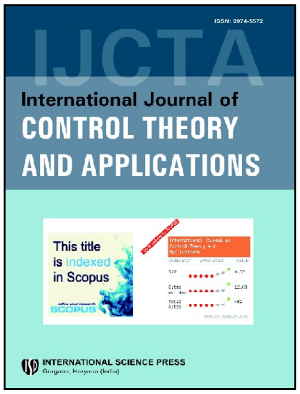

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Artificial Intelligent based Controller for Input Nonlinear System

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Abstract: This paper presents a novel approach for nonlinear system. Nonlinear systems are highly unstable in real world. Designing and modeling of nonlinear systems are very cumbersome and complex task. The stability analysis and stabilization control design for a class of nonlinear system by using artificial intelligent technique i.e fuzzy logic methodology for nonlinear systems to make feasible for unstructured systems. The nonlinear fuzzy controller helps to overcome the problems of ill-defined model of the systems, which are creating the undesirable performance. Here sliding surface or switching surface is being designed on error function of nonlinear system and sliding mode control is being designed here. The switching surface or sliding surface is being proven for its asymptotic stability. The computed error signal and change of error signal will be utilized for fabrication heuristic knowledge based fuzzy rule base in the fuzzy logic controller. The designed algorithm also brings in a systematic approach to the fuzzy logic control, thus overcoming lots of heuristics that was in vogue with earlier fuzzy logic applications. Fuzzy logic control has been applied to a second order model of a roll autopilot.

Keywords: Continuous-time system, fuzzy logic control, sliding surface, sliding mode control, stability

I. INTRODUCTION

Nonlinear systems are highly unstable in practical. Mathematical modeling of nonlinear system is typical cumbersome task. Different methodology has been developed to obtained stability of the system for obtaining stability of system. For last five decades some of the technique such as artificial intelligence based methods has been introduced. Fuzzy logic (FL) gained in popularity mainly due to the ability of representing rough models of system behavior via linguistic description of rules governing that behavior. It found numerous successful applications in many engineering and science fields. It is important to note that FL components can always be represented in terms of their input-output behavior, thus avoiding an explicit indication of their internal FL operational mechanisms. Also, if the strict mathematical analysis of the dynamic behavior of a FL system is required, then the description of the internal FL type functioning of the FL blocks, by use of membership functions, fuzzy inference rules and defuzzification methods, is not always sufficiently transparent for efficient analysis. In this paper we discuss this problem in the context of stability analysis and argue for the approach that, in a simple way, converts qualitative analysis of a very general class of FL dynamic systems to a 'conventional' qualitative analysis.

Zadeh introduced the fuzzy set theory in 1965, [1], it has received much attention from various fields and has also demonstrated nice performance in various applications. One of those successful fuzzy applications is to model unknown nonlinear systems by a set of fuzzy rules. On the other hand, most industrial plants have severe nonlinearities, which lead to additional difficulties for the analysis and design of control systems. In the past few years, the control technique based on the so-called K. Takagi-M. Sugeno (T-S) fuzzy model [2] has attracted lots of attention [3-8], since it is regarded as a powerful solution to bridge the gap between the fruitful linear control and the fuzzy logic control targeting complex nonlinear systems. The common practice is as follows, first, the T-S fuzzy model is employed to represent or approximate a nonlinear system. This fuzzy model is described by a family of fuzzy IF-THEN rules that represent local linear input-output relations of the system. The overall fuzzy model of the system is achieved by smoothly blending these local linear models together through membership functions. Then, based on this fuzzy model, a control design is developed to achieve stability and performance for the nonlinear system. The stability issue fuzzy control systems has been discussed in an extensive literature, i.e.[3-5], [7-8] and [12]. Most of the existing results were usually derived by using a single Lyapunov function (SLF) method, i.e. [3-5]. However, the main drawback associated to this method is that an SLF must work for all linear models, which in general leads to conservative results. To relax this conservatism, recently, the piecewise Lyapunov function approach [5] and the fuzzy Lyapunov function approach [6] have been proposed.

In recent years, based on the T-S fuzzy model, an intensive study on the stability issue of nonlinear time-delay systems has been made and several approaches have been proposed, i.e. The Lyapunov-Krasovskii functional (LKF) [9-17]. The stability analysis and stabilization problems for discrete-time T-S fuzzy systems with state-delay are dealt with by using a fuzzy LKF approach. A new fuzzy LKF is constructed for delay dependent stability analysis of open-loop systems, which can reduce the conservatism of using a non-fuzzy LKF. The paper has been organized as follows. The problem statement has been described in Section II. In Section III, sliding surface is being constructed. Section IV illustrates the designing of fuzzy rule base and simulation results are given in Section V to illustrate the effectiveness of the proposed method. Finally conclusions are drawn in Section VI.

II. PROBLEM STATEMENT AND DESCRIPTION

Consider the nonlinear system as follows:

$$\dot{x}(t) = f(x(t), u(t), t)$$

$$\dot{x}(t) = Ax(t) + B(u(t) + \xi(t)) \tag{1}$$

where $x(t) \in \Re^n$ and $u(t) \in \Re^m$ are the system state and control input vector. $A \in \Re^{n \times n}$, and $B \in \Re^{m \times n}$ are the state matrix and control vector respectively and they are with appropriate dimensions and parameter. $\xi(t)$ is a input nonlinearity.

Assumption: Pair (A, B) are controllable.

III. DESIGNING OF SWITCHING SURFACE

In general, the design of discrete-time SMC consists of two steps. The first step is to design a switching surface so that in the quasi-sliding mode system response acts like the desired dynamics. The second step is to design the control law in order that the quasi-sliding mode is reached and stays for all time. In the article, the switching surface is designed as follows:

If the desirable trajectory is $x_d(t)$, then error dynamics can be generated as follows:

$$e(t) = x(t) - x_d(t) \tag{2}$$

The generating the error dynamics of the system as follows

$$\begin{aligned} \dot{e}_1(t) &= A_{11}e_1(t) + A_{12}e_2(t) \\ \dot{e}_2(t) &= A_{21}e_1(t) + A_{12}e_2(t) + B_2(u(t) + \xi(t)) \end{aligned} \tag{3}$$

The switching surface can be generated as follows

$$S(t) = \sigma e(t) = \sigma[x(t) - x_d(t)] \tag{4}$$

The condition for sliding motion is as follows:

$$\begin{aligned} \dot{S}(t) &= S(t) = 0 \\ S(t) &= \sigma e(t) = 0 \\ \dot{S}(t) &= \sigma \dot{e}(t) = 0 \end{aligned} \tag{5}$$

Where $S(t)$ and σ are the switching surface and designer parameters for generating stable switching surface

$$e(t) = [e_1(t) \quad e_2(t)]^T \tag{6}$$

$$\begin{aligned} S(t) &= \sigma_1 e_1(t) + \sigma_2 e_2(t) \\ \sigma_1 e_1(t) &+ \sigma_2 e_2(t) = 0 \\ e_2(t) &= -\sigma_2^{-1}\sigma_1 e_1(t) \end{aligned} \tag{7}$$

$$\begin{aligned} K &= \sigma_2^{-1}\sigma_1 \\ e_2(t) &= -Ke_1(t) \end{aligned} \tag{8}$$

$$\begin{aligned} \dot{e}_1(t) &= A_{11}e_1(t) + A_{12}e_2(t) \\ \dot{e}_1(t) &= A_{11}e_1(t) - KA_{12}e_1(t) \\ \dot{e}_1(t) &= (A_{11} - KA_{12})e_1(t) \end{aligned} \tag{9}$$

Substituting the of eqn. (8) into eqn. (3)

$$\begin{aligned} \dot{e}_1(t) &= A_{11}e_1(t) + A_{12}e_2(t) \\ \dot{e}_2(t) &= A_{11}e_1(t) - KA_{12}e_1(t) + B_2(u(t) + \xi(t)) \end{aligned} \tag{10}$$

$$\dot{e}_1(t) = A_{11}e_1(t) + A_{12}e_2(t)$$
$$\dot{e}_1(t) = A_{11}e_1(t) - KA_{12}e_1(t)$$
$$\dot{e}_1(t) = (A_{11} - KA_{12})e_1(t) \tag{11}$$
$$\dot{e}_1(t) = Ge_1(t)$$

Where $G = (A_{11} - KA_{12})$ and for stability condition of the system all the eigenvalues of $G = (A_{11} - KA_{12})$ must lie in the left half side (LHS) of s-plane

IV. FUZZY LOGIC CONTROLLER

Fuzzy control algorithm is very successful methodology, especially for control of nonlinear systems. There is a drawback in the designs of such controllers with respect to performance and stability. The fuzzy logic system performs a mapping from $U \subset \Re^n$ to $V \subset \Re$. Let $U = U_1 \times .... \times U_n$ where $U_i \subset R, \quad i = 1,2,3,....,n.$ The fuzzifier maps a crisp point in U in to a fuzzy set U. The fuzzy rule base consists of a collection of fuzzy IF-THEN rules:

$$R^{(l)}: \text{IF } e_1(t) \text{ is } F_1^l, \text{ and } e_2(t) \text{ is } F_2^l, \text{ and }, \ldots\ldots, e_n(t) \text{ is } F_n^l,$$
$$\text{THEN } y_j \text{ is } Q_j^l, \quad j = 1,2,......., p \tag{12}$$

4.1. Design of proposed fuzzy controller

The computed error (Er) between desired state and plant state is one of the input variables and is partitioned into Fuzzy sets NL, NS, 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 bases for the reference model with fuzzy controller can be thought to be a two dimensional matrix as indicated in figures. The rows represent various linguistic values that can be assigned to the first input variable i.e. error between first state of plant and desired state. Similarly the columns represent linguistic values assigned to difference between second state of plant and desired state. The entries in the matrix are linguistic variables that represent control action. However, if error is PB and change in error is NS, 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 both 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 derivative of error (DEr) is NB or NS, then a negative change is required in the control output to arrest the trend and force plant state towards reference trajectory 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 Figure 1. Fuzzy rules are used to formulate control laws in a transparent human oriented fashion, using the linguistic variables defined by the membership functions. For each Mamdani controller, 4x4=16 fuzzy rules need to be defined to cover all possible combinations of the linguistic variables of the two inputs.

If (Process state) *then* (control output)

4.2. Structure of Fuzzy Controller

There are specific components characteristic of a fuzzy controller to support a design procedure, In the block diag. The controllers between a preprocessing block and a post-processing block and the basic function of the rule base is to represent in a structured way the control policy of an experienced process operator.

If (Process state) then (control Output)

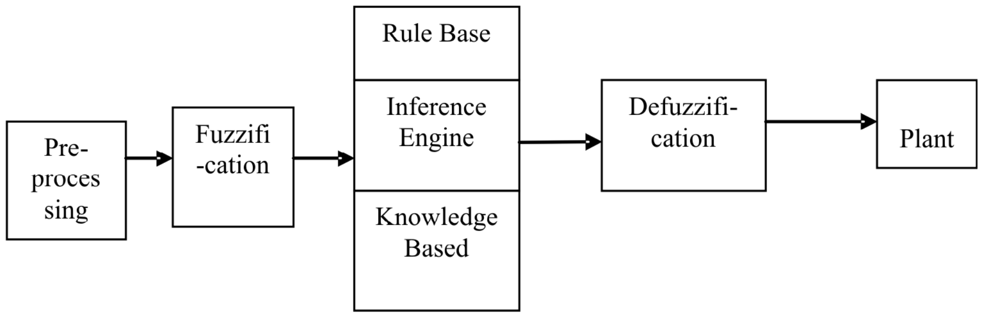

Figure 1: Fuzzy Logic Controller

4.3. Table of Rule Base for Input and Output

The following rules base have been designed for generating the stability of the system.

Table 1
Fuzzy Rule Bases for Input and Output

Er / DEr	*NB*	*NS*	*PS*	*PB*
NB	NB	NB	NS	NS
NS	NB	NB	NS	PS
PB	NS	PS	PS	PB
PB	NS	PS	PB	PB

4.4. Design of membership functions

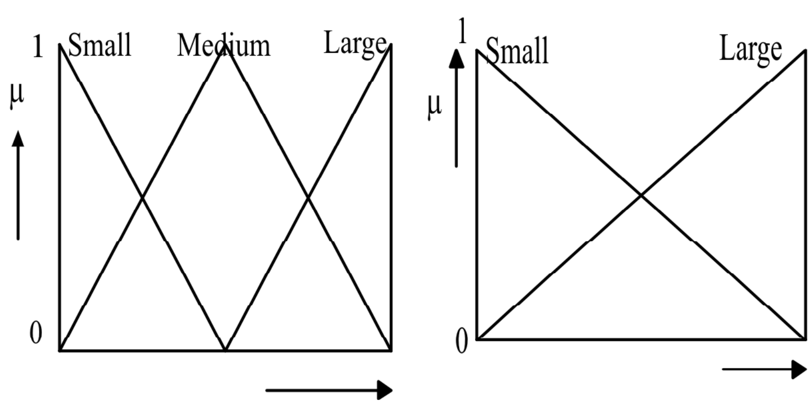

Figure 2: Membership function for input and output variables

III. SIMULATION RESULTS

The results have been obtained by simulating the algorithm with Matlab software.

5.1. Error signal

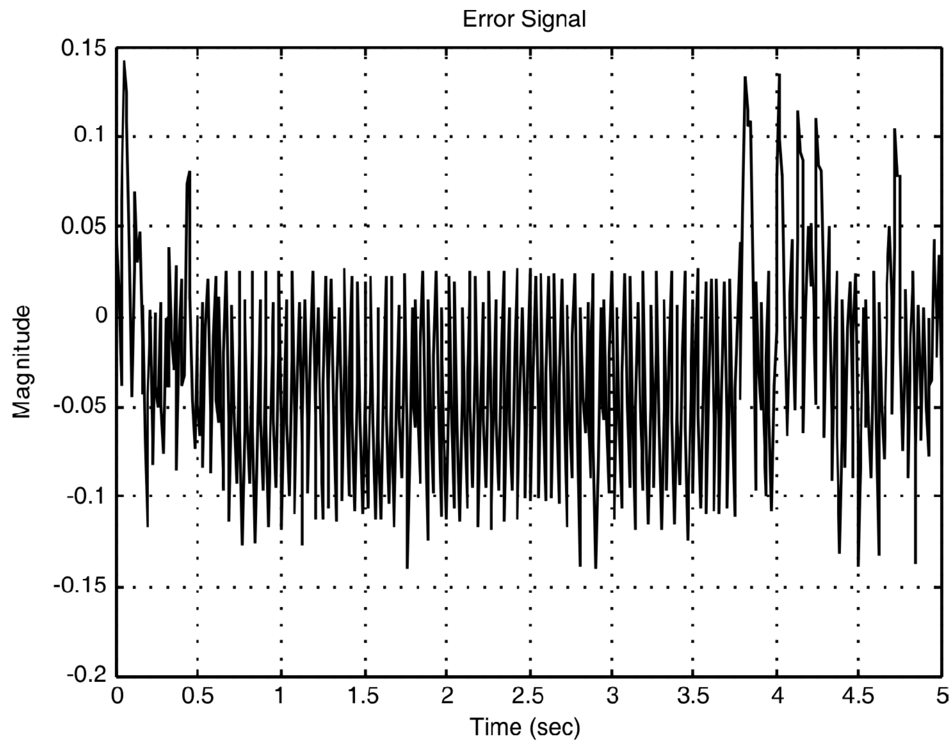

Figure 3: Error signal of the system

5.2. Derivative of error signal

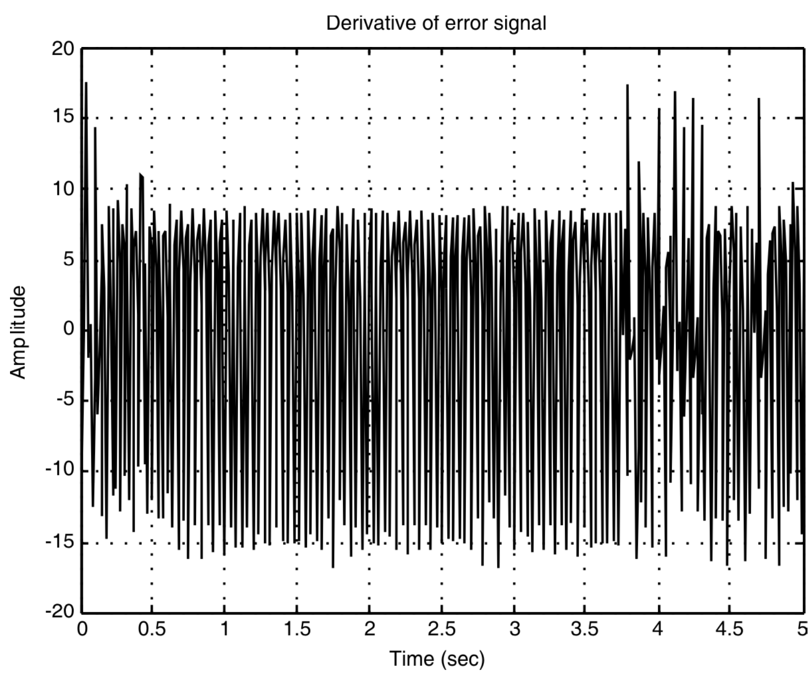

Figure 4: Derivative of error signal of the system

5.3. Stable Sliding Surface

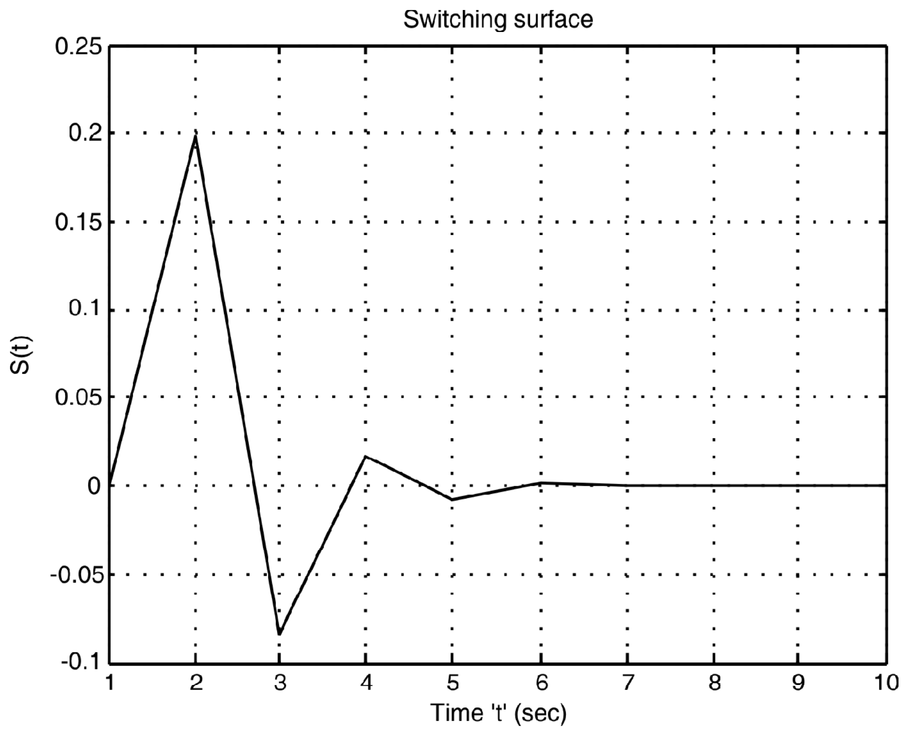

Figure 5: Stable Switching Surface

5.4. Stable output response by fuzzy controller

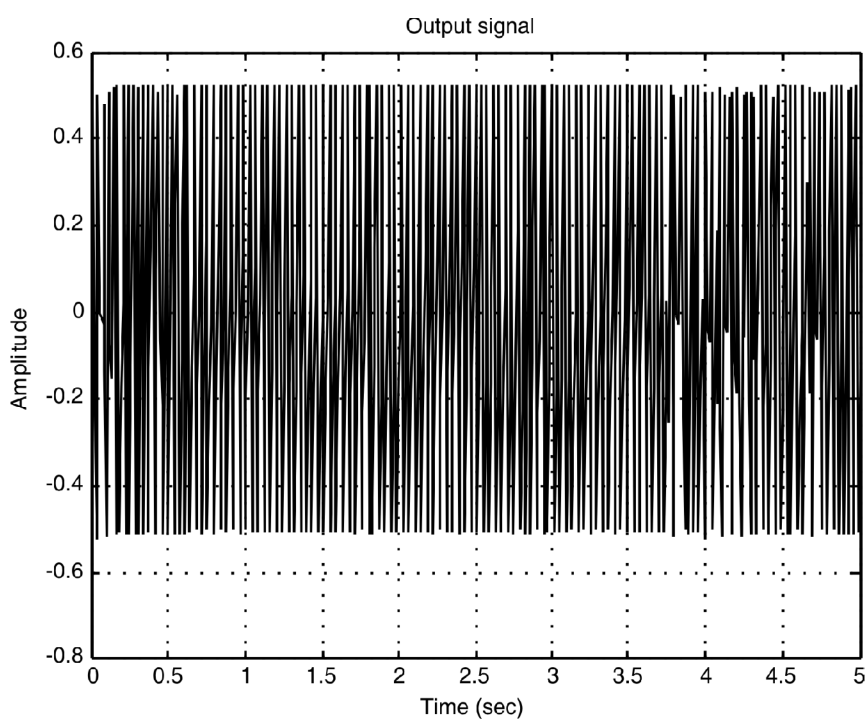

Figure 6: Stable output response by designed algorithm

V. CONCLUSION

This paper proposes the new fuzzy control algorithm for nonlinear systems. Nonlinear systems are complex in nature, which are highly unstable in nature and their stability problem has become the major issues. Designed fuzzy control based algorithm, which drives the state trajectory in the stable switching surface. The real world systems are complex in nature and their mathematical models are ill-defined and the classical methods are quite cumbersome to generate the desirable stable performance by the system. This new fuzzy controller is made on the intelligence heuristic method based. The proposed technique is more compatible even if in the variation of environmental conditions or any other type of uncertainties. The simulation results are showing stable output response when the parameters are perturbed. This newly designed controller will be more effective for highly unstable systems like aviation and aerodynamic systems.

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