Design of FLC based on the concept of VSC for Home VCR Drum Motor

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ABSTRACT

In this paper, the FLVSC (Fuzzy Logic Variable Structure Controller), of which control rules are extracted from the concepts of the VSC(Variable Structure Control) is proposed and designed for drum motor(BLDC motor) in home VCR. The FLC (Fuzzy Logic Controller) based on linguistic rules has the advantages of not needing of some exact mathematical model for plant to be controlled. The proposed method has the characteristics which are viewed in conventional VSC, e.g. insensitivity to a class of disturbances, parameter variations and uncertainties in a sliding mode. In addition, the method has the properties of the FLC-noise rejection capability etc.

The computer simulation and experiment using DSP(TMS320C30) have been carried out for the servo control of VCR drum motor to show the usefulness of the proposed method.

I. Introduction

The FLC (Fuzzy Logic Controller) is one of main applications of the fuzzy set theory, presented by Zadeh in 1965 and is known to be applicable to the type of unknown systems, nonlinear, time-varying system or ill-defined system with some uncertainties whose dynamics are difficult to describe in mathematical forms. The performance of FLC largely depends on the completeness and consistency of control rules but there are some superior aspects to those of conventional control strategy, e.g., PID control in the industrial processes.[1]

The FLC is regarded as a set of heuristic decision rules and can be implemented easily in a computer. But it is known that there were no systematic methods for obtaining the control rules but trial and error. In 1976, MacVicar-Whelan tried to overcome this limitation by providing some general control rules for the structure of FLC, which are used for the single input and single output system. These are called the meta rule which is described by two variables-the error between the setpoint and process output, and the change of the error.[2]

The purpose of this paper is to propose a method of the new control rules which can solve the above mentioned difficulties and to show the usefulness of those rules. In the proposed method, the rule is derived from the concept of variable structure control which has been recently interested in the area of servo control in a sense that it can remove some difficulties and assures system insensitivity to a class

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of disturbances and parameter variations. However, VSC scheme requires a prior information such as known state variable of the system and some mathematical conditions. So the FLC based on the concepts of VSC-we'll call this scheme FLVSC(Fuzzy Logic Variable Structure Controller)-proposed in this paper can have both the advantages of VSC and the FLC-the properties of fast response, high accuracy and the noise rejection capabilities. And the FLVSC has the design capability, that is no need of mathematical model but only the basic information for the process to be controlled-e.g., error, change rate in error of the concerning states. In addition, it can be applied to the process which has high uncertainty in modelling.[3]

And recently, digital techniques have been applied to servo systems of the home VCR, which result in high accuracy, high stability and a small number of parts required. The servo systems are now becoming more complex because the modern home VCRs are strongly required to have many functions, such as editing, slow/quick motion playback, and visual search, etc. However, it is very difficult to meet these requirements by using special purpose digital servo ICs.[4]

Given these circumstances, the proposed FLVSC software servo concepts are introduced to the VCR servo system. With the FLVSC software servo system, servo control of the VCR are carried out by high speed DSP (TMS320C30).

Ⅱ. The Proposed FLVSC

2.1 The control rules

The proposed FLVSC rules are extracted from the relations of switching line and switching input to obtain the characteristics of VSC assuming that the control input is proportional to the perpendicular distance from RP (representative point) to reference line in the phase plane.[5]

In other words, we calculate the control input u for FLVSC as defined eq.(2.1) and Fig. 1.

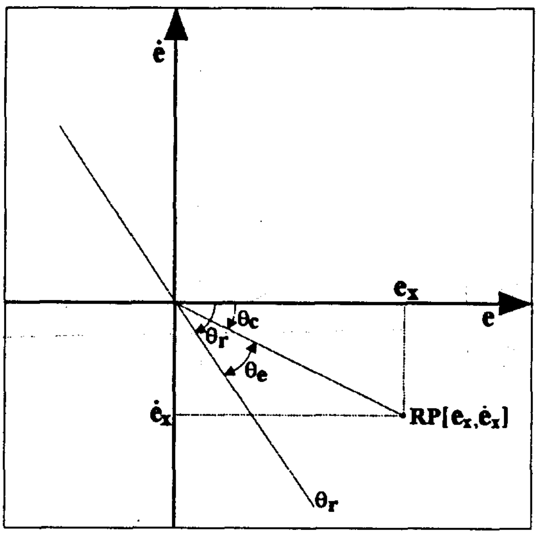

Fig. 1. Angle error and distance in the phase plane

$$u = f(e_x, \dot{e}_x) \rightarrow u = f(\theta_e, D) \tag{2.1}$$

where,

u: control input
e_x: error between current state and desired state
$\dot{e}_x$: change rate in error
θ_e: angle error in phase plane =
angle of current RP (θ_c) − angle of reference line(θ_r)
D: distance from origin to current RP, $D = \sqrt{e_x^2 + \dot{e}_x^2}$

We can calculate the current phase angle of RP, $\theta_c = atan2(\dot{e}_x, e_x)$ and the ranges of the angle error are as in Table 1.

Table 1. The angle of phase error θ_c

quadrant	e_x	$\dot{e}_x$	θ_c
1	+	+	$-360° < \theta_c < -270°$
2	−	+	$-270° < \theta_c < -180°$
3	−	−	$-180° < \theta_c < -90°$
4	+	−	$-90° < \theta_c < 0°$

To make states toward the reference line in phase plane, it needs positive control input($u > 0$) when $\theta_c > \theta_r$ and negative one($u < 0$) when $\theta_c < \theta_r$ and control input is smaller with nearer RP to the origin even if with same perpendicular distance D. From these ideas, we can make the new fuzzy rules such as in Table 2 using the variables θ_e, D and u having seven, four and seven fuzzy subsets respectively. For example if $\theta_e = NM$, $D = PS$ in those rules, the u is considered that the control input corresponds to $\theta_e(NS)$ i.e., θ_e of NS and $\theta_e(PS)$ i.e., θ_e of PS but this u doesn't suit the sliding-like control input conditions of eq. (2.2).

Table 2. The proposed rules

θ_e \ D	AZ	PS	PM	PB
NB	NS	NM	NB	NB
NM	NS	NM	NM	NB
NS	AZ	NS	NM	NM
AZ	AZ	AZ	AZ	AZ
PS	AZ	PS	PM	PM
PM	PS	PM	PM	PB
PB	PS	PM	PB	PB

NB : Negative Big
NM : Negative Medium
NS : Negative Small
AZ : Approximately Zero
PS : Positive Small
PM : Positive Medium
PB : Positive Big

$$u = \begin{cases} u^+ > u_{eq} & \text{if} \quad s > 0 \\ u^- < u_{eq} & \text{if} \quad s < 0 \end{cases} \tag{2.2}$$

where, $u^+(u^-)$ is control input greater(less) than equivalent control u_{eq} and s is the sliding line in VSS.

Because we don't know the magnitude of the equivalent control input u_{eq} for the case that the system is uncertain, we can imagine the self-generated reference line different from the reference line θ_r: i.e., in the vicinity of the certain level (e.g. PS), eq.(2.3) is satisfied.

$$u = \begin{cases} u^+ > u_{eq}(unknown) = u(\theta_e(PS)) & \text{if} \quad \theta_e > \theta_e(PS) \\ u^- < u_{eq}(unknown) = u(\theta_e(PS)) & \text{if} \quad \theta_e < \theta_e(PS) \end{cases} \tag{2.3}$$

The u in eq.(2.3) is the control input to maintain the sliding mode in the self-generated reference line. For example, if the equivalent control input is the input level of $\theta_e(PS)$, the angle error θ_e between θ_r and angle of self-generated reference line by the incipient control rules is remained at $\theta_e(PS)$ and the actual angle of the referecne line is $\theta_c = \theta_r + \theta_e(PS)$ as described in Fig. 2.

2.2 Modification of the rules

As remarked in the previous section, the control actions by the initial control rules take the sliding mode along the reference line drifted by θ_e, therefore we must modify the initial rules to maintain the sliding mode in the desired reference line. This can be derived from the facts that the difference of the control input sets between the desired reference line and the line generated by the initial control rules corresponds to the equivalent control inputs. To modify the rules, we adjust the control input sets upward or downward in the look-up table so that the equivalent control inputs may be at $\theta_e = AZ$ or between $\theta_e(PS)$ and $\theta_e(NS)$ and state trajectories move along the desired reference line as in Fig. 3.

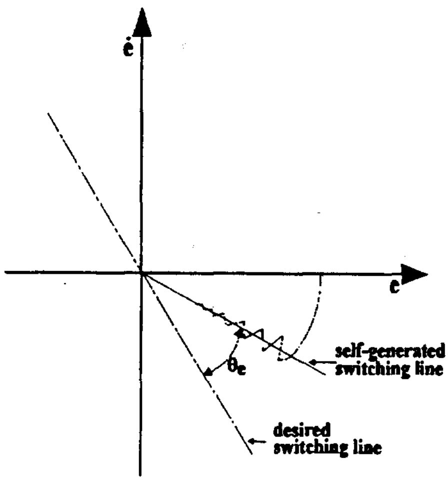

Fig. 2. Phase plane trajectory for initial control

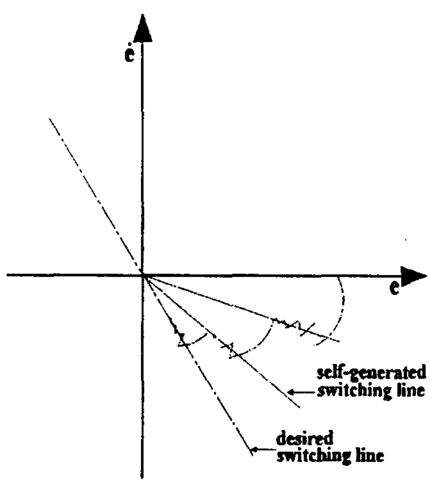

Fig. 3. Phase plane trajectory during rule modification

Ⅲ. Simulation and Experimental Results

Let's illustrate the above methodology on speed and relative phase control of drum motor for the home VCR system.

In the VCR, there are several dependent servo loops-the drum servo, the capstan servo, and the real servo etc. Two seperate control loops are used to control the drum motor that drives the rotating upper-drum assembly with the video heads. One loop is for speed control. The rotating frequency is 30rps (precisely 29.97 rps: NTSC) for the frame frequency in the color television. The other loop controls the phase, or timing. This loop makes it sure that one of the two video heads crosses the spot on the track where vertical sync. is to be recorded at the precise instant it occurs in the video signal.

The speed loop runs the drum motor at the correct speed for the first requirement. Also, the phase loop acts to speed up or slow down the rotation at the steady state in order to achieve the correct relative phase between a specific angular position of the video head and the arrival of vertical sync. So the purpose of the control is tracking the reference speed as well as remaining the phase error constant eg. zero.

For the system in Fig. 4 and Fig. 5, the speed information is obtained from the counter which counts the reference clock pulse of 2.5MHz during a period of the drum motor frequency generator(FG) which generates 24 pulses a revolution.

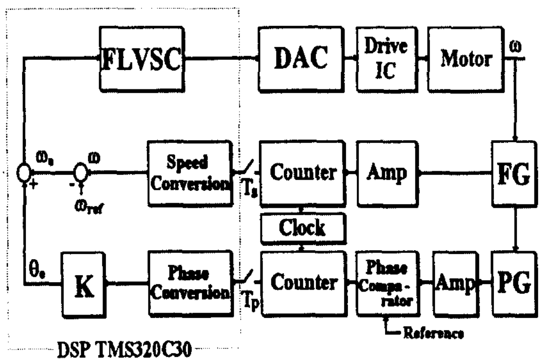

Fig. 4. FLVSC servo system for home VCR head drum motor

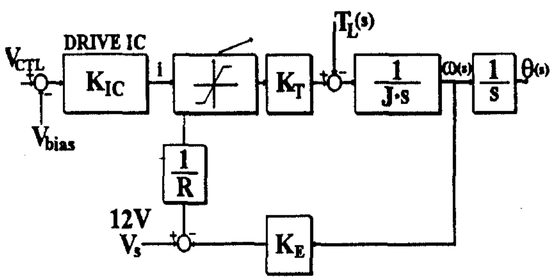

Fig. 5. Block diagram of a VCR drum motor with current drive IC

As shown in Fig. 6, the DSP is interrupted at every rising edge of FG signal to read the counter and immediately after that, clears the counter by means of hardware. The free-running counter repeats to count the reference clock pulses until the next interrupt.

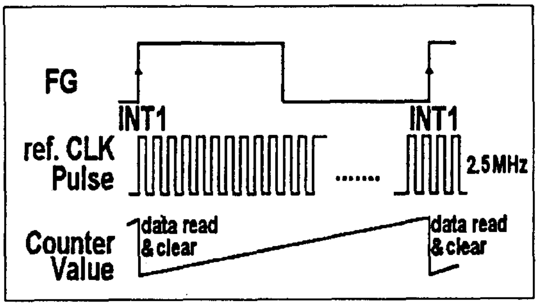

Fig. 6. Waveforms of the speed sensing part

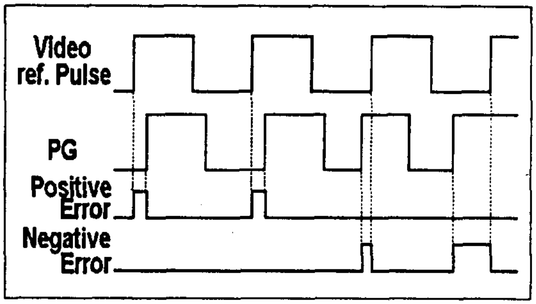

Fig. 7. Waveforms of the phase error sensing part

Since the drum motor is required to rotate with 30rps at the steady state, the reference speed ω_{ref} is given by eq.(3.1).

$$\omega_{ref} = 30\ rps = 60\ \pi\ [rad/\text{sec}] \tag{3.1}$$

If the actual counter value is N_{FG} during a period of FG signal, the actual speed ω is given by eq. (3.2).

$$\omega = \frac{\theta}{T} = \frac{2\pi/24}{N_{FG} \cdot f_{CLK}^{-1}} = \frac{\pi \cdot f_{CLK}}{12 N_{FG}} \quad [rad/\text{sec}] \tag{3.2}$$

where f_{CLK} is the reference clock frequency of 2.5 MHz. Thus, from eq.(3.1) and (3.2), the speed error ω_e is calculated as follows:

$$\omega_e = \omega_{ref} - \omega \tag{3.3}$$

Fig. 7 shows the phase error sensing part. The phase comparator generates a positive or negative error pulse corresponding to the phase difference between the reference signal of 30Hz and the signal of the pulse generator (PG) which generates one pulse a revolution. The counter counts the reference clock pulses during the ON state of the error pulse. The DSP reads the counter values at every rising edge of the reference signal and immediately clears the counter. Let N_{PG} be the counter value then corresponding phase error is calculated as eq.(3.4).

$$\theta_{pe} = \omega \cdot \Delta T_p = \omega \cdot N_{PG} \cdot f_{CLK}^{-1}\ [rad] \tag{3.4}$$

where ΔT_p is the timing interval corresponding to the ON state of the error pulse. Finally we define the new speed error and change rate of the error including the effect of phase error as following eq. (3.5).

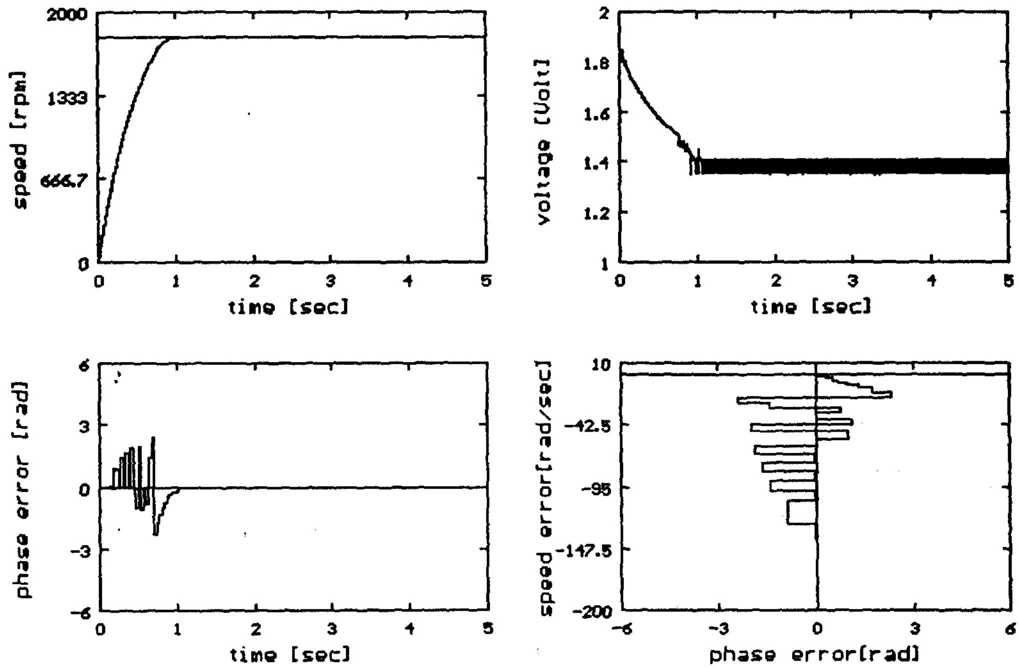

Fig. 8. Unit step response and phase plane trajectory(simulation results)

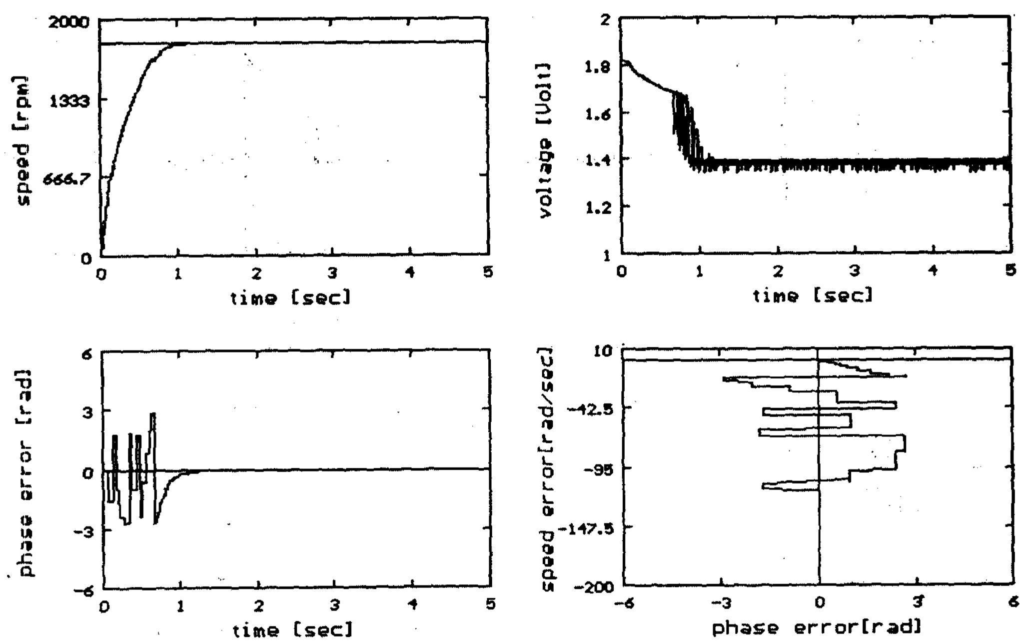

Fig. 9. Unit step response and phase plane trajectory(experimental results)

$$speed\ error = \omega_e + K \cdot \theta_{pe}$$
$$change\ rate\ of\ error = speed\ error - previous\ error \tag{3.5}$$

where K is the gain considering the effect of phase error to speed error and the phase error is limited between $-\pi$ and $+\pi$ radian.

We quantize the whole universe of discourse in 13 levels in the look-up table from the proposed rules, triangle-type membership function, max-min fuzzy inference and defuzzification of center of gravity.

Fig. 8 and Fig. 9 show the results from computer simulation and experiment, which can be regarded as a good performance as conventional approach.[4][6]

Ⅳ. Conclusions

In this study, we proposed a new fuzzy control scheme, FLVSC of which control rules are extracted from the concepts of variable control structure scheme which has the characteristics of robustness and fast response during the sliding mode. The study shows that the proposed control scheme has almost the same response of conventional VSC. And we will study about more general rule extraction methods in the future.

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