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Design of Adaptive Sliding Mode Control with Fuzzy Controller and PID Tuning for Uncertain Systems

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Abstract – *In this paper, a robust control system with the fuzzy sliding mode controller and sliding mode control with PID tuning method for a class of uncertain system is presented. The goal is to achieve system robustness against parameter variations and external disturbances. A Fuzzy logic controller using simple approach & smaller rule set is proposed. Suitable PID control gain parameters can be systematically on-line computed according to the developed adaptive law. To reduce the high frequency chattering in the switching part of the controller, a boundary layer technique is utilized. The proposed method controller is applied to a brushless DC motor control system.*

Key Words: **PID controller, fuzzy controller, sliding mode control, adaptive control.**

1. INTRODUCTION

The proportional – integral – derivative (PID) controller operates the majority of the control system in the world. It has been reported that more than 95% of the controllers in the industrial process control applications are of PID type as no other controller match the simplicity, clear functionality, applicability and ease of use offered by the PID controller[1,2]. The PID controller is used for a wide range of problems like motor drives, automotive, flight control, instrumentation etc. PID controllers provide robust and reliable performance for most systems if the PID parameters are tuned properly [3].

To control complex systems or imperfectly modeled systems using fuzzy logic, a lot of efforts have been made in the past and these have been fruitful in many areas. However the designing of fuzzy logic controller greatly depends upon the expert's knowledge or trial and errors. Furthermore, fuzzy controller does not guarantee the stability and the robustness due to the linguistic expressions of the fuzzy control. Disadvantage of PID controller is poor capability of dealing with system uncertainty, i.e., parameter variations and external disturbance. Sliding mode control (SMC) is one of the popular strategies to deal with uncertain control systems. The main feature of SMC is the robustness against parameter variations and external disturbances [4].

In this paper, A Fuzzy logic controller using simple approach & smaller rule set is proposed, and the adaptive PID with sliding mode controller is proposed for second-order uncertain systems. In this study, the PID parameters can be systematic ally obtained according to the adaptive law. To reduce the high frequency chattering in the controller, the boundary layer technique is used [5]. The proposed method controller is applied to the brushless DC motor control system. The computer simulation results demonstrate that the chattering is eliminated and satisfactory trajectory tracking is achieved [6-11].

2. SLIDING MODE CONTROL

The robustness to the uncertainties becomes an important aspect in designing any control system. Sliding mode control (SMC) is a robust and simple procedure for the control of linear and nonlinear processes based on principles of variable structure control [12-14]. It is proved to be an appealing technique for controlling nonlinear systems with uncertainties. Figure 1 shows the graphical representation of SMC using phase-plane, which is made up of the error ($e(t)$) and its derivative ($\dot{e}(t)$). It can be seen that starting from any initial condition, the state trajectory reaches the surface in a finite time (reaching mode), and then slides along the surface towards the target (sliding mode).The first step of the SMC design requires the design of a custom made surface. On the sliding surface, the plants dynamics is restricted to the equations of the surface and is robust to match

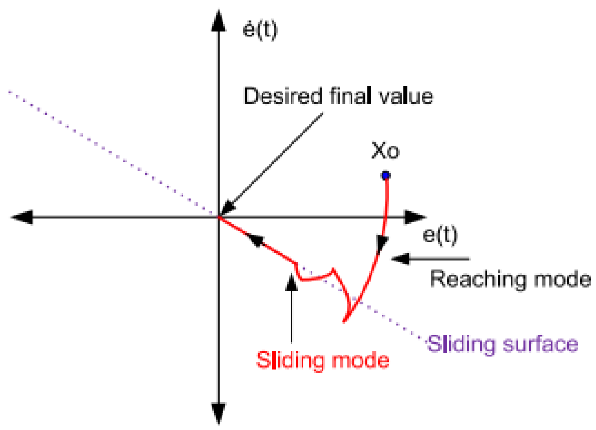

Fig -1: Graphical interpretation of SMC.

plant uncertainties and external disturbances. At the second step, a feedback control law is required to be designed to provide convergence of a systems trajectory to the sliding surface; thus, the sliding surface should be reached in a finite time. The systems motion on the sliding surface is called the sliding mode.

3. DESIGN OF FUZZY LOGIC CONTROLLER (FLC)

The model of the fuzzy controller and the plant with unity feedback is shown in Fig.

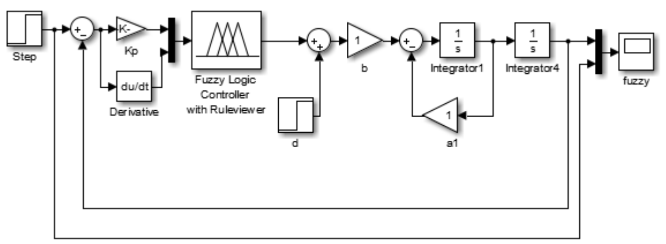

Fig -2: model of the fuzzy controller

For a two input fuzzy controller, 3,5,7,9 or 11 membership functions for each input are mostly used. In this paper, only two fuzzy membership functions are used for the two inputs error e and the derivative of error as shown. The fuzzy membership functions for the output parameter are shown in Fig, here N means Negative, Z means Zero and P means Positive.

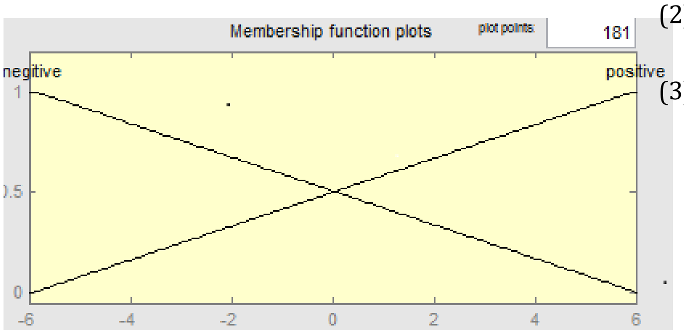

Fig -3: Membership functions for two inputs

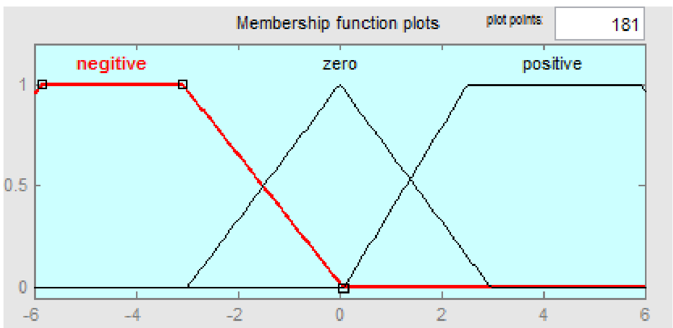

Fig -4: Membership functions for output

The system response can be divided in two phases. Phase A - System output is below the set point. Phase B - System output is above the set point. Depending upon whether the output is increasing or decreasing, 4 rules were derived for the fuzzy logic controller (Table I). These four rules are sufficient to cover all possible situations.

u		ė	
		N	P
e	N	N	Z
	P	Z	P

Table.1: Fuzzy rules

4. DESIGN OF SLIDING MODE CONTROLLER WITH PID TUNING:

4.1 Definition of the problem

Consider a second-order uncertain system which as shown below

$$\dot{x}_1(t) = x_2(t) \quad (1)$$

$$\dot{x}_2(t) = f(x_1, x_2, t) + \nabla f(x_1, x_2, t) + d(t) + bu \quad (2)$$

$$y(t) = x_1(t) \quad (3)$$

where $x_1(t)$ and $x_2(t)$ are measurable states, u is the input, y is the output, b is the input gain, $f(\cdot)$ is nominal parameter of plant, $\Delta f(\cdot)$ is the plant uncertainty applied to the system, and $d(t)$ denotes the external disturbance. It is assumed that there exist two positive upper bounds, g and α satisfying $\Delta f(\cdot) \le g$ and $d(t) \le \alpha$. Let e be the error between the desired trajectory y_d and the output y, i.e.

$$e = y_d - y \quad (4)$$

4.2 Design of the controller

The new reference signal is defined as

$$\dot{x}_r = \ddot{y}_d + k_1 e + k_0 e \quad (5)$$

Where k_1 and k_0 are chosen by the designers such that the roots of $s^2 + k_1 s + k_0 = 0$ are in the open left-half complex plane.

The sliding mode surface is defined so that in the sliding mode the system behaves equivalently as a linear system

$$\sigma = x_2 - x_r. \quad (6)$$

When the sliding mode occurs, σ goes to zero or