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Sliding Mode Fuzzy Controller for the Control of Nonlinear Systems

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ABSTRACT

The aim of the work described in this paper is to develop a suitable controller for positioning a pneumatic cylinder. The dynamics of a pneumatic servosystem is nonlinear because of the compressibility of air. In addition, on-off or binary valves often used in actuating pneumatic cylinders introduces a nonlinear element into the control loop. In this paper, a fuzzy logic controller based on the theory of Variable Structure Systems is proposed. The theory of variable structure has reduced the number of rules required for fuzzy logic control. Experimental results have shown that the controller is able to overcome the nonlinearities and position a pneumatic cylinder accurately.

ABSTRAK

Tujuan kerja yang diterangkan dalam kertas ini ialah untuk menghasilkan pengawal yang sesuai untuk penganjakan satu silender pneumatik. Dinamik sebuah sistem servo pneumatik adalah tidak lelurus disebabkan oleh kemampatan angin. Tambahan pula penggunaan injap tutup-buka atau binari yang biasanya diguna untuk memacu silender-silender pneumatik memperkenalkan unsur tidak lelurus dalam gelong kawalan. Dalam kertas ini sebuah pengawal lojik fuzzy berdasarkan teori sistem Struktur Berubah dicadangkan. Penggunaan teori ini telah mengurangkan penggunaan hukum-hukum yang diperlukan untuk kawalan lojik fuzzy. Keputusan ujikaji menunjukkan bahawa pengawal ini berjaya mengatasi masalah tidak lelurus dan menganjakkan silinder pneumatik dengan jitu.

KEYWORDS

Pneumatic servosystems, fuzzy control, variable structure systems, sliding mode.

INTRODUCTION

Variable positioning of a pneumatic cylinder without the use of mechanical brakes or stops is difficult because of its nonlinear dynamics. This is primarily due to the compressibility of air. In addition pneumatic cylinders are often actuated using on-off or binary valves which introduces a nonlinear element into the control loop. Although proportional control valves have been developed, there is still the problem of hysterisis in the solenoid driving the spool. Designs to overcome this tend to be expensive.

The pneumatic servosystem is a practical nonlinear system which poses a challenging and complex control problem to the control engineer. This is because the dynamics of a pneumatics servosystem is difficult to model accurately. The aim of this work is therefore to find a suitable controller to accurately position pneumatic cylinders without knowledge of its dynamics. One approach is to use fuzzy control [1, 2, 3]. The conventional approach to fuzzy control may lead to a large number of rules to achieve the desired performance. However in this paper it is shown that a small number of rules based on the theory of Variable Structure Systems is able to achieve the desired performance. Experimental results are also presented.

OVERVIEW OF FUZZY LOGIC CONTROL

A typical architecture of a fuzzy controller is shown in Figure 1. The plant is generally a multi-input, multi-output system with $y = [y_1, y_2 \ldots y_p]^T$ being the output and $u = [u_1, u_2 \ldots u_m]^T$ the inputs. The core of the fuzzy controller is an inference engine which selects the set of rules embodying the knowledge of operation of the plant in terms of the output vector, their rate of change or cumulative sum given a particular set of plant inputs. The appropriate control action is chosen according to condition ---> action rules of the form:

Ri : if $x_1(t)$ is $A_{i,1}$, $x_2(t)$ is $A_{i,2}$, ... $x_j(t)$ is A_{ij}, ... $x_n(t)$ is $A_{i,n}$,
then $u_1(t)$ is $B_{i,1}$, $u_2(t)$ is $B_{i,2}$, ... $u_j(t)$ is B_{ij} ..... $u_m(t)$ is $B_{i,m}$.

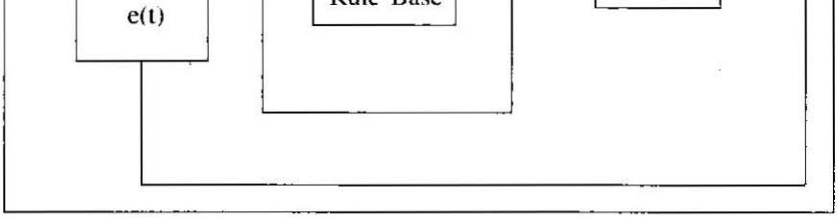

FIGURE 1. Architecture of a fuzzy control system

The subscript i is the rule index while $A_{i,1}$, $B_{i,1}$, ...etc. are lingustic terms such as low, medium, high positive ... etc which are fuzzy subsets of the universe of discourse. The universe of discourse corresponds to the domain of definition of the variables (see Figure. 2). To compute the appropriate control action, the mechanism of fuzzy logic is used [4, 5]. For example given two measurable variables x_1 and x_2. In this process $u_1(t)$ is computed by first computing of the membership values of $x_1(t)$ in $A_{4,1}$, and $x_2(t)$ in $A_{4,2}$, is propagated across to determine the conclusion of each rule. A crisp value for $u_1(t)$ is obtained by locating the centroid of the area covered by the overlapping conclusion fuzzy subsets and projecting this point onto the u_1 axis. The fuzzy membership function can have different forms such as trapezoidal, belt-shaped, trapezoidal or monotic. The basic computation of the control action is given as

$$u_1(t) = \frac{U_1\mu_B - (U_1)}{\mu_B - (U_1)} \quad (1)$$

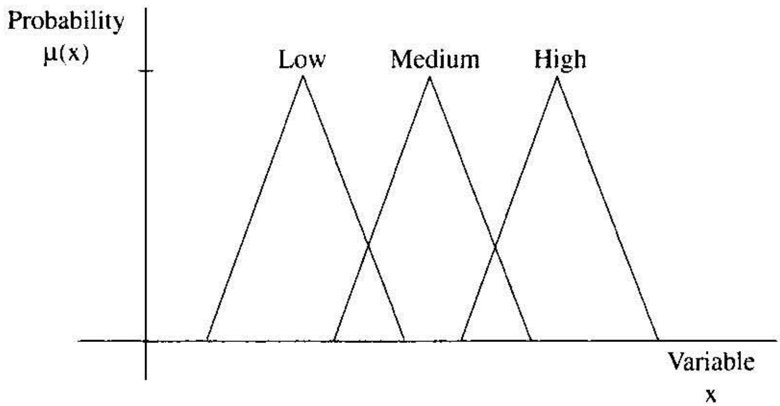

FIGURE 2. Universe of discourse

where B represent the fuzzy subset formed by the disjunction of the conclusions of all applicable rules (the shaded area in the right most part of Figure 3)

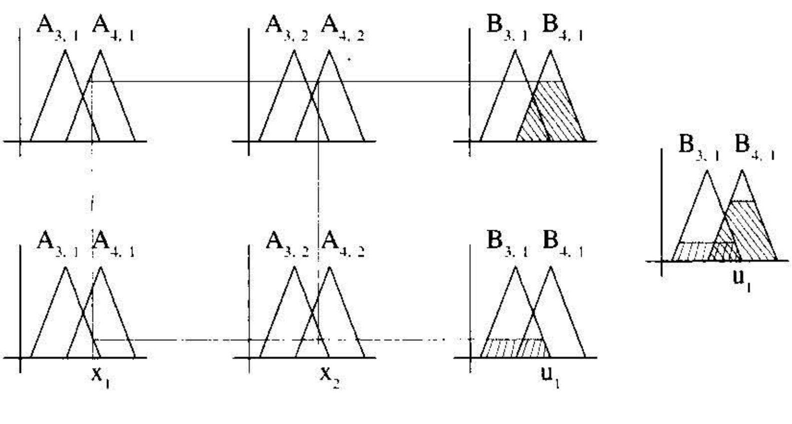

FIGURE 3. Computation of control action in fuzzy control

EXPERIMENTAL SET-UP

The system consists of a linear stroke cylinder with air supplied to or vented from both sides of the cylinder by 3 way solenoid operated binary (on or off) valves (see Figure 4). The displacement of the piston rod is measured by a linear transducer coupled to the piston rod and generating a voltage between 0 and 5 volts. A 12 bit analog to digital convertor transforms this analog signal into its digital equivalent which is sampled by a computer through the input port of a digital input/output board. The solenoid valves are switched on or off by solid state relays controlled by the computer through the output port of the digital input/output board.

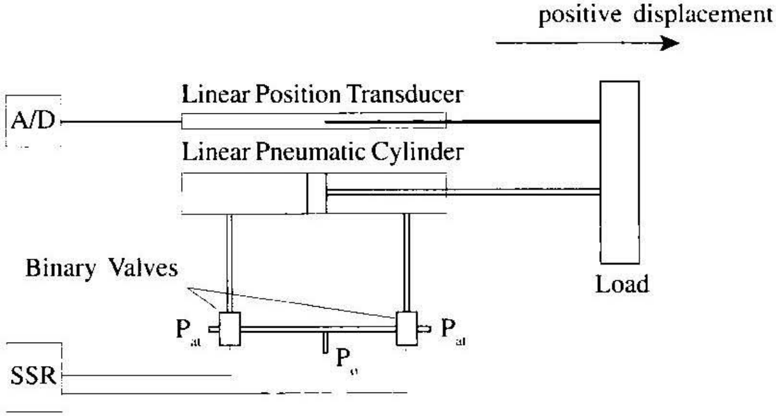

FIGURE 4. Schematic Diagram of Pneumatic Servosystem

DESIGN OF FUZZY CONTROLLER

The first task in designing a fuzzy controller is to formulate the linguistic rules describing the operation the process. Most fuzzy controller employ error and rate as inputs. The fuzzy sets "error" and "rate" have two fuzzy members and the fuzzy set for controller output has three fuzzy members. The members of the fuzzy set "error" are e.p (error. positive) and e.n (error. negative). The fuzzy set "rate" has two members r.p (rate. positive) and r.n (rate. negative) while the fuzzy set "output" has three members, o.p (output. positive). o.z (output. zero) and o.n (output. negative). In this paper the linguistic control rules used are

If error = e.p and rate = r.p then output = o.p

If error = e.p and rate = r.n then output = o.z

If error = e.n and rate = r.p then output = o.z

If error = e.n and rate = r.n then output = o.n

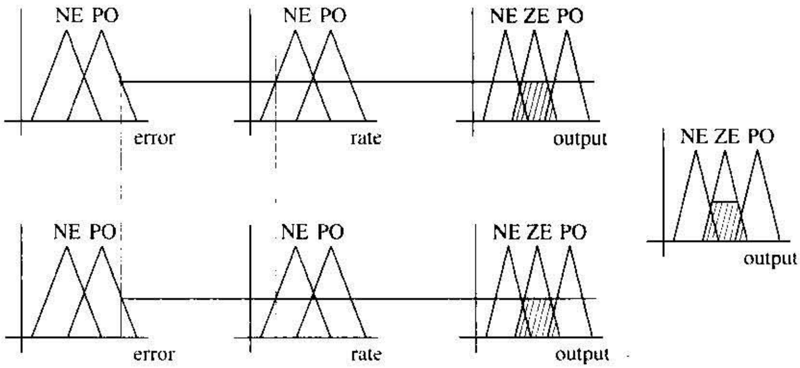

FIGURE 5. If error is positive and rate negative the output is zero

The computation of the control signal is as shown in Figure 5. Since the valves are either switched on or off only the sign of the control signal is used.

The performance the fuzzy controller is shown in Figure 6. It is observed that the response of the system is sluggish. The system looks as if it is overdamped. The system also oscillates about the desired positions which demonstrates clearly the effect of limit cycling due to the on-off valves. More rules can be added to improve the system perfomance. However instead of doing this a new approach based on the theory of variable structure systems is proposed to derive the fuzzy control rules.

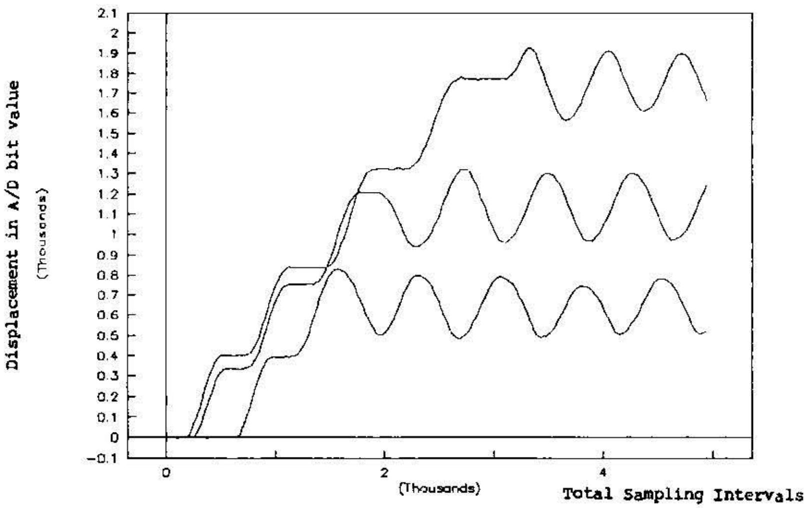

FIGURE 6. Response of system with target positions of 700, 1800 (12 bit a/d reading)

FUZZY CONTROL BASED ON THEORY OF VARIABLE STRUCTURE SYSTEMS

In the theory of Varible Structure Systems the system is forced towards a sliding surface. Once trapped in this surface it is completely governed by the equations that defined the surface. The system is said to be in sliding mode [6,7]. In this mode it becomes invariant to parameter changes and disturbances. If the sliding surface is a line given by

$$s = ce + e \tag{2}$$

where $c > 0$

Whilst sliding $s = 0$ such that

$$e = -ce \tag{3}$$

or since $e = yd - y$ and $e = -dy/dt$, the Laplace form is

$$y/yd = 1/(1 + Ts) \tag{4}$$

where T = time constant = $1/c$. Thus in the sliding mode the systems behaves as a first order system. A set of fuzzy rules can be derived by looking at the system state in the phase plane (Figure 7). When the system is a at X, $s>0$ and $e>0$ thus $se>0$ and the output must be positive so as to force the system towards the switching line. If the system overshoots and goes to Y, $s<0$ and $e>0$ thus $se<0$. In this case the output to the controller must be negative to pull back the system towards the switching line. This is repeated over the sampling period and the system will be forced to slide along the switching line.

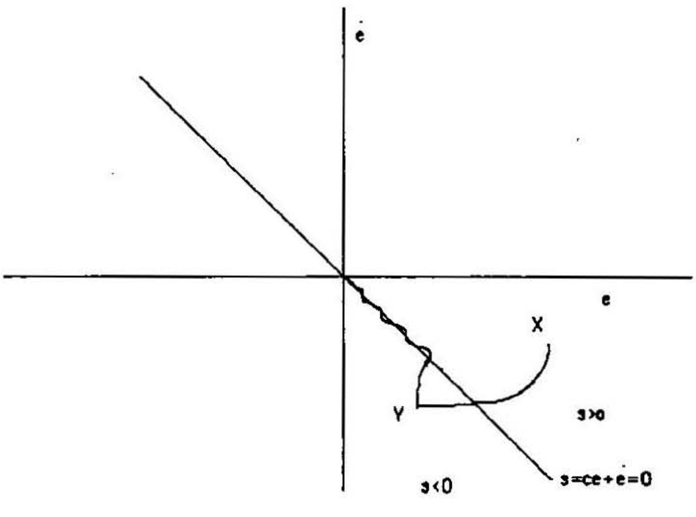

FIGURE 7. Pinciples of sliding mode

A new fuzzy set "se" is defined consisting of the members se.p (se.positive) and se.n (se.negative). The fuzzy rules are thus established as follows:

If se = se.p then output = o.p
If se = se.n then output = o.n

The computation of the control signal is much simpler to implement (Figure 8). Figure 9 shows the performance of the new fuzzy controller. Clearly the system has been made invariant to the nonlinearity of the dynamics. In general, except for the response at the position of 1800 where there is a slight glitch before the system settles at the desired position, the transients are smooth and fast. The controller is also able to position the pneumatic cylinder accurately.

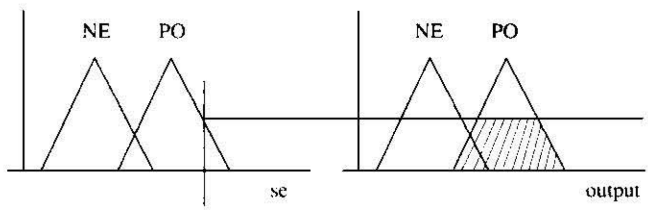

FIGURE 8. Very simple fuzzy rules from VSS theory

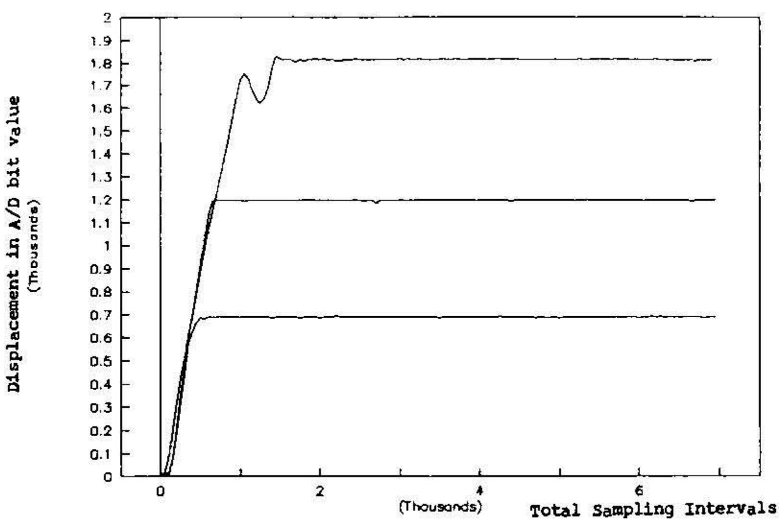

FIGURE 9. Response of system using new fuzzy rules. Desired positions are 700, 1200 and 1800 (12 bit a/d reading)

CONCLUSIONS

A new controller has been proposed for nonlinear systems. The proposed controller is based on the theory of fuzzy logic and Variable Structure Systems (VSS). Fuzzy control does not require knowledge of the system dynamics. However problem arise in formulating the rules required for smooth control. In this paper the theory of VSS is used to formulate the required fuzzy rules. The resulting rules are simpler to implement. The proposed controller has been implemented on a pneumatic servosystem with encouraging result. Further research will be conducted on other nonlinear systems.

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