POSITION CONTROL OF SERVO MOTOR USING SLIDING MODE FUZZY CONTROLLER

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ABSTRACT

This paper deals with the development of different control techniques such as Fuzzy, Sliding mode, and Sliding Mode fuzzy controllers for the servo drive system. Servomotors are widely used in industry due to their relatively low cost and high reliability. To get high performances we have to control the input variable in uncertainties and disturbance. Two cases are discussed for each control scheme. Normal case, parameter variation case, and disturbance case are considered. When fuzzy Controller is implemented in the system. Fuzzy controller gives better performance compared to other controllers but results are ineffective for disturbance case. Sliding mode fuzzy control is then implemented. It is observed that system performance increases when compared to fuzzy control for parameter variation case and for disturbance case which shows the robustness of SMFC. So sliding mode fuzzy control is superior when compared to other controller in terms of control performance. Various control schemes are then compared with each other. Simulations are carried out on MATLAB.

Index Terms

SMC, Fuzzy Logic, SMFC, Servo Drive

1. INTRODUCTION

It is very important to develop a high performance and robust position control. Sliding mode fuzzy control is powerful scheme in order to make the system robust. The principal goal of the sliding mode control technique is to force a system state to a certain prescribed manifold, known as the sliding hyper surface. Once the manifold is reached, the system is forced to remain on it thereafter. A Fuzzy Controller is good in dynamic environment. A combination of fuzzy control and sliding mode is then used in order to make the system robust in dynamic environment and in disturbance.

The advantage of SMC is

- The most distinguished feature of VSC is its ability to result in very robust control systems.
- Sliding mode represents the behaviour of the system during transient period. So, switching line determines the transient response, which is lower order than the original model.

The advantage of Fuzzy Logic is

- A fuzzy control design does not require a formal model.
- The designing of fuzzy logic controller is very simple and meaningful. FLC offers low development costs and high-speed implementation.

2. FUZZY LOGIC CONCEPT

In recent years the fuzzy logic control technique has been used in many applications, by which the controller performance can be improved significantly as compared to conventional methods in presence of model uncertainties. As its name implies, the theory of fuzzy sets is basically a theory of graded concepts- a theory in which everything is a matter of degree. From last two decades since its inception, the theory matured in to a wide-ranging collection of concepts and techniques for dealing with complex phenomena that do not lend themselves to analysis by classical methods based on probability theory and bivalent logic. Fuzzy set theory is generation of ordinary crisp set theory and was introduced by Lofti. A. Zadeh in 1965. Fuzzy logic is a convenient way to map an input space to an output space.

This is a knowledge-based controller with reasoning mechanism rather than relying solely on the system mathematical model. Consequently, this can solve problems encountered in the use of the conventional controller such as unknown system parameters and their variation or noise perturbation as well as lack of reasoning or multiple control decisions. Among the intelligent techniques, the fuzzy logic (FL) perform better in terms of reduced mathematical model complexity and fast real-time operation as well as being least affected by parameter uncertainty or fault tolerance as compared to other techniques. Fuzzy logic control has been successfully used in many industrial applications and has shown significant performance and improvements over other controllers, especially in dealing with complex systems.

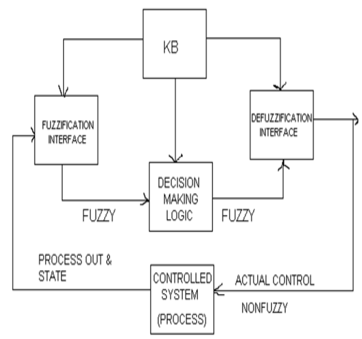

Fig.1 Basic configuration of FLC

The basic configuration of an FLC, which comprises four principal components:
1) A fuzzification interface
2) A knowledge base
3) Decision making logic
4) A defuzification interface.

3. SLIDING MODE CONCEPT

The SMC is a special class of nonlinear control mechanism characterized by a discontinuous control action, which changes the structure upon reaching a set of sliding surfaces. During the motion on the sliding surface (sliding phase), the system has invariance properties, yielding motion that is independent of certain perturbations including external disturbances. In most of the SMC design strategies, the use of over-conservative high feedback gain is inevitable since the upper bound of the perturbation is normally employed to guarantee robust control performance. However, this causes undesirable chatter problem, which deteriorates control accuracy.

Sliding mode control (SMC) is basically a high-speed switching feedback control. It utilizes a discontinuous control to force system state trajectories to some pre-defined sliding manifolds on which the system has desired properties such as stability, disturbance rejection capability, tracking and etc. One of the most distinguished features of the SMC is that after reaching the sliding mode, the system has robustness to Parameter uncertainties and external disturbances. In general, a sliding motion can be divided into two phases: a reaching phase and a sliding phase. As mentioned above, on the sliding mode, the system has robustness to disturbance, however, during the reaching phase; the SMC system may be sensitive to parameter variations and external disturbances.

3.1 Sliding mode fuzzy control:

A Sliding Mode Fuzzy Controller (SMFC) inherits the robustness property of Sliding Mode Control and Interpolation property of Fuzzy Logic Control such that the nonlinear switching curve can be approximated and the robustness can be maintained. Sliding mode control is known for its robustness to the external disturbance and system modelling error. In Sliding Mode Fuzzy Controller (SMFC) each fuzzy rule output function is exactly a sliding mode controller, the slope of the sliding mode controller in each rule is determined by the approximate slope of the nonlinear switching curve in that partition of the phase plane where the rule covers.

3.2 Takagi-sugeno type fuzzy logic controller:

Mainly there are two types of FLCs. One is Mamdani type, the other is Takagi-Sugeno (TS) type. The general form for the ith rule of a Multi-Input-Single-Output (MISO) TS type FLC is as following:
IF X_1 is A_{i1} and/or X_2 is A_{i2} and/or . . . X_n, is A_{in},

THEN $y_i = f_i(X_1 . . . X_n, C_{i0} . . . C_{in})$

Here

$X_1 ... X_n$, are linguistic variables with respective universe of discourses. Generally they Corresponds to state variables.

$A_{i1} … A_{in}$, are fuzzy sets in the i -th rule for the linguistic variables X_1 . . . . . X_n.

Y is a linguistic variable standing for the control action to the plant.

f_i is an arbitrary rule output function

$C_{i0} …, C_n$ are constants in the rule output function f_i.

The only different between a TS type FLC and a Mamdani type FLC is that for a TS type FLC, the rule consequents are functions of crisp inputs, whereas the rule consequents for a Mamdani type FLC are also fuzzy values.
The defuzzification of a TS type FLC is given by:

$$U = \frac{\sum_{i=1}^{n} \beta_i y_i}{\sum_{i=1}^{n} \beta_i} \quad (1)$$

Where n is the total number of rules in the rule base. β_i is the truth value of the i -th rule.

Y_i is the rule consequent of the ith rule. Depending on the fuzzy connection operators for rule antecedents. β_i can have different values. Generally, a MIN operator is used for "and". In this Case, β_i can be calculated as:

$$\beta_i = MIN(\mu_{Ai1}(x_1),....\mu_{Ain}(x_n)) \quad (2)$$

Here μ_{Aij} is the membership function for fuzzy set A_{ij}.

3.3 Sliding Mode Control:

In general, SMC design consists of two phases: the design of the sliding surface and the selection of an appropriate control law. To illustrate the design method, consider a simple second-order nonlinear system described by

$$\ddot{x}(t) = f(x, \dot{x}, t) + bu(t) + d(x, \dot{x}, t) \quad (3)$$

Where $u(t) \in R^x$ is the system control input. b is a constant with $b \neq 0$; $f(x, \dot{x}, t) \in R^x$ is a nonlinear function with respect to x, $\dot{x}$ and t ; $d(x, \dot{x}, t) \in R^x$ presents a time dependent disturbance, nonlinear friction and unpredicted uncertainties.

The objective of the design is to obtain the state *x* for tracking the desired state x_d in the presence of unpredicted uncertainties and disturbances. That is, the tracking error $e = x - x_d \to 0$
Select the sliding surface as

$$s = \dot{e} + \lambda e = 0 \tag{4}$$

Where λ is strictly positive real numbers that guarantee the stability of the sliding motion. A possible choice of the sliding mode control law is as follows:

$$u = u_{eq} + u_{dis} \tag{5}$$

Where

$$u_{eq} = -\frac{1}{b}[f(x, \dot{x}, t) + \lambda \dot{e} - \dot{x}_d] \tag{6}$$

Where u_{eq} represents the model-based equivalent control for the system (5) in the absence of disturbance, obtained by setting $\dot{s}(t) = 0$; u_{dis} *is* a discontinuous component of *u,* intended to compensate for the uncertainties and the effect of disturbances. To satisfy the sliding mode existence condition and reaching condition, *k* might be any positive number. Because of the discontinue component (u_{dis}), the chattering is unavoidable. One effective solution is to introduce a boundary layer around the sliding surface. Employing saturation function sat (•) instead of sgn (•) in (9), we obtain

$$\text{u} = u_{eq} - ksat\,(s/\phi) \tag{7}$$

Where φ >0 represents the boundary layer thickness, sat(*s/φ) is* a saturation function, which defined as

$$sat\,(s/\phi) = \begin{cases} \text{sgn}(s/\phi), if\,|s/\phi| \geq 1 \\ s/\phi, if\,|s/\phi| \leq 1 \end{cases} \tag{8}$$

The system may be sensitive to the parameter variations and disturbances during the reaching phase. Initially, the surface is designed to pass the initial condition and is subsequently moved towards a Predetermined-switching surface by rotating or/and shifting. We call it a moving switching surface (MSS).

A moving sliding surface for a second-order system can be described by

$$\text{S}\,(\text{e}, \dot{e}, \text{t}) = \lambda(t)\,\text{e}\,(\text{t}) + \dot{e}(\text{t}) - \gamma(t). \tag{9}$$

The rotating is associated with the time-varying slope $\lambda(t)$ of the surface, whereas the shifting is accomplished by employing the time-varying intercept $\gamma(t)$ of the surface.

Based on the discussion above, a sliding mode control law with a boundary layer and a moving sliding surface is given by

$$u = u_{eq} - ksat\left[\frac{\lambda(t)e + \dot{e} - \gamma(t)}{\phi}\right] \tag{10}$$

Where

$$u_{eq} = -f(x,\dot{x},t) - \lambda\dot{e} + \ddot{x}_d \quad (11)$$

The i-th rule for SMFC with sugeno type fuzzy inference can be expressed as:

IF *e* is A_i and $\dot{e}$ is B_i then

$$u_i = u_{eq} - ksat\left[\frac{\lambda_i e + \dot{e} - \gamma_i}{\phi_i}\right] \quad (12)$$

Where $\lambda_i, \gamma_i and \phi_i$ can be adjusted according to *e* and $\dot{e}$. Since the switching line can be the function with respect either to *e* or to $\dot{e}$, we can simplify the fuzzy rule base. If the RP is in the first or third quadrant, we only shift the switching surface by adjusting the intercept γ mainly according to $\dot{e}$. If the RP is in the second or fourth quadrant, we only rotate the switching surface by tuning the slope mainly according to *e*. In addition, the thickness of boundary layer φ can be tuned in terms of e.

4. RESULTS

The simulation of servo drive is carried out with the various Controllers in three cases in order to know the performance of the controller. The Fuzzy, Sliding Mode, Sliding mode Fuzzy Controllers were designed for the following three cases and the simulation are presented. Comparison for Fuzzy, SMC, and SMFC with the following three cases is done.
Case1: Normal case: when J=J, B=B, T_d=0
Case 2: parameter variation case: when J=2J, B=B, T_d=0
Case 3: Disturbance Case: when J=J, B=B, T_d=2sin (4t) U (t-8)

4.1 Fuzzy Logic Controller to the Servo Drive:

The inputs to fuzzy are error (e) and derivative of error ($\dot{e}$).The membership function for error and derivative of error is shown in following fig 2 and fig 3 respectively.

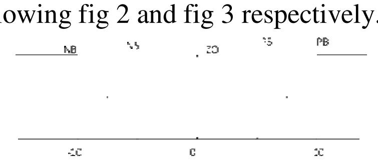

Fig 2 Input membership function for e

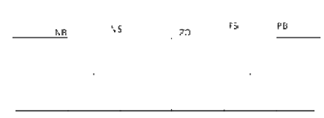

Fig 3 Input membership function for $\dot{e}$

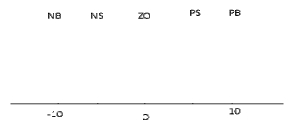

Fig 4 output membership function

Table 1 Rule base for fuzzy controller

		Change in error Δe				
		NB	NS	ZO	PS	PB
Error e	NB	uNB	uNB	uNS	uNS	uZO
	NS	uNB	uNS	uNS	uZO	uPS
	ZO	uNS	uNS	uZO	uPS	uPS
	PS	uNS	uZO	uPS	uPS	uPB
	PB	uZO	uPS	uPS	uPB	uPB

Case 1: when J=J, B=B, T_d=0

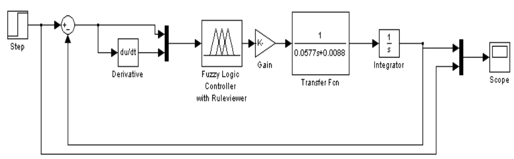

Fig 5 Block diagram of servo with Fuzzy Controller

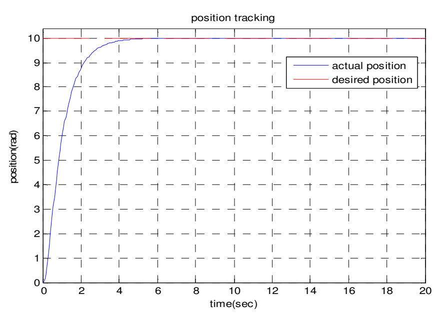

Fig 6 Position tracking of servo with Fuzzy Controller

Case 2: when J=2J, B=B, T_d=0

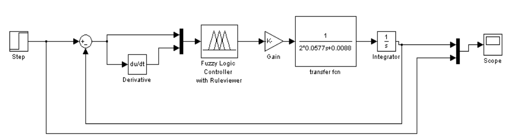

Fig 7 Block diagram of servo with Fuzzy Controller for parameter variation

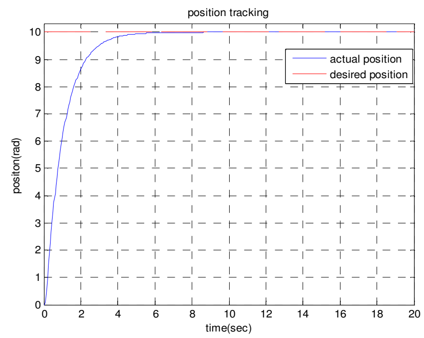

Fig 8 Position tracking of servo with Fuzzy Controller for parameter variation

Case 3: when J=J, B=B, T_d=2sin (4t) U (t-8)

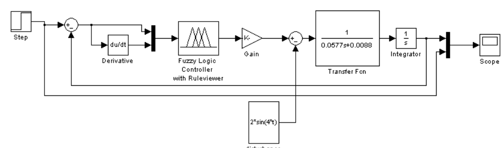

Fig 9 Block diagram of servo with Fuzzy Controller for disturbance case

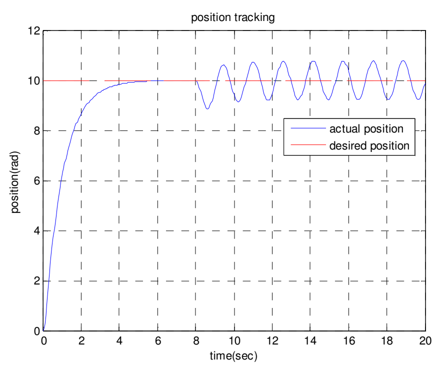

Fig 10 Position tracking of servo with Fuzzy Controller for disturbance case

4.2 Sliding Mode Fuzzy Control To The Servo Drive:

Case 1: when J=J, B=B, Td=0

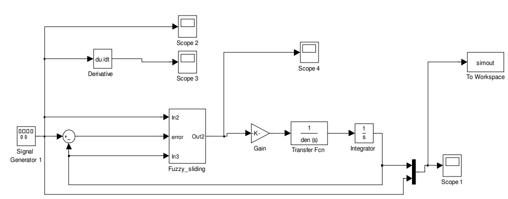

Fig 11 Block Diagram of servomotor with SMFC

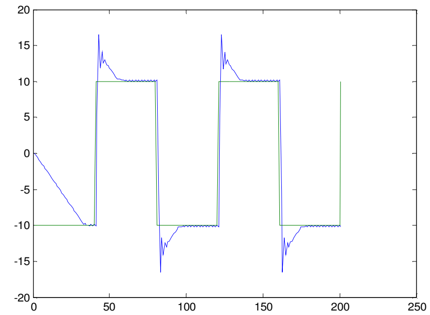

Fig 12 Position tracking of servomotor with SMFC

Case 2: when J=2J, B=B, T_d=0;

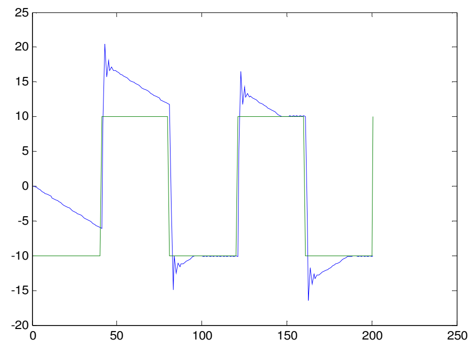

Fig 13 Position tracking of servo with SMFC for parameter variation

Case 3: when J=J, B=B, T_d=2sin (4t) U (t-8)

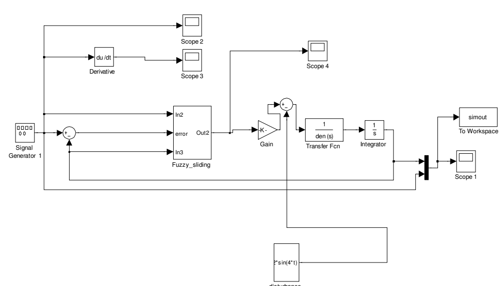

Fig 14 Block Diagram of servo with SMFC for disturbance case

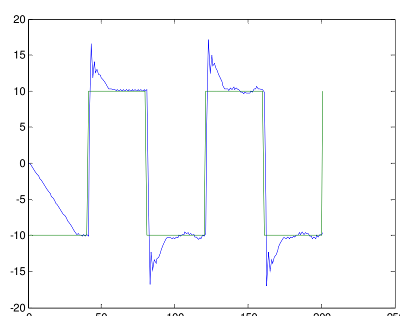

Fig 15 Position tracking of servo with SMFC for disturbance case

5. CONCLUSION

First basics of servomotor and different control schemes are presented. Then Position Control of servomotor is discussed with different schemes. Different schemes that are presented in this dissertation are PID, Fuzzy and sliding mode Fuzzy Control. Three cases are discussed for each control scheme. Normal case, parameter variation case, and disturbance case are considered. When PID is implemented results are effective for a constant reference input but are ineffective with parameter variation and disturbance cases. Then fuzzy Controller is implemented in the system. Fuzzy controller gives better performance compared to PID controller but results are ineffective for disturbance case.

Sliding mode fuzzy control is then implemented. It is observed that system performance increases when compared to PID and fuzzy control for parameter variation case and for disturbance case which shows the robustness of SMFC. So sliding mode fuzzy control is superior when compared to other controller in terms of control performance.

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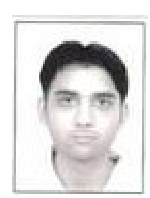
Authors Biographies



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