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Robust Model Reference Adaptive Control For Liquid Level Control In Process Industry

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ABSTRACT: Control of liquid level in any process industries plays vital role for smooth operation of entire production the pant. Liquid level control is important control strategy in process industries. The conventional PID controller (Proportional-Integral-Derivative controller) is generally used in process industries for level control. In this paper, Model Reference Adaptive Control (MRAC) Mechanism for cylindrical tank interacting having external disturbances (noise) is applied and robust nature of MRAC is discussed via Matlab/Simulink. Robust MRAC gives better transient performance and stability of the plant and the results are compared for varying adaptation mechanisms due to variation in adaptation gain and result is compared for different value of adaption gain in presence of noise and without noise and its show that system is stable.

Keywords: Adaptive Control, MRAC (Model Reference Adaptive Controller), Adaptation Gain, MIT rule, Level control, Noise, Robust, Disturbances.

I. INTRODUCTION.

Traditional non-adaptive controllers are good for industrial applications, PID controllers are cheap and easy for implementation. Nonlinear process is difficult to control with fixed parameter controller. Adaptive controller is best tool to improve the control performance of parameter varying system

In process industries level control and flow control play vital role for smooth operation. Conical tank is generally used in process industries. Conical tanks are highly non liner in nature hence level and flow control may be difficult. Conical tank flow and level control is widely used in chemical industries, food industries, petroleum industries [4]. Control of liquid level in tanks and their flow between the tanks are a basic problem in process industries. In process industries liquid to be pumped and stored in different tanks. Each tank having their own process but objective is to control the level and flow between the tanks. Majority of control theory has been discussed for liner system. In case of non liner time invariant system controller parameter needs to be adjusted [5]. Real time model prediction having many challenging due to non liner behavior of process industries. Due to non liner nature of conical tank, design of controller is challenging to achieve better performance [2].

Adaptive controller is a technique of applying some system identification to obtain a model and hence to design a controller. Parameter of controller is adjusted to obtained desired output [6]. Model reference adaptive controller has been developed to control the nonlinear system. MRAC forcing the plant to follow the reference model irrespective of plant parameter variations. i.e decrease the error between reference model and plant to zero[9]. MRAC implemented in feedback loop to improve the performance of the system [7].

Robustness in Model reference adaptive Scheme is established for bounded disturbance and unmodeled dynamics. Adaptive controller without having robustness property may go unstable in the presence of bounded disturbance and unmodeled dynamics[16].

In this paper adaptive controller for interacting system using MIT rule in the presence of first order and second order bounded disturbance and unmodeled dynamics has been discussed first and then simulated for different value of adaptation gain in MATLAB and accordingly performance analysis is discussed for MIT rule for second order system in the presence of bounded disturbance and unmodeled dynamics .

II. MODEL REFERENCE ADAPTIVE CONTROL

Model reference adaptive controller is shown in Fig. 1. The basic principle of this adaptive controller is to build a reference model that specifies the desired output of the controller, and then the adaptation law adjusts the unknown parameters of the plant so that the tracking error converges to zero [6]

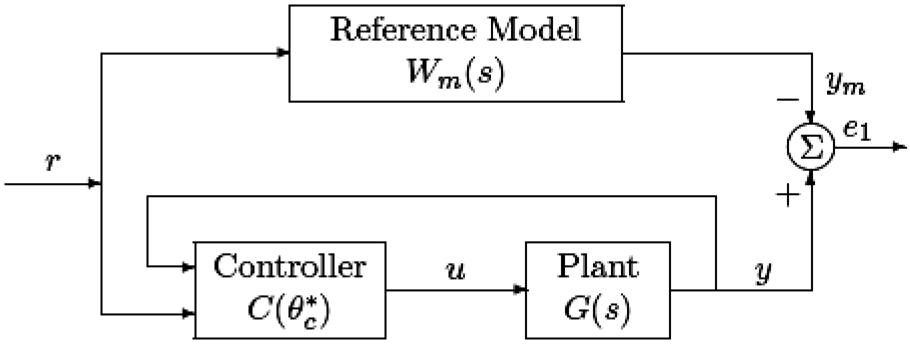

Figure. 1

III. MATHEMATICAL MODELING FOR MODEL REFERENCE ADAPTIVE CONTROL FOR TWO TANK INTERCATING SYSTEM.

Consider the process consisting of two interacting liquid tanks in the Fig.2. The volumetric flow into tank1 is qin(cm3 /min), the volumetric flow rate from tank1 to tank2 is q1(cm3 /min), and the volumetric flow rate from tank2 is qo(cm3 /min). The height of the liquid level is h1(cm) in tank1 and h2 in tank2(cm). Both tanks have the same cross sectional area denotes the area of tank1 is A1(cm2) and area of tank2 is A2(cm2), qL1 is the inflow of tank1 as load disturbance(cm3 /min) and qL2 is the inflow of tank2 as load disturbance(cm3 /min) [2], [3]

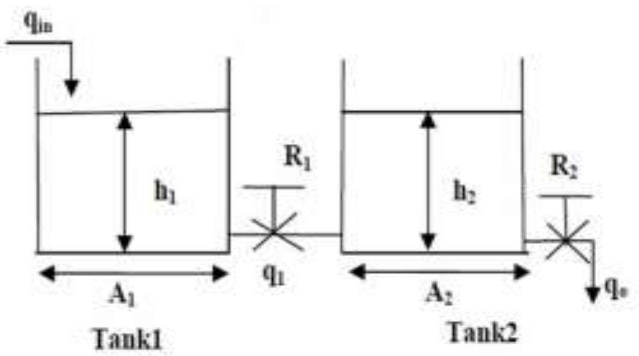

Figure 2. Interacting system

Based on mass balancing equation Laplace transformation, transfer function of two tank interacting system is expressed as

$$\frac{h_2(s)}{q_{in}(s)} = \frac{R_2}{\tau_1\tau_2 s^2 + s(\tau_1 + A_1R_2 + \tau_2) + 1}$$

Where, $\tau_1 = A_1 R_1$ and $\tau_2 = A_2 R_2$

Based on the analysis, following transfer function of interacting system is considered for study of performance analysis in presence of first order and second order bounded disturbance and unmodeled dynamics

$$G(s) = 7.865/(s^2 + 10.235s + 7.865)$$

IV. MIT RULE

There are different methods for designing such controller. While designing an MRAC using the MIT rule, the designer selects the reference model, the controller structure and the tuning gains for the adjustment mechanism. MRAC begins by defining the tracking error, e. This is simply the difference between the plant output and the reference model output:

system model e=y(p) −y(m) (1)

The cost function or loss function is defined as
F (θ) = e^2 / 2 (2)

$$J(\theta) = \frac{1}{2} e^2(\theta) \quad (3)$$

$$\frac{d\theta}{dt} = -\gamma \frac{\delta J}{\delta \theta} = -\gamma e \frac{\delta e}{\delta \theta} \quad (4)$$

– Change in γ is proportional to negative gradient of J

$$J(\theta) = |e(\theta)|$$

$$\frac{d\theta}{dt} = -\gamma \frac{\delta e}{\delta \theta} sign(e) \quad (5)$$

$$\text{where} \quad sign(e) = \begin{cases} 1, & e > 0 \\ 0, & e = 0 \\ -1, & e < 0 \end{cases}$$

From cost function and MIT rule, control law can be designed.

The parameter θ is adjusted in such a way that the loss function is minimized. Therefore, it is reasonable to change the parameter in the direction of the negative gradient of F, i.e

V. MATHEMATICAL MODELLING IN PRESENCE OF BOUNDED AND UNMODELED DYNAMICS.

Model Reference Adaptive Control Scheme is applied to a second order system using MIT rule has been discussed [3] [4]. It is a well known fact that an under damped second order system is oscillatory in nature. If oscillations are not decaying in a limited time period, they may cause system instability. So, for stable operation, maximum overshoot must be as low as possible (ideally zero).

In this section mathematical modeling of model reference adaptive control (MRAC) scheme for MIT rule in presence of first order and second order noise has been discussed

Considering a Plant: $\ddot{y}_p$ = -a$\dot{y}_p$ - by + bu (6)

Consider the first order disturbance is $\dot{y}_d$= -$y_d k$ + $u_d k$

Where y_p is the output of plant (second order under damped system) and u is the controller output or manipulated variable.

Similarly the reference model is described by:

$\ddot{y}_m$ = -$a_m \dot{y}_m$ - b_my + b_mr (7)

Where y_m is the output of reference model (second order critically damped system) and r is the reference input (unit step input).

Let the controller be described by the law:

$$u = \theta_1 r - \theta_2 y_p \qquad (8)$$

(9)

$$e = y_p - y_m = G_p G_d u - G_m r$$

$$y_p = G_p G_d u = \left(\frac{b}{s^2 + as + b}\right)\left(\frac{k}{s+k}\right)(\theta_1 r - \theta_2 y_p)$$

$$y_p = \frac{bk\theta_1}{(s^2 + as + b)(s+k) + bk\theta_2} r$$

Where G_d = Noise or disturbances.

$$e = \frac{bk\theta_1}{(s^2 + as + b)(s+k) + bk\theta_2} r - G_m r$$

$$\frac{\partial e}{\partial \theta_1} = \frac{bk}{(s^2 + as + b)(s+k) + bk\theta_2} r$$

$$\frac{\partial e}{\partial \theta_2} = -\frac{b^2 k^2 \theta_1}{[(s^2 + as + b)(s+k) + bk\theta_2]^2} r$$

$$= -\frac{bk}{(s^2 + as + b)(s+k) + bk\theta_2} y_p$$

If reference model is close to plant, can approximate:

$$(s^2 + as + b)(s+k) + bk\theta_2 \approx s^2 + a_m s + b_m$$

$$(10) \quad bk \approx b$$

$$(11) \quad \frac{\partial e}{\partial \theta_1} = b/b_m \frac{b_m}{s^2 + a_m s + b_m} u_c$$

$$\frac{\partial e}{\partial \theta_2} = -b/b_m \frac{b_m}{s^2 + a_m s + b_m} y_{plant}$$

Controller parameter are chosen as $\theta_1 = b_m/b$ and $\theta_2 = (b - b_m)/b$

Using MIT

$$\frac{d\theta_1}{dt} = -\gamma \frac{\partial e}{\partial \theta_1} e = -\gamma\left(\frac{b_m}{s^2 + a_m s + b_m} u_c\right) e \qquad (12)$$

$$\frac{d\theta_2}{dt} = -\gamma \frac{\partial e}{\partial \theta_2} e = \gamma\left(\frac{b_m}{s^2 + a_m s + b_m} y_{plant}\right) e \qquad (13)$$

Where $\gamma = \gamma' \times b/b_m$ = Adaption gain

Considering a =10.235, b = 7.864 and a_m =10.235 , b_m = 393.514

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VI. SIMULATION RESULTS FOR MIT RULE WITHOUT BOUNDED DISTURBANCE AND UNMODELED DYNAMICS.

To analyze the behavior of the adaptive control the designed model has been simulated in Matlab-Simulink.
The simulated result for different value of adaptation gain for MIT rule is given below:

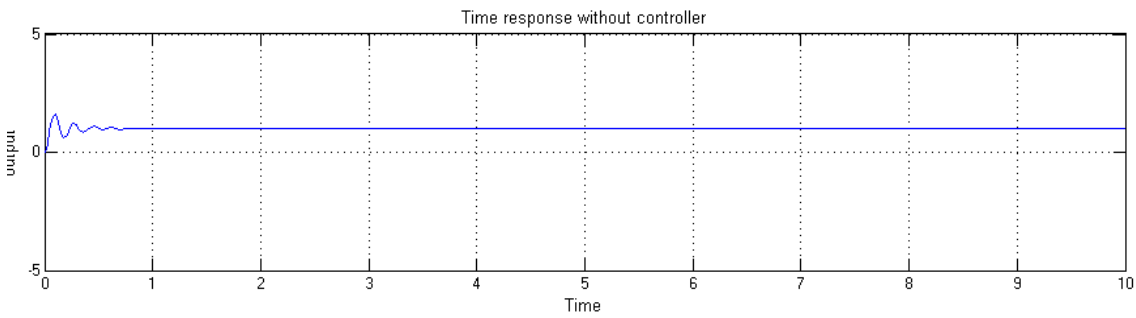

Figure- 3

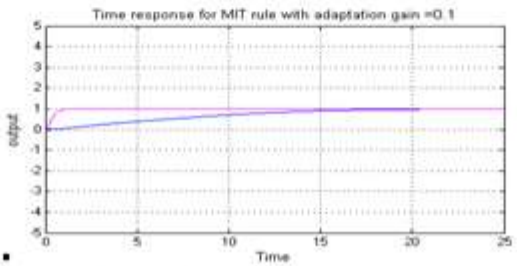

Figure-4

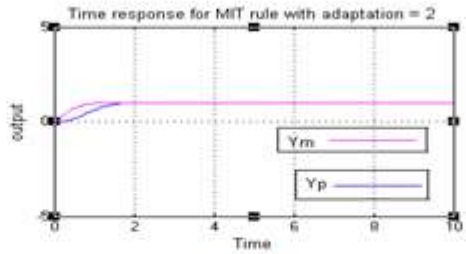

Figure 5

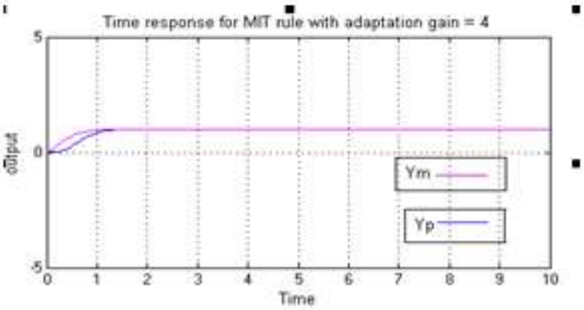

Figure 6

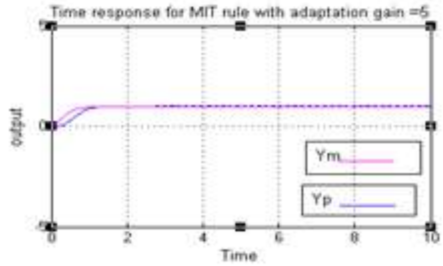

Figure 7

The time response characteristics for the plant and the reference model are studied. It is observed that the characteristic of the plant(tank) is oscillatory with overshoot and undershoot whereas the characteristic of the reference model having no oscillation. Dynamic error between these reduced to zero by using model reference adaptive control technique.

Results with different value of adaptation gain for MIT rule is summarized below:

	Without any controller	With MRAC			
		γ =0.1	γ =2	γ =4	γ =5
Maximum Overshoot (%)	65%	0	0	0	0

Undershoot (%)	47%	0	0	0	0
Settling Time (second)	1.7	25	2.5	2.35	2.25

Without controller the performance of the system is very poor and also having high value of undershoot and overshoot(fig.3). MIT rule reduces the overshoot and undershoot to zero and also improves the system performance by changing the adaptation gain. System performance is good and stable (fig. 4, fig. 5, fig. 6 & fig. 7) in chosen range (0.1< γ <5).

VII. MIT RULE IN PRESENT OF BOUNDED DISTRUBANCE AND UNMODELED DYNAMICS:

Consider the first order disturbance:

$$G_d = \frac{1}{s+1}$$

Time response for different value of adaption gain for MIT rule in presence of first order disturbance is given below:

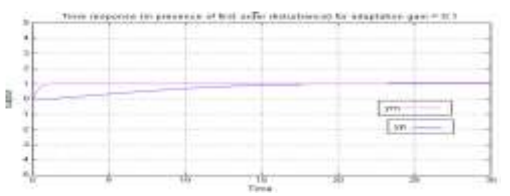

Figure 8

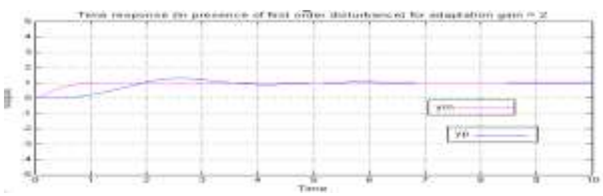

Figure 9

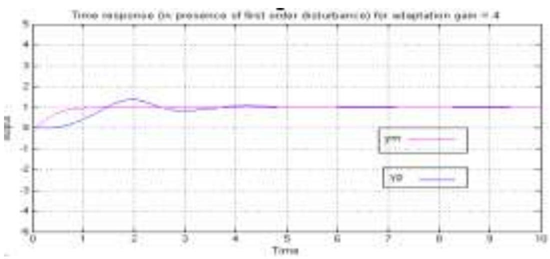

Figure 10

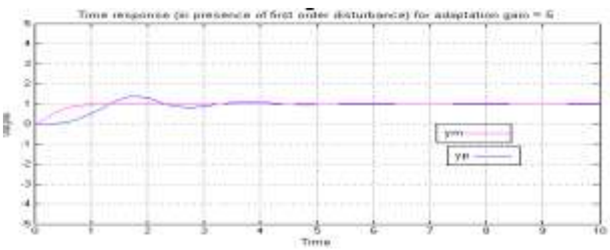

Figure 11

Simulation results with different value of adaptation gain for MIT rule in presence of first order bounded and unmodeled dynamics is summarized below:

	Without any controller	In presence of first order bounded and unmodeled dynamics			
		γ =0.1	γ =2	γ =4	γ =5
Maximum Overshoot (%)	65%	0	25%	28%	32%
Undershoot (%)	47%	0	13%	15%	21%
Settling Time (second)	1.7	26	7	5	3

In the presence of first order disturbance, if the adaptation gain increases the overshoot and undershoot increases, but the settling time decreases. This overshoot and undershoot are due to the first order bounded and unmodeled dynamics. It shows that even in the presence of first order bounded and unmodeled dynamics, system is stable.

Consider the second order disturbance:

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$$G_d = \frac{25}{s^2 + 30s + 25}$$

Time response for different value of adaption gain for MIT rule in presence of first order disturbance is given below:

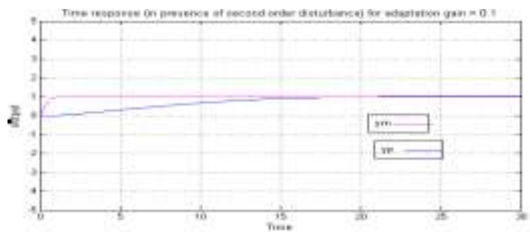

Figure 12

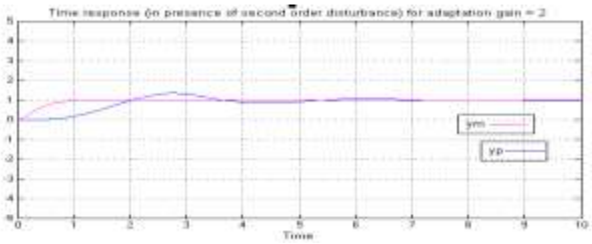

Figure 13

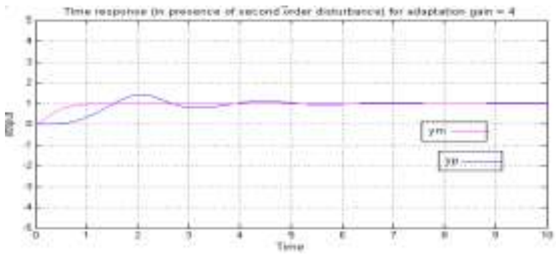

Figure 14

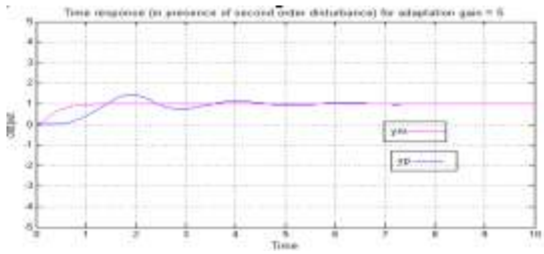

Figure 15

Simulation results with different value of adaptation gain for MIT rule in presence of second order bounded and unmodeled dynamics is summarized below:

	Without any controller	In presence of second order bounded and unmodeled dynamics			
		γ =0.1	γ =2	γ =4	γ =5
Maximum Overshoot (%)	65%	0	30%	35%	40%
Undershoot (%)	47%	0	11%	13%	20%
Settling Time (second)	1.7	30	10	7	5

In the presence of second order disturbance, if the adaptation gain increases the overshoot and undershoot increases, but the settling time decreases. This overshoot and undershoot are due to the second order bounded and unmodeled dynamics. It shows that even in the presence of second order bounded and unmodeled dynamics, system is stable.

VIII. CONCLUSION:

Adaptive controllers are very effective where parameters are varying. The controller parameters are adjusted to give desired result. This paper describes the MRAC by using MIT rule in the presence of first order & second order bounded and unmodeled dynamics for control of level of liquid in the interacting tank. Time response is studied in the presence of first order & second order bounded and unmodeled dynamics using MIT rule with varying adaptation gain. It has been observed that, disturbance added in the conventional MRAC has some oscillations at the peak of signal, hence these disturbances can be considered as a random noise. These oscillations reduce with the increase in adaptation time. These overshoots and undershoots are due to the presence of bounded and unmodeled dynamics or noise. It can be concluded that even in the presence of bounded and unmodeled dynamics, system performance of is stable.

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