itkis, 1976) and has subsequently been used in the design of a wide spectrum of system types including linear and nonlinear systems, large-scale and infinite-dimensional systems, and stochastic systems. It has also been applied to a wide variety of engineering systems. The most distinguished feature of variable structure control based on sliding modes is the ability to improve the robustness of systems which are subject to uncertainty. If, however, the uncertainty exceeds the values allowed for the design, the sliding mode cannot be attained and this results in an undesirable response (Utkin, 1964). In the continuous-time case this problem was solved by combining variable structure and adaptive control (Slotine and Li, 1991), but this requires that all the system variables are available and can be measured. This case has also been discussed for linear discrete systems using input output plant models (Furuta, 1990, 1993; Hung et al., 1993; Pan and Furuta, 1995) and for nonlinear discrete systems where the input output model is unknown (Liu et al., 1997b, 1999b).

This chapter presents a neural network based variable structure controller design procedure for unknown nonlinear discrete systems. A neural network based affine nonlinear predictor is introduced so that the control algorithm is simple and easy. Two performance functions are considered for the design of variable structure neural control. The first performance function is concerned with minimisation of the prediction error. The second performance function includes minimisation of the prediction error and the control input. A recursive learning algorithm for neural networks for the neural network affine nonlinear predictor is also discussed. This algorithm can be used for both on-line and off-line weight training. It is shown that both the weights of the neural networks and the estimation error converge.

A brief introduction to variable structure control for linear systems is given in Section 8.2. Then, Section 8.3 considers the structure of the affine nonlinear predictors, which is based on neural networks. Variable structure neural control is studied for nonlinear systems in Section 8.4. Generalised variable structure neural control is discussed in Section 8.5. Section 8.6 develops the recursive learning algorithm for the neural networks used for the $d$-step-ahead predictor.
and the properties of the algorithm are analysed. Finally, simulation results are given in Section 8.7.

8.2 Variable Structure Control

Variable structure control is a high-speed switched feedback control. For example, the gains in each feedback path switch between two values according to a rule that depends on the value of the state at each instant. The purpose of the switching control law is to drive the nonlinear plant’s state trajectory onto a prespecified (user-chosen) surface in state-space and to maintain the plant’s state trajectory on this surface for all subsequent time. The surface is called a switching surface. When the plant’s state trajectory is above the surface, a feedback path has one gain, and a different gain if the trajectory drops below the surface. This surface defines the rule for proper switching. The plant dynamics restricted to this surface represent the controlled system’s behaviour. The first critical phase of variable structure control design is to define properly a switching surface so that the plant, restricted to the surface, has the desired dynamics, such as stability, tracking, regulation, etc. Therefore, a variable structure control design breaks down into two phases. The first phase is to design or choose a switching surface that represents the desired dynamics. The second phase is to design a switched control that will drive the plant state to the switching surface and maintain it on the surface upon interception.

This section briefly introduces variable structure control for linear discrete-time systems. Let us consider a single-input single-output discrete-time linear system which is represented by

\[ Ay_t = q^{-d} Bu_t \]  
(8.1)

where \( y_t \) is the output, \( u_t \) is the control input, \( d \) is the time delay, \( A \) and \( B \) are polynomials in the backward shift operator \( q^{-1} \):

\[ A = 1 + a_1 q^{-1} + \ldots + a_n q^{-n} \]  
(8.2)

\[ B = b_0 + b_1 q^{-1} + \ldots + b_m q^{-m} \]  
(8.3)

\( n \) and \( m \) are the orders of the polynomials. It assumes that the above system is minimum phase, that is, all zeros of the polynomial \( B \) are within the unit disk.

The structure of a variable structure control system is governed by the sign of the switching function. A switching function is generally assumed to be linear. For discrete time systems, a simple switching function is defined as

\[ s_{t+d} = C(y_{t+d} - r_{t+d}) \]  
(8.4)

where \( r_t \) is the reference input and \( C \) is a Schur polynomial defined as

\[ C = 1 + c_1 q^{-1} + \ldots + c_n q^{-n} \]  
(8.5)