Fuzzy modified Model Reference Adaptive Controller for improved transient response

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Abstract— **Liquid level control has been a basic control problem in almost all process industries. As the level process is nonlinear Model Reference Adaptive Controller is preferred to PID controllers in this paper. To improve the transient performance of the MRAC has been a point of research for a long time. The main objective of the paper is to design an MRAC with improved transient performance. The paper proposes a modification to the standard direct MRAC and the proposed controller is called Fuzzy modified MRAC (FMRAC) in the paper. The FMRAC uses a Mamdani-type Fuzzy inference system (MFIS) to improve the transient performance of a direct MRAC. In this study, an MRAC and an FMRAC are designed for a hybrid tank process and their transient performances are compared. The simulation results show the proposed controller gives better transient performance than the direct MRAC. It is concluded that that the proposed controller can be used to obtain very good transient performance during the control of nonlinear processes.**

Keywords- Model Reference Adaptive Controller; Coupled tank process; Fuzzy Inference System; Fuzzy modified Model Reference Adaptive Controller.

I. INTRODUCTION

Liquid level control has been a basic control problem in process industries such as petroleum and paper industries. Traditionally, PID controller has been used for this purpose. As PID controller parameters are tuned for a particular operating point and its neighborhood, the controller would give sub-optimal performance whenever the operating point is shifted out of the linearized region. As the level process is nonlinear [5] adaptive controllers are more suitable than PID controller. Model Reference Adaptive Controller (MRAC) has been used in the control of nonlinear processes [1], [2], [3], and [4]. In a Model Reference Adaptive System (MRAS) the output y of the process asymptotically converges with the output y_m of a reference model and then tracks it. The output y takes some time to converge with y_m. To improve the transient performance of the MRAC has been a point of research for a long time. A GA based modified MRAC has been used by [1] to obtain improved transient performance in controlling the level of a hybrid tank process.

Fuzzy logic provides a simple method to design nonlinear controllers based on heuristic approach [9]. It has been used in controlling of nonlinear processes such as surge tank level control [9], continuous stirred tank reactor [8], level process in steam generators [7] and force control in end-milling [6]. This paper proposes the application of a Mamdani-type Fuzzy Inference System (MFIS) to improve the transient performance of a direct MRAC. The proposed controller and a direct MRAC are designed and implemented to control liquid level in a coupled tank process in this study. The proposed controller is called Fuzzy modified MRAC (FMRAC) in this paper.

II. EXPERIMENTAL SETUP

Fig. 1 shows the schematic representation of a coupled tank system. The coupled tank system consists of two cylindrical tanks, inter connected by two coupling channels at different heights. Two variable-area valves are used to vary the interaction between the tanks. Water from a reservoir is pumped to tank1 through a control valve. F1 is the flow rate of the influent stream to tank1 and is measured by a turbine flow meter. Water from tank1 flows to tank2 through the coupling channels, and then it finally drains out. Level of water in tank2 (L2) is measured by a Differential Pressure Transmitter (DPT). The flow rate F1 and level L2 are acquired by a Data Acquisition Card NI USB 6008 in Lab VIEW environment. Command signal to open the control valve to vary F1 is given through the Lab VIEW program. The flow rate F1 is selected as the manipulated variable, and level L2 is the output or the controlled variable.

III. MODEL REFERENCE ADAPTIVE CONTROLLER

Fig. 2 shows the block diagram of an MRAC. This is an adaptive servo system in which the output y of the process need to follow the output y_m of the reference model. The adaptive mechanism either changes the parameters of the

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controller or modifies the controller output based on the error e which is given as

$$e = y - y_m \quad (1)$$

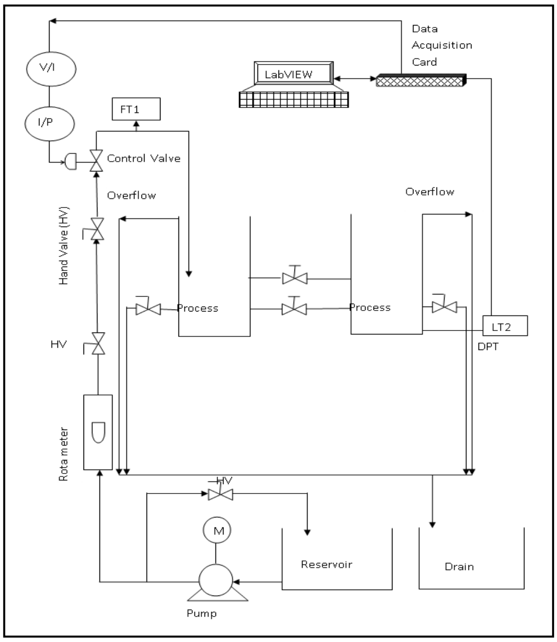

Fig. 1. Coupled tank setup

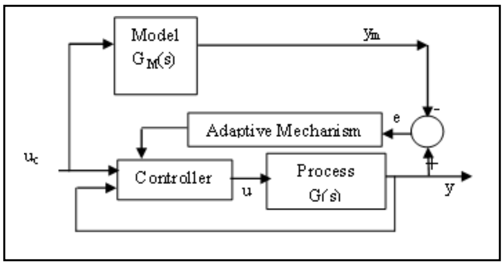

Fig. 2. Model Reference Adaptive Controller

An MRAC which uses the MIT rule is [1] designed and implemented as shown in Fig. 2. The process input u is modified by adaptively changing the controller parameters θ_1 and θ2. The controller output is given as

$$u = \theta_1 u_c - \theta_2 y \quad (2)$$

If the cost function *J(θ)* is taken as *1/2*(e^2)*, change in the value of controller parameters with respect to time as per the MIT rule is given in (3)

$$d\theta/dt = -\gamma\, \partial J/\partial\theta = -\gamma\, e\, \partial e/\partial\theta \quad (3)$$

where $\partial e/\partial\theta$ is the sensitivity derivative of the system, γ is the adaptation gain, e is the tracking error ($y-y_m$).

The speed of convergence depends on the value of the adaptation gain. If the adaptation gains are too small it takes a long time for the output y to converge with y_m. On the other hand, if they are too large the output y will oscillate. Hence, a trade-off is always required between the stability and the speed of convergence while selecting the value of γ. Very small values are assigned for γ_1 and γ_2 initially and then they are gradually increased so that y asymptotically converges with y_m in the shortest possible time.

In order to improve the transient performance a modification to the MRAC scheme is proposed in this paper. In the proposed controller, the controller output u is modified as shown in Fig. 3. Here, a Mamdani-type fuzzy inference system (MFIS) is also employed along with the MRAC and the resultant controller is called Fuzzy modified MRAC (FMRAC) in this paper.

IV. FUZZY INFERENCE SYSTEM

The MFIS used in the paper has the tracking error of the MRAC as its input and the defuzzified output of the MFIS is added with the controller output. Centroid defuzzification method is used. Table I shows the design parameters of the MFIS used in the study.

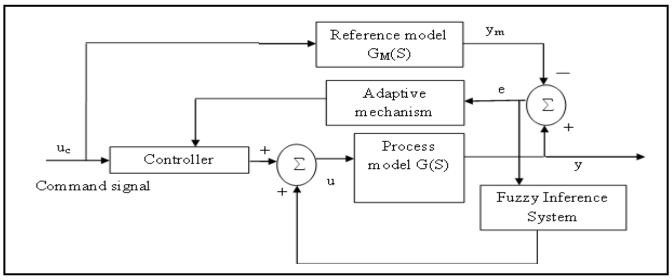

Fig. 3. Fuzzy modified MRAC

TABLE I DESIGN PARAMETERS OF THE MFIS

Variable	**Range**	**Fuzzy set**	**Membership function (MF)**	**Corner points of MF**
Input	[-10 10]	Large negative	Trapezoidal	[-14.5 -10 -2.5 -0.005]
		Small negative	Triangular	[-2.5 -0.005 0]
		Zero	Triangular	[-0.005 0 0.005]
		Small positive	Triangular	[0 0.005 2.5]
		Large positive	Trapezoidal	[0.005 2.5 10 14.5]
Output	[-200 200]	Negative high	Trapezoidal	[-290 -206.7 -150 -120]
		Negative medium	Trapezoidal	[-150 -120 -19.98 0]
		Zero	Triangular	[-19.98 0 20.02]
		Positive medium	Trapezoidal	[0 20.02 120 150]
		Positive high	Trapezoidal	[120 150 200 290]

V. RESULTS AND DISCUSSION

The transfer function of the coupled tank process, $G(s) = 0.1816 / (30000s^2 + 700s + 1)$, and of the reference model, $G_M(s) = 0.1 / (40000s^2 + 400s + 1)$, are taken from [1]. The time constants in these transfer functions have been scaled by a factor of 50 in [1]. The operating region of the coupled tank process is from 18.5 cm to 41 cm with the corresponding influent flow rate ranging from 615 liters per hour (lph) to 740 lph. The maximum value of F1 is 880 lph. This control element constraint is incorporated in the simulation experiments. In this paper, zero level represents 30 cm and zero influent flow represents 677 lph and, from this point onwards all the values of F1 and L2 are given in relative values.

Fig. 4 shows the step responses of the MRAC and the FMRAC for a step input of 40 to the command signal. The output of the FMRAC converges with the reference signal right from the beginning whereas the output of the MRAC takes a long time to do so. The settling times (T_S) of the responses of the MRAC and the FMRAC are 3.7222e4 seconds and 2.1431e3 seconds respectively. Fig. 5 shows the process inputs during the experiment and they remain well within the bounds. The controller output of the MRAC gradually increases towards the final value whereas in the case of FMRAC it reaches the final value quicker after some initial oscillations. Once the output y of the process has converged with the output y_m of the reference model, the process inputs also remain constant at the final value. This shows that the FMRAC does not overly affect the final control element i.e. the control valve.

In order to test the robustness of the FMRAC different types of command signals and reference model are applied and the performances are compared below. Fig. 6 shows the responses of the two controllers to a sinusoidal input of amplitude 40. The time period of the sinusoidal input is 10000 seconds. Only after seven cycles does the output of the MRAC converge with y_m. But the output of the FMRAC closely follows y_m right from the beginning. Fig. 7 shows the process inputs for this experiment.

Fig. 8 shows the step responses of the two controllers for a step input of 70 to the command signal. Even for a large change in the command signal the output of the FMRAC closely follows y_m and the controller output remain well within the bounds as shown in Fig. 9. Fig. 10 and Fig. 11 show the step responses and process inputs of the two controllers respectively when the reference model is $G_{M1}(S) = 0.2 / (35000S^2 + 500S + 1)$. The results shows that the proposed controller performs very well even in the case where the reference model parameters are very different from that of process model parameters.

Table II shows the performance criteria calculated for the two controllers. The rise time (T_R) is the time the response y takes to rise from 10% to 90% of the steady-state value and T_S is the time y takes to reach within ± 5% of the steady-state value and stay within that range. The FMRAC has reduced values of T_R and T_S when compared to the values of MRAC. The value of mean square error (MSE) in the case of FMRAC is far less than that of MRAC. Thus it can be said that the proposed FMRAC has met the objective of improved transient performance.

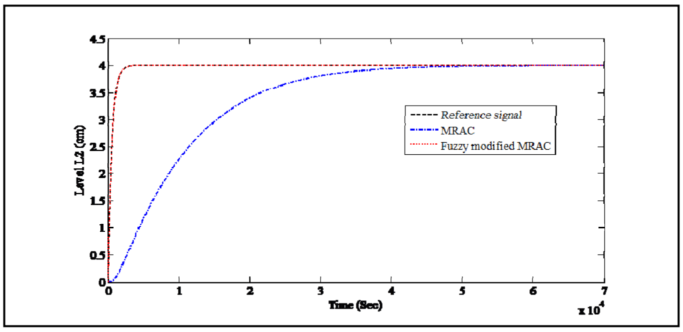

Fig. 4. Step responses of MRAC and Fuzzy modified MRAC

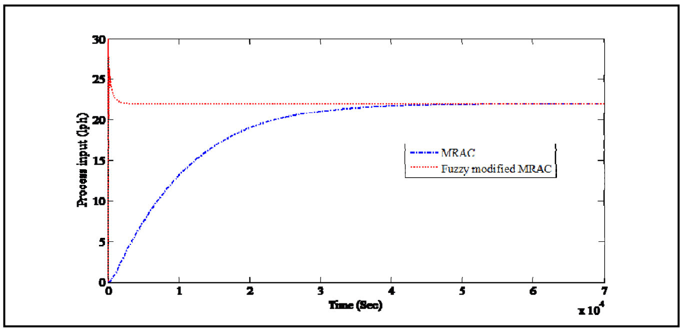

Fig. 5. Process inputs for a step input of 40 to the command signal

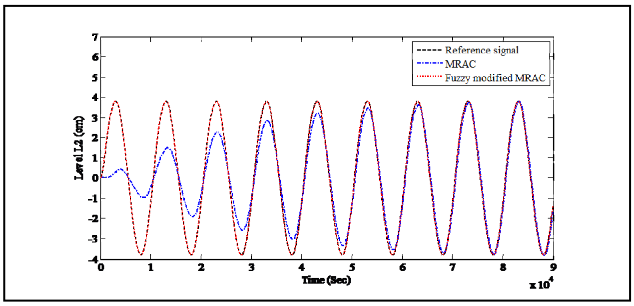

Fig. 6. Responses of the two controllers to a sinusoidal command signal

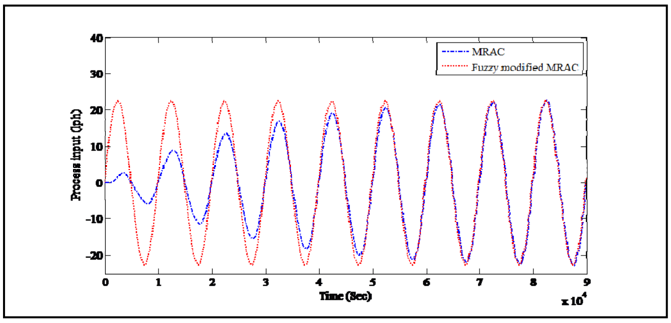

Fig. 7. Process inputs for a sinusoidal input of 40 to the command signal

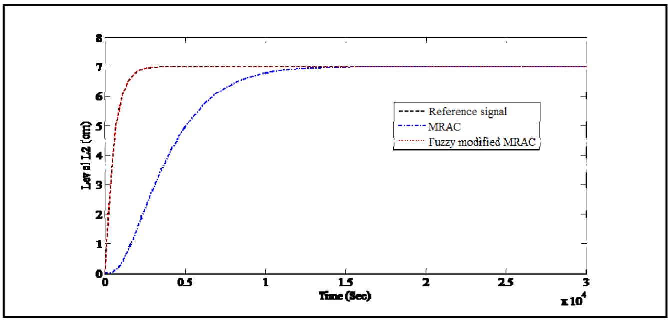

Fig. 8. Responses of the two controllers to a step input of 70 to the command signal

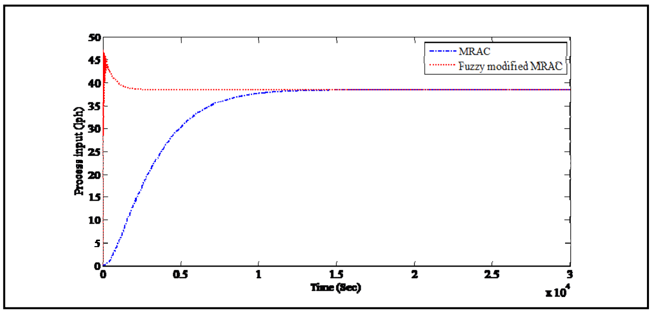

Fig. 9. Process inputs for a step input of 70 to the command signal

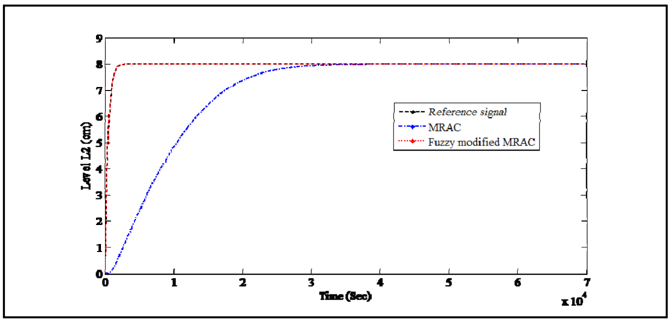

Fig. 10. Step responses of the two controllers when $G_{MI}(S)$ is used as the reference model

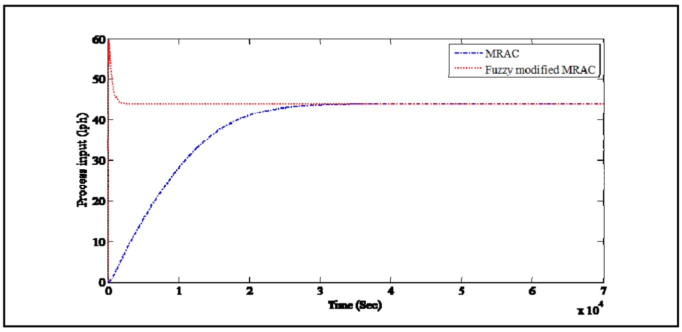

Fig. 11. Process inputs for a step input of 40 to the command signal when $G_{MI}(S)$ is used as the reference model

TABLE II COMPARISON OF STEP RESPONSES OF THE MRAC AND THE FUZZY MODIFIED MRAC FOR A STEP SIZE OF 70

Performance index	**Reference model**	**MRAC**	**Fuzzy modified MRAC**
T_R (Sec)	1178.8	6187.3	1178.8
T_S (Sec)	2143.1	10898	2143.2
MSE	-	3.0625	4.2765e-7

From the analysis of the results it can be said that the proposed FMRAC gives improved transient performance for any type of command signal. It performs very well even in the case where the reference model parameters are very different from the process model parameters.

VI. CONCLUSION

The proposed modification to the MRAC has resulted in an improved transient performance when compared to MRAC. The simulation results shows that the proposed FMRAC performs better than MRAC as far as T_R, T_S and MSE are concerned. The proposed FMRAC have performed very well even when the reference model parameters are quite different from the process model parameters. The FMRAC has performed very well for step as well as sinusoidal command signals. Hence, it is concluded that the proposed FMRAC can be used to obtain improved transient performance in the control of nonlinear processes.

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