Neuro Fuzzy and Self Tunging Fuzzy Controller to Improve Pitch and Yaw Control Systems Resposes of Twin Rotor MIMO System

Thair Sh. Mahmoud, Tang Sai Hong, and Mohammed H. Marhaban

***Abstract*—**In this paper, Neuro-Fuzzy based Fuzzy Subtractive Clustering Method (FSCM) and Self Tuning Fuzzy PD-like Controller (STFPDC) were used to solve non-linearity and trajectory problems of pitch AND yaw angles of Twin Rotor MIMO system (TRMS). The control objective is to make the beams of TRMS reach a desired position quickly and accurately. The proposed method could achieve control objectives with simpler controller. To simplify the complexity of STFPDC, ANFIS based FSCM was used to simplify the controller and improve the response. The proposed controllers could achieve satisfactory objectives under different input signals. Simulation results under MATLAB/Simulink® proved the improvement of response and superiority of simplified STFPDC on Fuzzy Logic Controller (FLC).

***Keywords*—** Fuzzy Subtractive Clustering Method, Neuro Fuzzy, Self Tuning Fuzzy Controller, and Twin Rotor MIMO System.

I. Introduction

TRMS control has attracted many researchers in the last few years, as it represents a control and modeling challenge for them. Among different control approaches, fuzzy logic has been widely used with different control schemes to cope with control objectives of TRMS [2-10]. It has been shown that FLC could improve the response of TRMS in terms of tracking and transient response [2-3]. FLC has been utilized in many different hybrid schemes to cope with TRMS control objectives. Hybrid schemes could be implemented with the use of classical and/or intelligent control. As in [4-9] fuzzy logic has been proposed in different schemes with the use of Genetic Algorithms (GA) and conventional PID controller. Another use of fuzzy logic has been proposed in [10] to be used for the switching grey prediction. In previous works, a simple fuzzy control system (SFCS) was investigated, whose advantage was simple and easy to use. But a major limitation is the lack of a systematic methodology for developing fuzzy rules. A set of fuzzy rules often needs to be manually adjusted by trial-and-error before it reaches the desired level of performance. Hence, it is desirable to develop a fuzzy self-tuning controller that can improve its performance based on its experience, and to adapt its response in relation to variations in the process dynamics [11]. Later, to have better response and simple controller at the same time, applying ANFIS based FSCM would improve trajectory performance and reduce number of rules and simplify the controller as well [12-13].

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II. Twin Rotor MIMO System

TRMS is a laboratory set-up designed for control experiments. It exemplifies a high-order non-linear system with significant cross-couplings from control point of view. A libratory set-up of TRMS is depicted in Fig. 1 below.

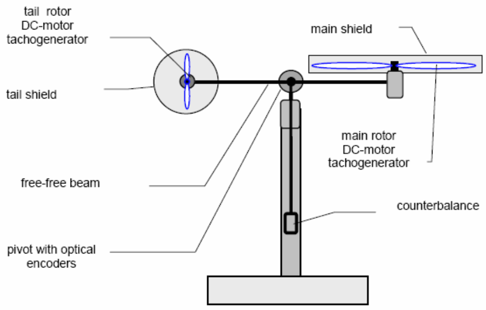

Fig. 1 Libratory set-up of TRMS [1]

A detailed approach to control problems connected with TRMS involves some theoretical knowledge of lows of physics [1]. The main parts of TRMS are the pedestal, the jib connected to pedestal, and two propellers at each end of the jib. These two propellers are driven by two Direct Current (DC) motors. The system jib can freely rotate around vertical axes by about 330 degree and horizontal axis by about 100 degree. The system inputs are the voltages used to drive the DC motors of the propellers, and the outputs are the angular rotations with respect to horizontal and vertical axes. A counterbalance arm with a weight at its end is fixed to the beam at the pivot. More details about TRMS and its mathematical model used in this work are all provided in [1].

III. Self Tuning Fuzzy PD-like Controller

Generally, fuzzy rules are dependent on the control purpose and the type of a controller. This section presents the design of the proposed STFPDC for pitch and yaw angles control of TRMS. Hence that design procedure was repeated again for STFPDC for yaw angle. STFPDC is an adaptive FLC. FLC is called adaptive if any one of its tunable parameters (scaling factors, membership functions and rules) is changed on-line when the controller is being used; otherwise it is a non-adaptive or conventional FLC [14]. The block diagram of the proposed STFPDC is shown in Fig. 2 [15]. Fig. 2 shows that the output α changed by the value of STFLC. Thus, the output-scaling factor of the FLC does not remain fixed while the controller is in operation; rather it is modified in each sampling time by the gain updating factor α, depending on the trend of the controlled process output.

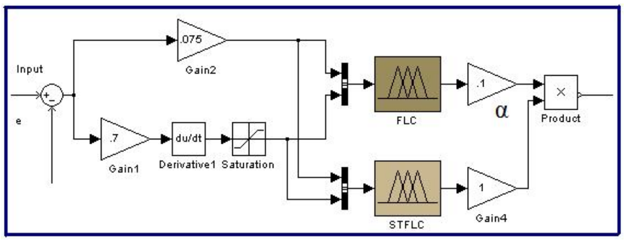

Fig. 2 Block Diagram of the Proposed Controller (STFPDC) [15]

From Figure 2, it is observed that the value of α is computed from the normalized values of error and change of error by a fuzzy rule base. The rule base has 49 rules for computing the value of α and computing the control output of STFLC. Table I shows the rule base used in these designs.

TABLE I Fuzzy systems rule base

Δe\e	NB	NM	NS	M	PS	PM	PB
NB	NVB	NB	NB	NM	NS	NS	M
NM	NB	NB	NM	NM	NS	M	PS
NS	NB	NM	NS	NS	M	PS	PM
M	NM	NS	NS	M	PS	PS	PM
PS	NM	NS	M	PS	PS	PM	PM
PM	NS	M	PS	PS	PS	PM	PB
PB	M	PS	PM	PM	PB	PB	NVB

In this work, it was possible to use the same fuzzy rule base for FLC and STFLC for both angles control systems. The membership functions designs of FLC for both planes are depicted in Figure 3 and 5. Each of the two inputs (e and Δe) to the fuzzy rule base (corresponding to α) has seven fuzzified variables. For the STFLC Figure 4 and 6 shows the proposed design to cope with the changes of e and Δe of the pitch angle control system. The input signals in this work were between [-0.3 0.3].

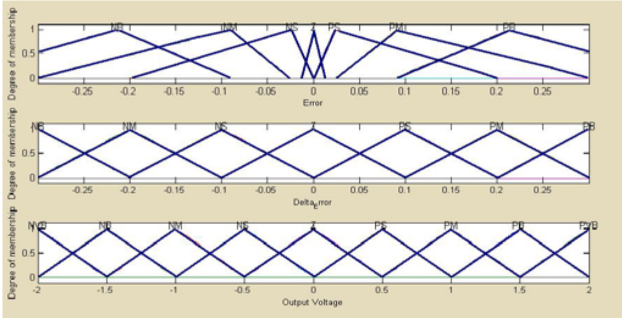

Fig. 3 Membership Function Design for FLC of the Pitch Angle Control

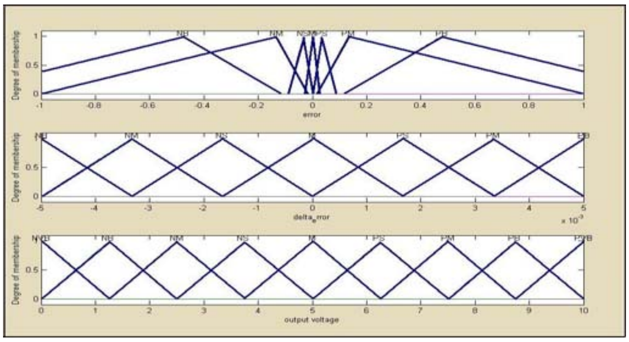

Fig. 4 Membership Function Design for STFLC of the Pitch Angle Control

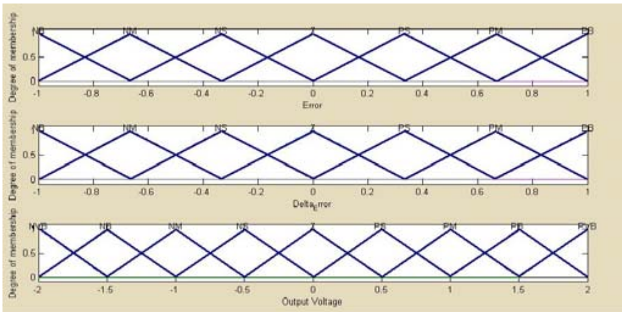

Fig. 5 Membership Function Design for FLC of the Yaw Angle Control

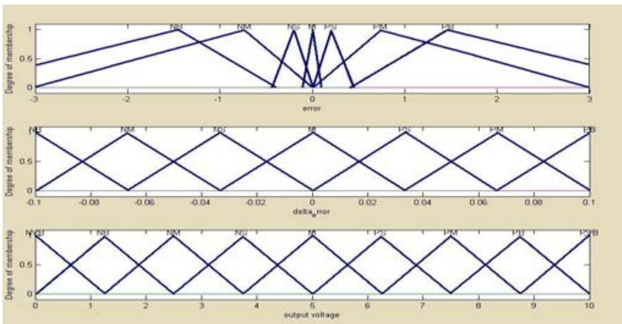

Fig. 6 Membership Function Design for STFLC of the Yaw Angle Control

The control scheme of the STFPDC and TRMS pitch angle plant is shown in Figure 7 below.

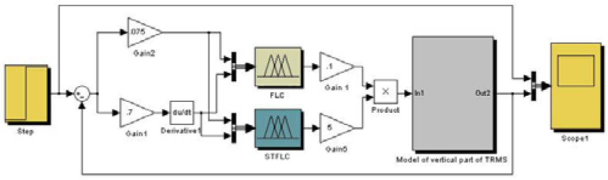

Fig. 7 TRMS pitch angle control system with STFPDC

Hence, the control schem of yaw angle control is the same as the schem of pitch angle wich is listed in figure 7 above.

IV. CONTROLLER IDENTIFICATION

Identification of STFPDCs is achieved by applying random input signal to both inputs of STFPDCs. Data collected from both applied inputs and output of controller are stored in a file or sent to MATLAB® workspace. Figure 8 below explains the structure of STFPDC training. The collected data are stored in workspace, and then recalled again to be processed by MATLAB/ANFIS [16]. Next step is generating the new Fuzzy Inference System (FIS). ANFIS provides many methods for extracting FIS. In this work FSCM is used to extract the new FIS.

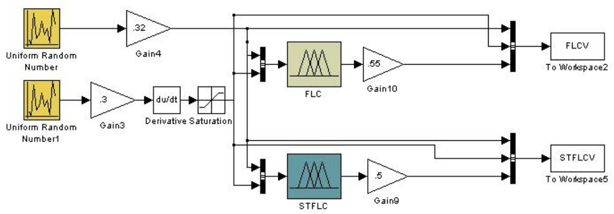

Fig. 8 STFPDC training structure

V. FUZZY SUBTRACTIVE CLUSTERING METHOD

FSCM is a method which extracts rules from supplied input-output training data. It is a statistical classification technique which is used for discovering whether the individuals of a population fall into different groups by making quantitative comparison of multiple characteristics. Subtractive clustering method was firstly proposed by [17]. For using FSCM and ANFIS to extract the new fuzzy models, [12-13] have brief details about the methodology on how to convert each of the fuzzy systems used in this control system. In this work, this methodology is used to simplify our controller and reduce the number of rules in each fuzzy system.

VI. SIMULATION EXPERIMENTS

To evaluate the effectiveness of the proposed method, three simulation experiments to compare between FLC and STFPDC in each plane have been done. The three experiments included different inputs signals to evaluate the robustness of the proposed controller. Simulation results under MATLAB/simulink showed the superiority of the proposed method on conventional FLC under step, sinusoidal and square inputs signals. In case of step input reference as it shown in figure 9 and 10 for pitch and yaw angles respectively as shown below, the results showed that STFPDC is better in terms of rise time and steady state error for both planes.

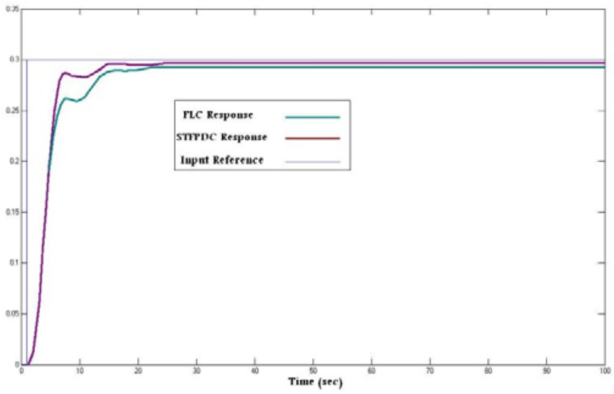

Fig. 9 TRMS pitch angle control system response with step input reference with STFPDC

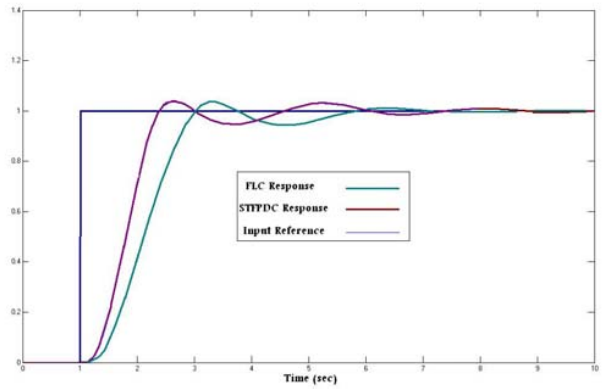

Fig. 10 TRMS yaw angle control system response with step input reference with STFPDC

In square input signal the results showed that STFPDC is better for both planes in term of rise time, overshoot, and steady state error. Figure 11 and 12 below shows the square input reference response for pitch and yaw angles control systems respectively.

In sinusoidal signal results showed that STFPDC has better response too in both planes in term of less integral square of error [1] than FLC response as shown in Figure 13 and 14 below for pitch and yaw angles respectively. In this work we could also simplify the controller and reduce the rules from 98 to 43 rules for pitch angle and from 98 to 22 rules in yaw angle.

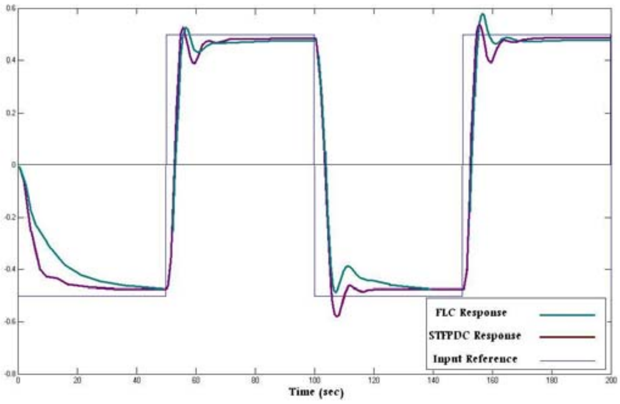

Fig. 11 TRMS pitch angle control system response with square input reference with STFPDC

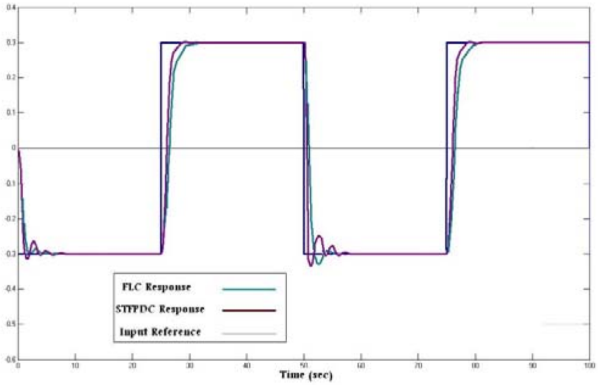

Fig. 12 TRMS yaw angle control system response with square input reference with STFPDC

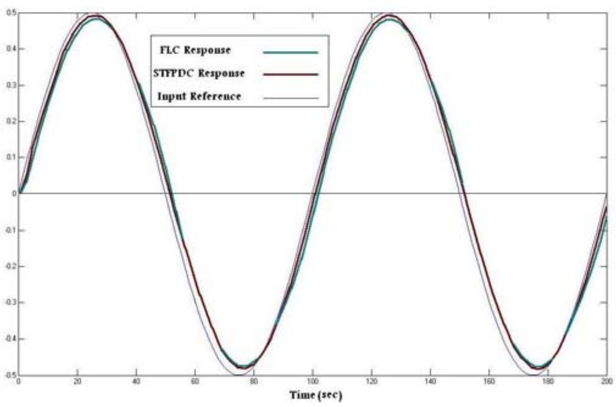

Fig. 13 TRMS pitch angle control system response with sinusoidal input reference with STFPDC

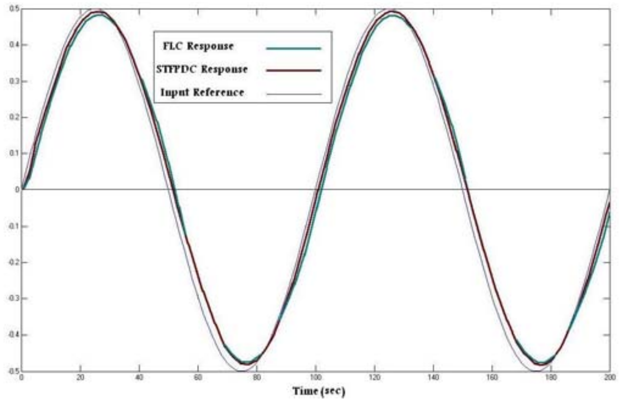

Fig. 14 TRMS yaw angle control system response with ssinusiodal input reference with STFPDC

VII. Conclusion

This paper has presented STFPDC to solve control challenges of TRMS. The proposed STFPDC was superior to FLC performance but has the problem of complexity and high computation resources. ANFIS based FSCM was used to re-extract the fuzzy systems in two systems instead of four for both planes of motion of TRMS. After all, the comparison made between the new ANFIS-STFPDCs and FLC. Simulation results showed the effectiveness of the proposed methodology in terms of improving time domain characteristics and the simplicity of controller. The method could reduce the number of rules to less than half for pitch angle system and less than quarter for yaw angle system; which reduce the computation resources needed to achieve control objectives.

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