Design of ANFIS Controller for First order process with time delay

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ABSTRACT

This paper presents a novel method for designing an ANFIS controller for FOPTD (First order process with time delay). The proposed method derives the training data from the closed loop response by employing a proportional only controller for delay free process. This data is used to train the ANFIS controller. The derived controller for delay free processes can be used for the process with delay by scaling down the out put of the controller to a suitable level. The proposed method is compared with recently proposed other method and found to be robust in nature.

Keywords: ANFIS, FOPTD, PID, Fuzzy

1.Introduction

The time delay associated with the process is always a challenge as it makes the controller design complex. The time delay results from measurement lag, process lag etc. Several researchers have come up with PID controllers for first order process with time delay[1]. The robustness of controller is highly crucial as there will be difference between estimated process and actual process parameters. An ideal controller should handle the mismatch of parameters efficiently.

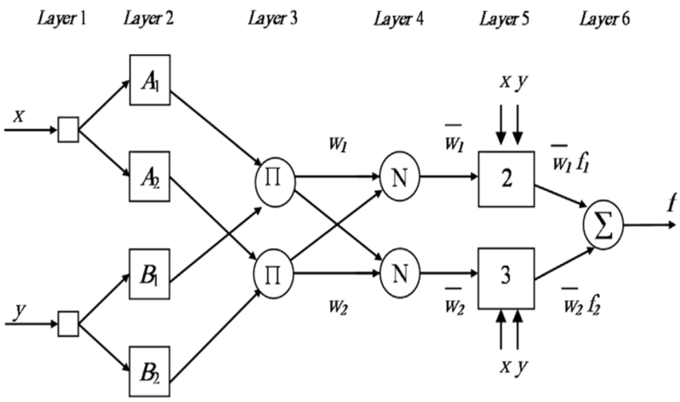

Fig. 1. Structure of ANFIS

The fuzzy controller is known to be robust when compared to PID. However, selection of member ship functions and the range of membership functions makes it a cumbersome procedure in designing a Fuzzy controller[2]. ANFIS (Adaptive Neuro Fuzzy Inference System) is a hybrid system which composes of both neural networks and fuzzy systems as shown in Fig. 1. The present work describes the design procedure of an ANFIS controller for FOPTD (First order process with time delay) presented in Eqn. 1.

$$G(s) = \frac{k}{\tau s+1} e^{-\theta s} \qquad (1)$$

2. Proposed method

The proposed method employs a proportional only controller to generate training data as shown in Fig. 2. It is known that, with only proportional controller, there always exist a offset. However , the offset is calculated and subtracted from the actual error to generate an error profile which is driven to zero. The training data is composed of error, change in error and change in controller output. To explain the derivation process of training data , a simple first order process shown in Eqn. 2 is selected.

$$G(s) = \frac{1}{s+1} \tag{2}$$

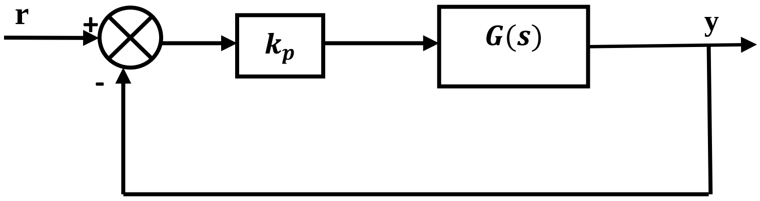

Fig. 2. Closed loop control system with proportional only controller

For instance, For a set point of 1 and $k_p = 0.5$, there exist offset and error will not go to zero. This error profile is not suitable for training the ANFIS as it is not driven to zero. However, if the set point is considered as 1/3 instead of actual set point in calculating error, the error profile appears to be driven to zero. Both the error profiles are presented in Fig.3.

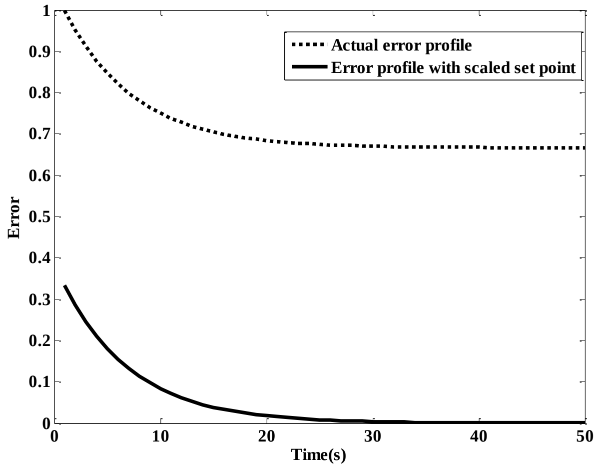

Fig. 3. Error Profile

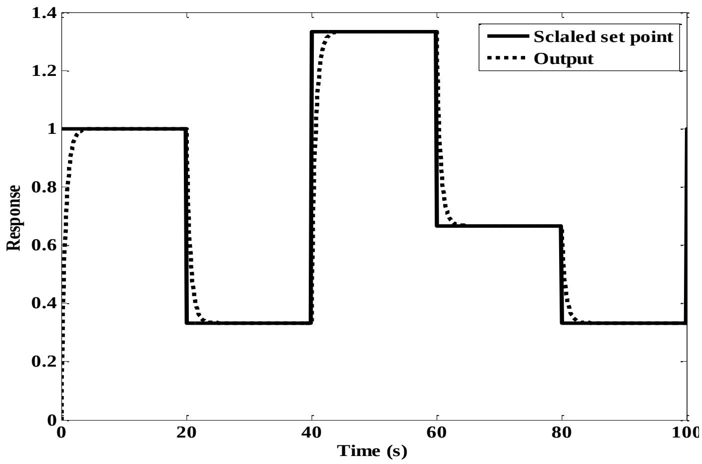

Fig. 4. Response for several scaled set points.

In a similar fashion, set of scaled set points are considered and error profiles are generated from the response as shown in Fig 4. This data is used to train the ANFIS controller. The SIMULINK diagram employed to generate training data is shown in Fig 5. For the processes with delays, the training data generated for delay free processes is used and the ANFIS out put is scaled to a suitable factor to achieve better response characteristics.

The Control scheme with ANFIS controller is shown in Fig.6. The ANFIS receives information of error and change in error. The output of ANFIS is change in controlled variable. So the controller adds the fraction of manipulated variable depending on the values of two variables i.e. error and change in error.

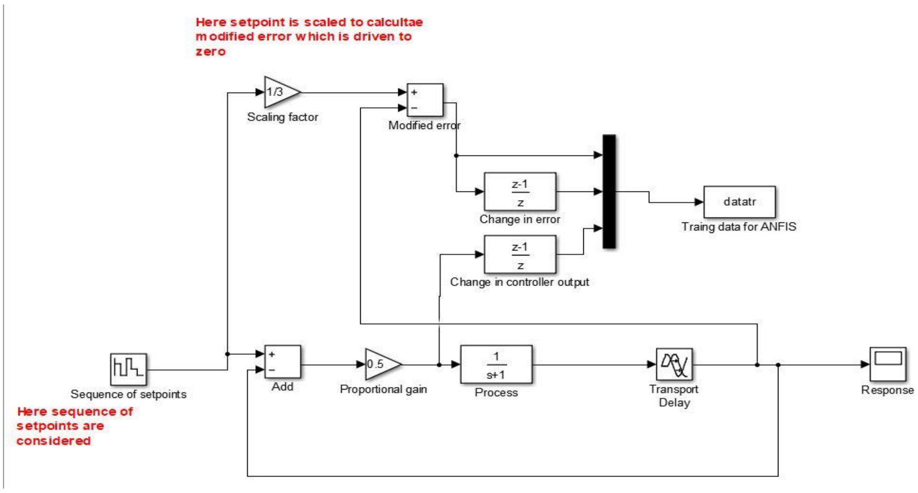

Fig. 5. Simulink diagram for error profile generation

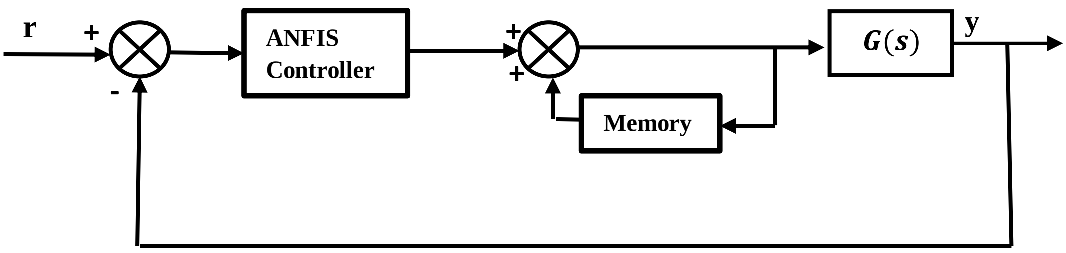

Fig. 6. Closed loop control system with ANFIS Controller

3. Performance Analysis

The mathematical description of profoundly used evaluation parameters are presented through Eqns. 3-6.

Integral Absolute Error (IAE) = $\int_0^\infty |e|\, dt$ (3)

Integral Square Error (ISE) = $\int_0^\infty e^2\, dt$ (4)

Integral Time Absolute Error (ITAE) = $\int_0^\infty t|e|\, dt$ (5)

Total Variation (TV) = $\sum_{i=0}^{\infty} |u_{i+1} - u_i|$ (6)

where, e is error and u_i represents the manipulated input to process at ith instant.

Control loops that are optimized for IAE produce less oscillations in response. Control loops that are optimized for ISE can eliminate large errors quickly. Control loops that are optimized for ITAE result faster settling times relatively. It is very important to ensure smooth variations in input to the process to protect the final control element against wear and tear. TV is a measure of smoothness of process input which should be considered when evaluating a method. The process input is sampled at an interval of $0.1s$ in order to calculate TV.

The proposed method is implemented on a first order process with time delay shown in Eqn. (7)

$$G(s) = \frac{1}{s+1} e^{-2s} \tag{8}$$

It is always difficult to control processes with time delay. Tis particular process is previously discussed by several researchers Vijayan and panda[3], Zhang [4]. The proposed method is compared against a recently proposed method [3] which is proven to be better than the method proposed by [4]. However, as the considered process is associated with delay, The ANFIS output is scaled by a factor 0.25 as mentioned in section 2. The nominal response and corresponding manipulated variable (control signal) are shown in Fig. 7 and Fig. 8 respectively. The performance analysis is presented in Table 1. It is under stood that, ANFIS produced similar performance in set point tracking and the method of Vijayan and Panda is giving better performance in disturbance rejection. The proposed method superior in terms of TV only.

The estimated process may not represent the actual process always. To verify the robust performance, +10%,-10% and +20% perturbations are considered in k, τ and $\boldsymbol{\theta}$ respectively. The response and corresponding manipulated variable are presented in Fig. 9 and Fig. 10 respectively. From the figures and response analysis presented in Table 2, it is clear that the proposed method is superior to the other method.

Table 1: Performance comparison under nominal conditions

Method	Set point tracking					Disturbance Rejection				
	$t_s(s)$	IAE	ISE	ITAE	TV	$t_s(s)$	IAE	ISE	ITAE	TV
Proposed	10.55	4.04	3.099	10.83	1.79	7.37	1.988	0.617	110.6	1.126
Vijayan and Panda	9.14	3.86	3.114	8.874	2.28	9.01	1.592	0.375	89.38	2.1

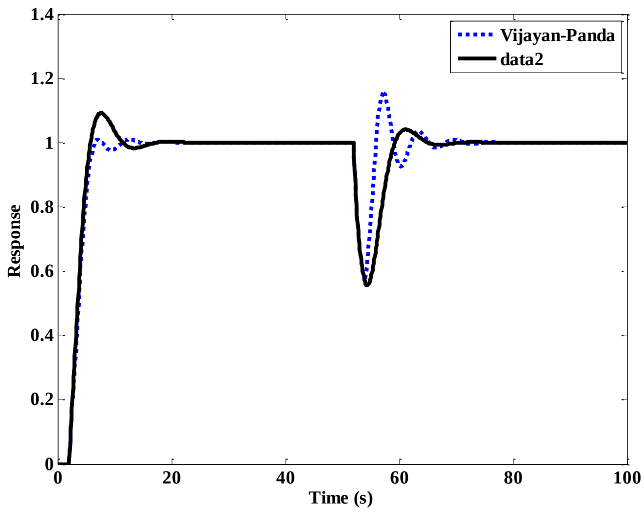

Fig.7. Nominal Response

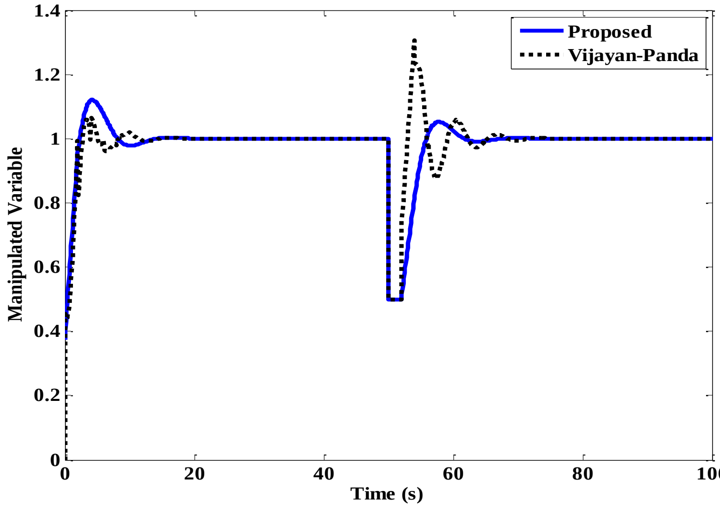

Fig. 8. Variation of manipulated variable

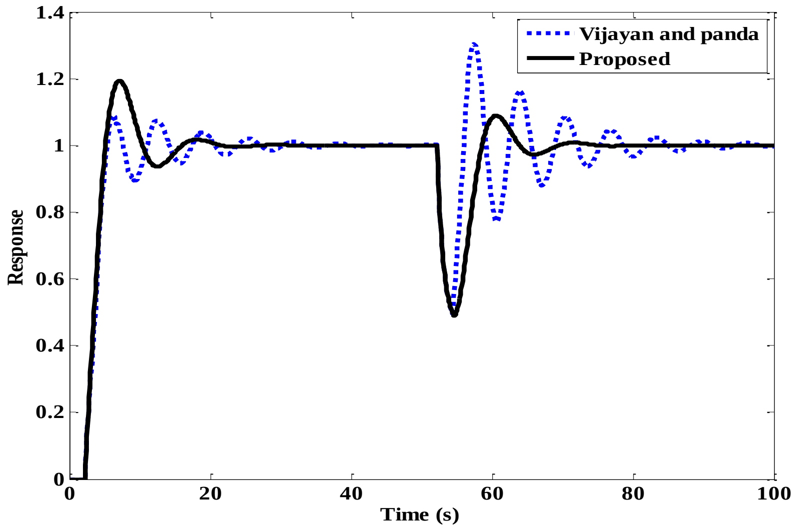

Fig. 9. Perturbed response

Table 2: Performance comparison under perturbed conditions

Method	**Set point tracking**					**Disturbance Rejection**				
	$t_s(s)$	**IAE**	**ISE**	**ITAE**	**TV**	$t_s(s)$	**IAE**	**ISE**	**ITAE**	**TV**
Proposed	15.03	4.522	3.223	16.01	2.024	18.41	2.382	0.7885	134.5	1.28
Vijayan and Panda	25.71	4.539	3.175	21.02	3.420	40.5	3.504	0.7744	217.7	4.1184

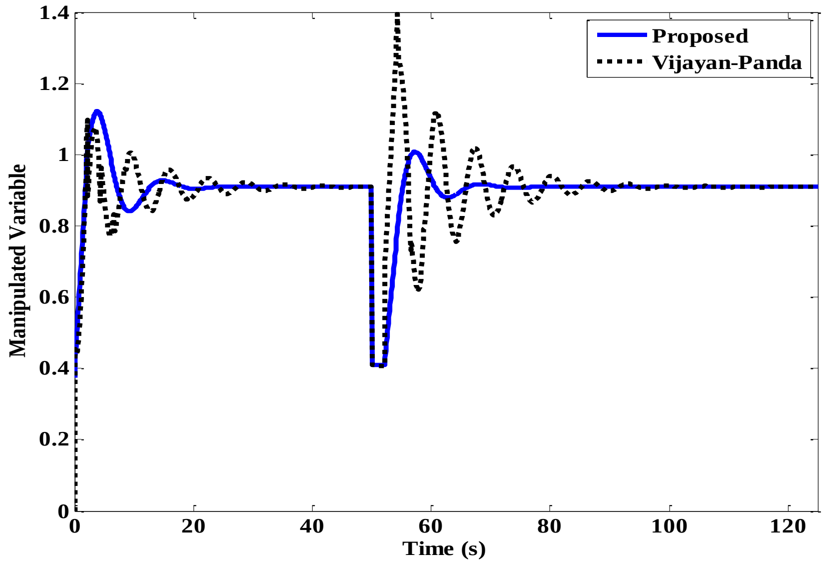

Fig. 10. Manipulated variable for perturbed response

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