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NEW CONTROL ALGORITHM BASED ON ARTIFICIAL INTELLIGENCE

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This paper introduces a new model following approach to the design of an artificial intelligence control technique that employs Mamdani Type Fuzzy Logic Control. A model following approach has inherent advantage of being suitable for practical applications as it eliminates the requirement to specify a complicated cost function as a figure of merit for the system performance. It enables the designer to pass second order time domain specifications successfully to the design of fuzzy logic controller. The generation of error signal and derivative of the error signal that are required in formation of rule base in fuzzy logic control are facilitated in a very systematic way, thus doing away with the involvement of a human expert. In the proposed scheme the error between plant and model states is used to compute the error and error derivative, and a fuzzy law is developed. The proposed technique also brings in a systematic approach to the fuzzy logic control, thus overcoming a lot of heuristics that was in vogue with earlier fuzzy logic applications. The technique employs fuzzy tuning using scaling and decsaling factors obtained through Non Linear Controller Design Blockset In this paper, Model following fuzzy logic control has been applied to a second order model of a roll autopilot . It has been found that proposed scheme is robust and works satisfactorily even when parameters are perturbed as much as fifty percent from their geometric mean value.

Keywords: Model following fuzzy control, Sliding mode Control Model reference adaptive

1. Introduction

A large number of AI Fuzzy logic based control system techniques are reported in the literature that are based on PI/PD/PID controllers [1-3]. Some of the fuzzy controllers are actually nonlinear PI, PD and PID controllers with variable gain that can outperform their linear counterparts [9]. Application of Fuzzy theory to the design of control applications poses several challenges and one of them is to design fuzzy control laws that can incorporate conventional design specifications. Design of conventional fuzzy controllers is largely based on heuristics and a very limited work has been reported on meeting the time domain specifications or designing fuzzy controllers based on pole placement. In a departure from reported work a Model following fuzzy control based on the theory of Model reference adaptive control has been proposed in this paper to addresses the issue in a simple, yet an effective way. Instead of employing an adaptive law based on MIT rule or Lyapunov theory, the proposed method utilizes the inherent adaptive nature of fuzzy control to formulate the control law such that the response of the plant being controlled becomes same as the reference model, which is formulated as par second order time domain specifications. In this approach all design specifications can be specified for a reference model and the fuzzy control laws are developed so that plant is forced to follow the model. Such a technique enables the designer to pass second order time domain specifications to the fuzzy design.

This paper is organized as follows. Section 2 presents development of conventional fuzzy control section 3 presents model following fuzzy control Section 3 deals with development of Model following fuzzy control. In section 4 the model following rule base design principle is explained. In section 5 law is applied to a second order representation of a roll autopilot. Detailed simulation results are presented to see the performance of model following control, when the system parameters are varied by 50% to their nominal values.

2. Design of Conventional Fuzzy Controller

A Over last two decades the use of fuzzy logic in control system has become ubiquitous. A general block diagram of fuzzy logic based control system is depicted in Fig. 2 Feedback of the plant is processed to generate input signal (which may be error, derivative of error and integral of error) for the fuzzy controller. The process of fuzzification associates crisp values of input to fuzzy sets that are linked to linguistic variables through membership function. A fuzzy inference engine processes the fuzzy inputs based on fuzzy rule base that is formulated by human experts and is based on experience and heuristics. Output of the inference engine is further defuzzified to produce crisp values of control variable i.e. fed to the plant. Design of fuzzy controller requires more design decision than usual, for example regarding rule base, inference engine and data pre & post processing [6]. Single loop fuzzy control design procedures, which are under international standardization, employ a PID controller as a starting point [1-3].

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A conventional Fuzzy control design approach follows a three step design approach, that builds on PID control. First a PID controller is designed, whose linear behavior can be approximated by the model:

$$u(t) = k\left[e(t) + \frac{1}{\tau_i}\int_0^t e(t)dt + \tau_d\left(\frac{de(t)}{dt}\right)\right] \tag{1}$$

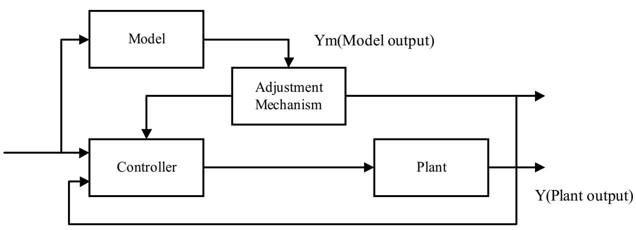
The second step is to generate universe of discourse for error and error derivative. The fuzzy controller corresponding to the PID controller has the form

$$u = k_p e + k_d \dot{e} + k_i \int edt \tag{2}$$

where e is the error *kp, kd, ki* are constants. Theoretically speaking, there is no limitation to the starting point in the control strategy, i.e. instead of using a PID controller one can start with an adaptive controller then use a fuzzy rule base to fine tune the same.

(B) Design of Model following Fuzzy Logic Controller

In the proposed method, starting point is Model Following Control, which provides the basis for generating universe of discourse for error and error derivative. Adopting a model reference or model following approach to the design of a Model following fuzzy controller has the inherent advantage that the technique can be easily applied to any practical problem. A general block diagram of Model Reference or Model Following Adaptive control (MRAC) is illustrated in Fig. 1



Figue 1: Block Diagram of Model Following Adaptive Control

A model following control is one in which a mathematical model forms a larger part of controller. The desired performance is expressed in terms of reference model, which gives desired response to the reference signal [5].

A model following control system is composed of four parts:

Plant: The plant has a known structure containing partially known or unknown parameters e.g. a transfer function representing missile roll dynamics using the single degree of freedom roll equation can be written as

$$\frac{\phi}{\delta} = \frac{k_\phi}{s(s - L_p)}, \tag{3}$$

where, k_ϕ and Lp are aerodynamic derivative, s is laplace operator, ϕ is the roll angle of the missile and δ is the input in terms of deflection of the control surface. The value of K_ϕ and L_p vary with operating altitude and speed. At any given time one may know the range of these values, which could vary in a range.

(C) Reference Model

A reference model is used to specify the ideal response of the model following control system to an external command. The choice of reference model should incorporate performance specification such as settling time, damping ratio. For a second order system these can be specified easily.

(D) Controller

In order to address the problem illustrated above, wherein there is a large uncertainty of plant parameters, a model reference adaptive controller may be used to adaptively vary the control law to compensate for the changes in the plant parameters. In MRAC, controller is specified as a parameterized controller, wherein a number of parameters can be adjusted. The control law is usually a linear combination of adjustable parameters. This is done to achieve guaranteed stability and tracking convergence [5]. However, in the proposed scheme instead of using a fixed adaptation law based on MIT rule or an adaptation law based on Lyapunov function that guarantees convergence, use of inherent adaptive nature of fuzzy laws has been exploited. The scheme combines merits of MRAC scheme with the flexibility of fuzzy technique. The practical design aspects of a Model following fuzzy controller are as understated.

3. DESIGN OF MODEL FOLLOWING FUZZY CONTROLLER

Here a plant is considered that can be represented be represented as sum of a nominal plant and perturbations around nominal point.

(a) *Representation of Plant:* One could represent a plant in continuous domain as

$$\dot{X}_p = A_p X_p + B_p u \tag{4}$$

where A_p, B_p are system and input matrices of the form $A_p = A + \Delta A$, where first term represents system matrix and second term the uncertainty in the system matrix

$$A = \begin{bmatrix} 0 & 1 & & \cdots \\ 0 & 0 & 1 & \cdots \\ -a_0 & -a_1 & & \cdots - a_{n-1} \end{bmatrix} \tag{5}$$

on similar lines

$$B_p = B + \Delta B, \text{ where}$$
$$B = [0 \quad \cdots \quad b]^T \quad (6)$$

and ΔB represents uncertainty in the input matrix u, is the control input.

(b) *Model representation:* A model with desired response to a reference input may be written as

$$\dot{X}_r = A_r X_r + B_r r \quad (7)$$

where Ar is the model system matrix and Br is the input matrix for the model, r is the reference input for which the model has desired response.

(c) Universe of discourse for error and error derivative

Error equation may be defined as

$$\text{Error} = X_e = X_p - X_r \quad (8)$$

Objective of model following control is to force error to go to zero. Dynamic error equation can be written as

$$\text{Error Derivative} = \dot{X}_e = \dot{X}_p - \dot{X}_r \quad (9)$$

Assigning a fuzzy set to each of the variables we obtain fuzzy rule base as stated below for a second order system.

4. Design of Fuzzy Model Following Fuzzy Controller

The error between model states and plant state is one of the input variables and is partitioned into Fuzzy sets NL, NS, ZE, PS and PL. Similarly the error between second state of plant and model is another input variable, which is also partitioned into fuzzy sets. The rule base for the Model Following Fuzzy Controller can be thought to be a two dimensional matrix as indicated in Fig. The rows represent various linguistic values that can be assigned to the first input variable i.e. error between first state of plant and Model. Similarly the columns represent linguistic values assigned to difference between second state of plant and model. The entries in the matrix are linguistic variables that represent control action. The control actions are decided on the logic exhibited by the reference model response which is shown in fig. 1

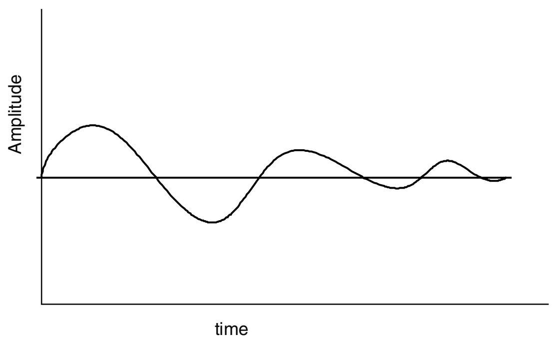


Figure 2: Desired Response

For the points which are slightly deviated (i.e Input variable error and error derivative are ZE) and are in the vicinity of steady state control action required is of a lower magnitude. However, if error is PB and error derivative is ZE then the control needs to be large and additive to the earlier output so that operating point moves closer to the reference point (i.e. U is PB) . In another case when error is zero and error derivative is either PB or PS it indicates plant state is moving away from reference state and Control output needs to be positive to arrest this trend and make plant state move towards reference state. On the other hand if error is zero and error derivative is NB or NS, then a negative change is required in the control output to arrest the trend and force plant state towards reference model state. All the fuzzy rules for above controller can be designed by extrapolating this logic to all possible combinations of linguistic variables which are represented by various entries in the matrix. Thus we obtain fuzzy rule base as stated below for a second order system. The inferencing method used is Mamdani and membership function for input and output variable is as shown in Fig 3.

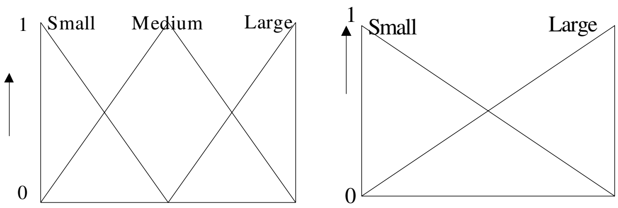


Figure 3: Membership Function Input/Output Variables

E → / de ↓	NL	NS	ZE	PS	PL
PL	ZE	PS	PL	PL	PL
PS	NS	ZE	PS	PL	PL
ZE	NL	NS	ZE	PS	PL
NS	NL	NL	NS	ZE	PS
NL	NL	NL	NL	NS	ZE

Fuzzy Tuning The fuzzy tuning is based on evaluating parameters of the model which may employ a simple PID controller whose parameters k_p, k_i, k_d can be evaluated classical design methods such as root locus, Zeiger Nicholas and reaction curve method. However, are based on optimization method using Non linear Controller Design Blockset. The scaling factors (GE, GR and GU) are evaluated using following formulas as enumerated in [12]. These factors play a role similar to the gain coefficient in a conventional PID controller

The understated formulas are used to relate the gain of conventional PID controller of the model with the scaling factors

$$k_p = \frac{GU \times GR \times H}{4L} \tag{10}$$

$$k_p = \frac{GU \times GE \times H}{4L} \tag{11}$$

Since unit step function is applied as the test signal in one time period, for the purpose of tuning $GE = 1$

GU = 4 xk_i Also $L = 1$ and $H = 1$ for the fuzzy controller

In the continuous domain the normalization and denormalisation are given by

$$GE = 1 \tag{12}$$

$$GU = 4xk_i \tag{13}$$

$$GR = \frac{k_p}{k_i} \tag{14}$$

5. Numerical Example

(A) *Problem:* To test the model following fuzzy law we apply it to roll autopilot design of a missile and check its performance by perturbing the parameters by 50% to 75% of their nominal value

(B) *Plant*: The dynamics of a typical roll auto pilot ignoring the non linear cross coupling terms can be expressed as [5]

$$\begin{bmatrix} \dot{\Phi} \\ \dot{p} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 0 & l_p \end{bmatrix} \begin{bmatrix} \Phi \\ p \end{bmatrix} + \begin{bmatrix} 0 \\ l_\xi \end{bmatrix} \xi \tag{16}$$

Here ϕ is the roll orientation of missile and p is the roll rate, l_p, l_ξ are the aerodynamic derivatives and ξ is the aileron deflection angle. The uncertainties in the plant and input matrices are given as

$$\begin{aligned} -37.3 &< l_p < -22.3 \\ -13500 &< l_\xi - 7050 \end{aligned} \tag{15}$$

Let actuator dynamics be an ideal one. The control input is aileron deflection angle. Nominal values of parameters are as undermentioned

(a) Nominal value of *lp* is taken as arithmetic mean, which equals to –29.8-30.

(b) Nominal value of *lg* is given by geometric mean, which equals to –9755.77 –10,000.

(C) **Model**: A fast model is selected with a settling time of 250mS and damping ratio of 0.8. Model dynamics can be written as.

$$\ddot{X}d + 32\dot{X}d + 400Xd = 400r \tag{17}$$

(D) **Simulation Results:** Extensive simulations in Matlab were carried out to check the response of closed loop system to a reference square wave input. It is seen that plant closely follows the model.

Results for Model Following Fuzzy Control Applied to Nominal Plant

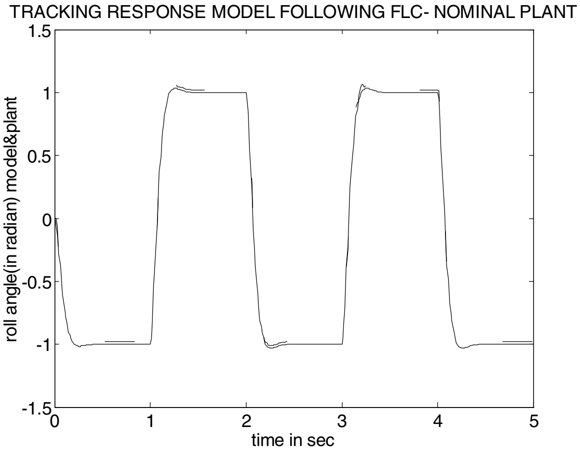


Figure 4: Tracking Response

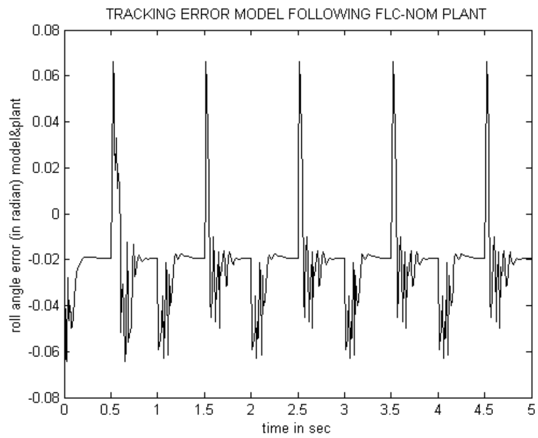


Figure 5: Tracking Error (Nominal Values)

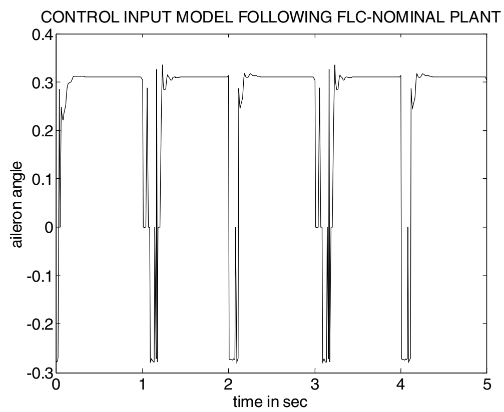


Figure 6: Control Effort in Nominal Plant

Results for Model Following Fuzzy Control Applied to Perturbed Plant

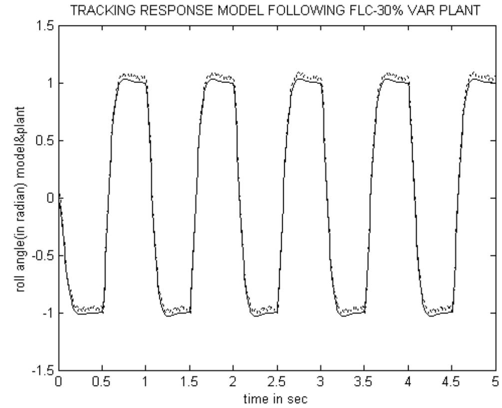


Figure 7: Tracking Response

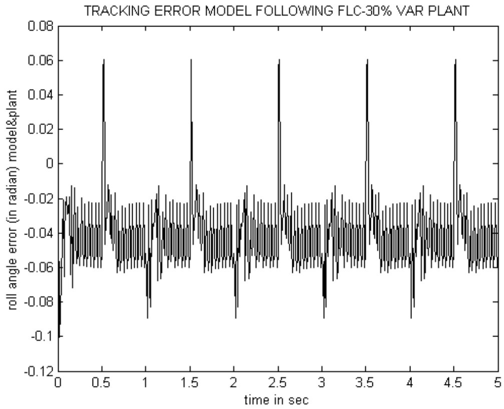


Figure 8: Tracking Error with Values Perturbed

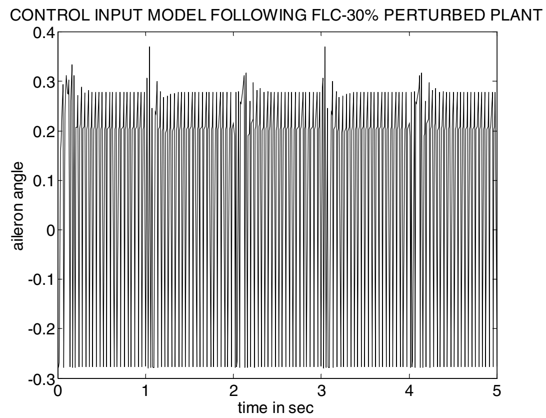


Figure 9: Control Effort in Case of Perturbed Nominal Values

6. CONCLUSION

In this paper a new AI technique based on model following Fuzzy Control has been presented and its performance has been checked by applying it to the to roll auto pilot of a missile. Simulation results have shown that the proposed scheme works satisfactorily even when system parameters are perturbed to 30% of their nominal values.

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