Performance Analysis of Hopper tank Process using Model Reference Adaptive Control

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Abstract

Adaptive controllers are becoming increasingly common for closed-loop control applications in industry, particularly in chemical processes. Changes in the dynamics of the process and disturbances might cause an adaptive controller to change its behaviour. Model Reference Adaptive control (MRAC) is a direct adaptive approach with some configurable controller settings and a way to adjust them. The most important aspect of MRAC is that it only requires one parameter, adaptation gain, and controller tuning varies according to the well-known MIT-rule based on its selection. As a result, adaptive control is a frequently utilised control strategy for developing advanced control systems with improved performance and accuracy. The purpose of this study is to construct an adaptive controller for a hopper tank system utilising the MRAC scheme and the Modified MIT rule. Simulations using MATLAB and Simulink are used to assess and demonstrate the performance of the suggested control algorithms.

Keywords

Model-based adaptive control system, FOPDT process, Hopper tank system, MIT Rule, Adaptive controllers, Non-linear process, Integral error

Introduction

A control system that governs or controls the behaviour of another plant or process. One of the most extensively utilised control strategies for designing sophisticated control systems for higher performance and accuracy is adaptive control [5]. Adaptive controllers are much more successful at dealing with unknown parameter variations and environmental changes than the well-known and easy structured fixed gain PID controllers. The outer loop, or regular feedback loop, and the inner loop, or parameter adjustment loop, make up an adaptive controller [6]. The disparity between model response and real process output is defined as error in MRAC design, and our major goal is to use the Modified MIT-rule to minimise the cost function (expressed as squared error). In this case, we propose that the reference model be FOPTD in nature. The time constant (τ) and dead time (θ) values chosen should be 10% of the real process model and the related process gain is considered to be unity [4]

Hopper Tank System

A Hopper Tank is a non-linear process that consists of a cylindrical component positioned on top of a conical component. The cylinder and conical parts have the same height, hence the name "Hopper"[1]. The principle of superposition does not apply to this tank since its structure is non-linear. This type of tank is essential for enterprises with huge amounts of input feed and high sludge material evacuation at the output. This tank is used by many pharmaceutical, petrochemical, and food processing industries since routine cleaning is required. As a result, it saves energy and money on material handling [3].

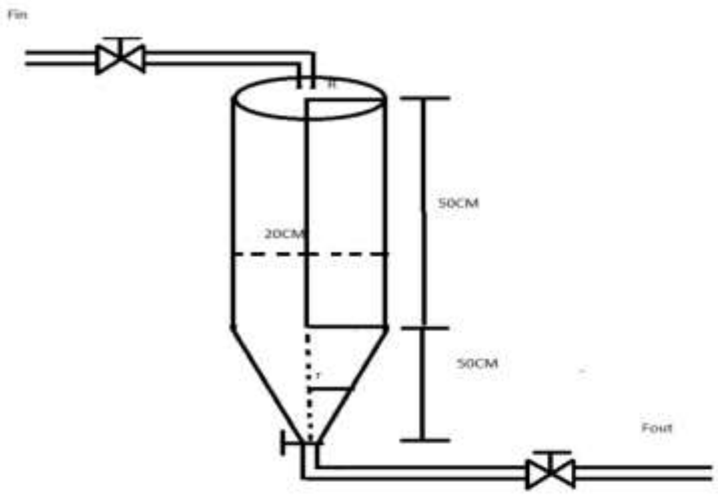

Figure1: Hopper tank system

The tank's specifications are as follows: The tank's overall height is 100 cm. height H. R is the radius of the top of the cone and R is the radius of the cylinder. The cylinder's diameter is 20cm. The radius of a cone that can change is called r. F_{in} and F_{out} are inflow, outflow rates the flow rate. The co-efficient of a valve is β. Area A, Volume V. [1]

The process Mass-Balance equation is given as based on the parameters,

$$\frac{dv}{dt} = F_{in} - F_{out} \quad \text{---------------------(1)}$$

$$A\frac{dv}{dt} = F_{in} - \beta\sqrt{h} \quad \text{---------------------(2)}$$

The generic equation for a First Order Process with Dead Time is as follows:

$$G_p(s)= \frac{h(s)}{Fin} = \frac{kp\, e^{-\theta s}}{\tau s+1} \quad \text{---------------(3)}$$

FOPDT Transfer function models at various levels can be obtained by solving the above two equations and substituting the process parameters. The first-level transfer function is as follows:

$$G_p(s) = \frac{h(s)}{Fin} = \frac{2.7\, e^{-0.15s}}{0.75s+1} \text{------(4)}$$

Inflow %	Range (cm^3/sec)	Level Range (cm)	k	τ	θ
40	I region	0-15	2.70	0.75	0.15
60	II region	15-30	0.68	1.50	0.70
80	III region	30-40	0.18	0.78	0.22
100	IV region	40-50	0.09	0.30	0.30

Table 1: model parameters for different operating region

Model Reference Adaptive Control

Model Reference adaptive controller is designed using the adaptive control approach, which operates on the idea of modifying the controller settings so that the actual plant output matches the output of a reference model with the same reference input. To create the adjusting mechanism, mathematical methodologies such as the MIT rule, Lyapunov theory, and theory of augmented error can be used [6]. This component is used to change the controller's parameters so that the actual plant can follow the reference model. In this study, we combine the MIT rule with the Normalized Algorithm, resulting in the Modified MIT rule. There are two major groups of reported adaptation schemes: direct and indirect. In the case of indirect adaptation, the process model is identified live, as well as the controller parameter is optimised. For direct adaptation, on the other hand, the controller parameter is fine-tuned based on online minimization of a predefined cost function.

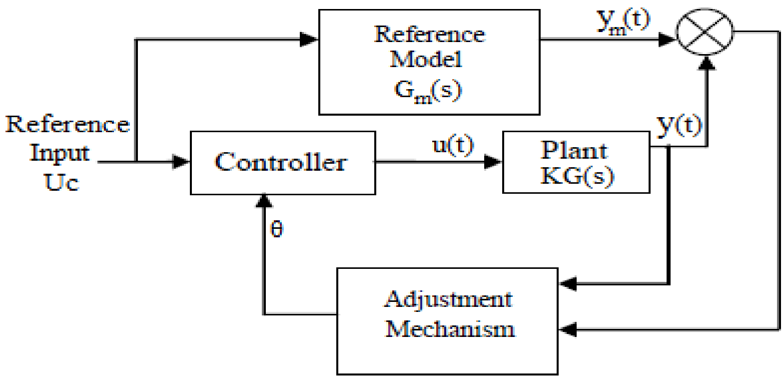

Figure 2: Block diagram of conventional MRAC

An additional loop with basic feedback structure is included in fig.2. This extra loop is in charge of adjusting the controller tuning parameter. The adaptive feature can effectively regulate the shortcomings of the conventional controller (with fixed gain) in the presence of plant uncertainty and big disturbances. As indicated in Figure 2, ym(t) is the output of the reference model, while y(t) is the output of the actual plant, with error e denoting the difference between them (t) [6].

$$e(t) = y(t) - ym(t) \text{-----------(5)}$$

mit rule

The MIT rule was first devised in 1960 by Massachusetts Institute of Technology (MIT) researchers [6], and it may be used to design a controller for any system using the MRAC scheme. A cost function is defined as follows in this rule:

$J(\theta) = \frac{e^2}{2}$ ----------------------------(6)

(θ) is adjustable parameter and its adjusted so that the cost function is minimized to zero. Then

$$\frac{d\theta}{dt} = -\gamma \frac{\partial j}{\partial \theta} \text{ -------------------- ----(7)}$$

Equ(7) depicts the change in the parameter as a function of time, allowing the cost function $J(\theta)$ to be decreased to zero. The equation (6),

$\frac{d\theta}{dt} = -\gamma e \frac{\partial e}{\partial \theta}$ ----------------------(8)

$\frac{\partial e}{\partial \theta}$ shows how the error changes as a function of the parameter. The law's control is described as follows:

$$u(t) = \theta * u_c \text{ ------------------- ----(9)}$$

$$\frac{d\theta}{dt} = -\gamma e y_m \text{ ---------------------(10)}$$

Equ (10) give us the law for adjusting the parameter θ

Normalized Algorithm

The MIT rule-based controller produces satisfactory results, but it is extremely sensitive to variations in the amplitude of the reference input. The system may become unstable if the reference input is huge. To solve this problem, the control law is developed using the Normalized algorithm and the MIT rule. [6]

The adaption law is modified in the following way by the normalised algorithm.

$$\frac{d\theta}{dt} = \frac{-\gamma e \varphi}{\alpha + \varphi' \varphi} \text{---------------------(11)}$$

Where, $\varphi = \frac{\partial e}{\partial \theta}$ and α ($\alpha > 0$) is introduced to remove the difficulty of zero division when φ is small.

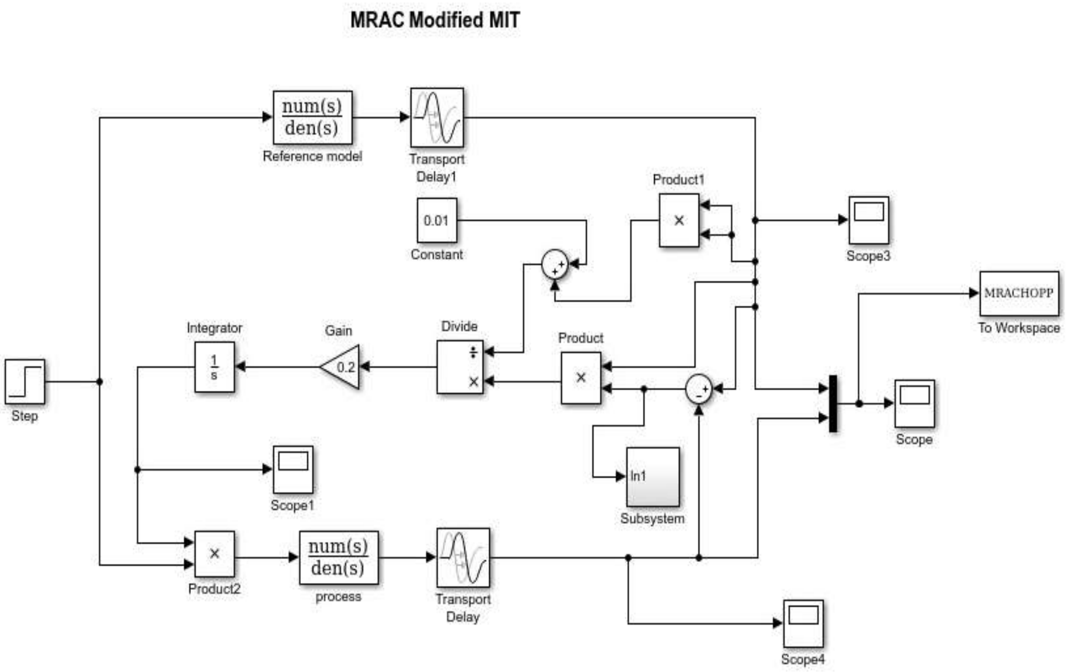

Figure.4: Simulink diagram of MRAC with modified MIT rule for FOPDT

Results

Adaptation gain	Basic MIT				Normalized MIT			
	ISE	IAE	ISTE	IATE	ISE	IAE	ISTE	IATE
0.1	2.27	3.98	8.11	18.27	1.62	3.28	5.46	14.55
0.2	1.33	2.28	3.68	7.29	0.74	1.59	1.84	4.64
0.3	1.01	1.904	2.58	5.91	0.486	1.24	1.10	3.67
0.4	0.85	1.73	2.10	5.48	0.37	1.11	0.83	3.44
0.5	0.75	1.64	1.84	5.32	0.32	1.07	0.73	3.44

Table 2. Comparison of Error criterion for the different values of "γ"(Adaptation gain).

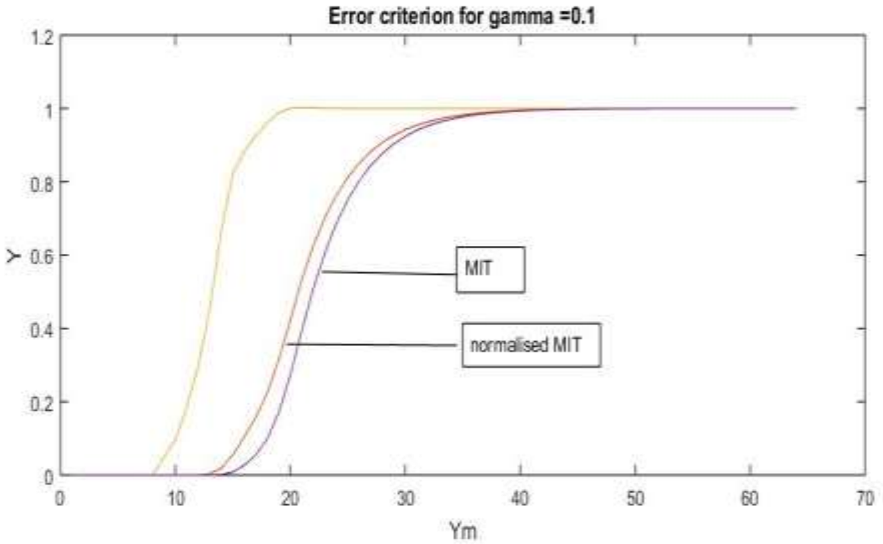

Figure.5. Comparison of error criterion between MIT and Normalized MIT " γ"= 0.1

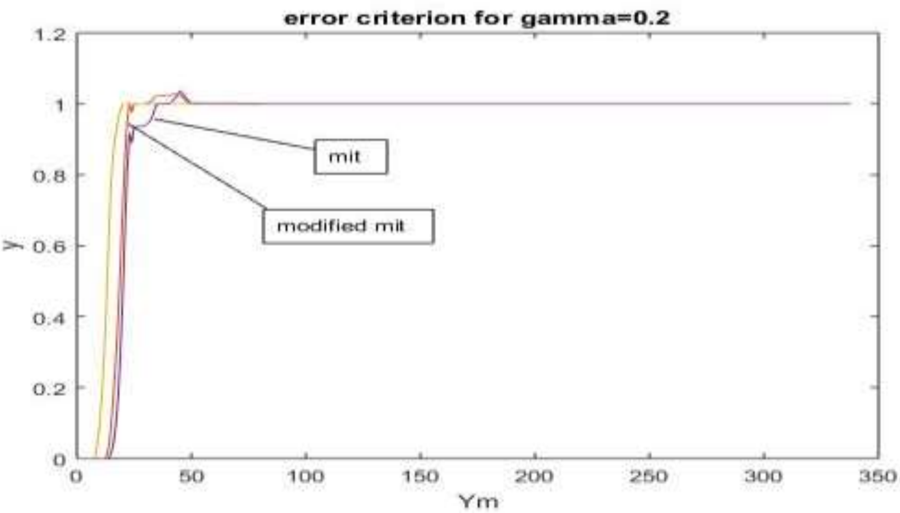

Figure.6. Comparison of error criterion between MIT and Normalized MIT " γ"= 0.2

Servo Response

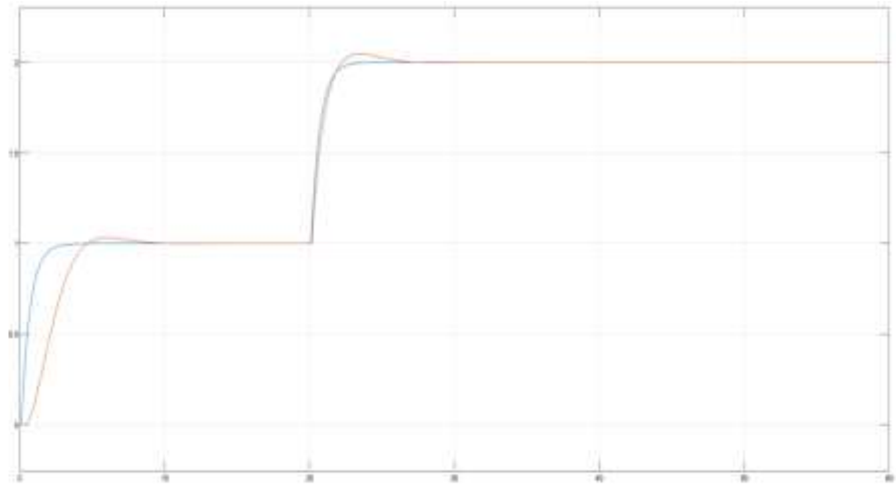

Figure.7. Servo Response of the system set-point change is given at 20 (time secs)

Regulatory Response

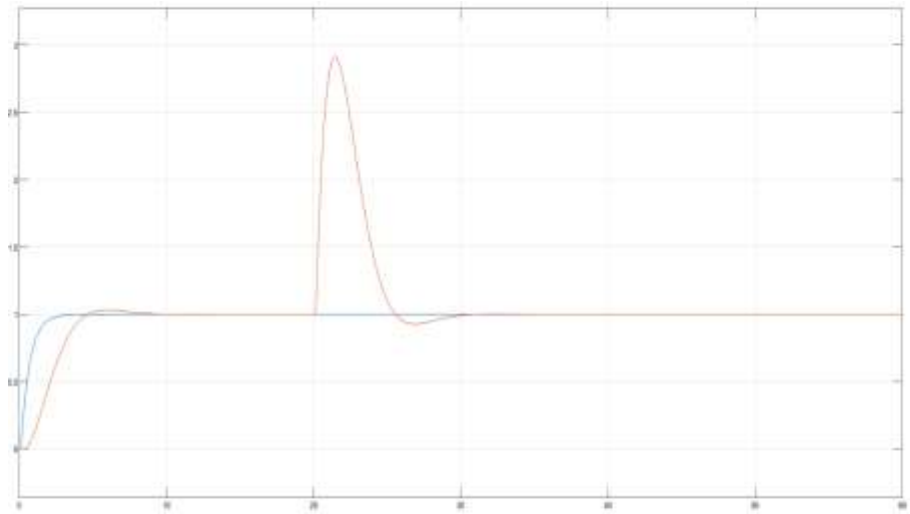

Figure.8.Regulatory Response of the system load disturbance is given at 20 (time secs)

Comparison of integral error criterion for set-point (SP) change and Load Disturbance (LD) of different operating region are shown in table 3.

Process	Reference model	ISE		IAE		ITSE		ITAE	
		SP	LD	SP	LD	SP	LD	SP	LD
$\frac{2.7\,e^{-0.15s}}{0.75s+1}$	$\frac{2.1\,e^{-0.11s}}{0.55s+1}$	2.76	28.3	4.07	20.6	6.34	406	21.3	312
$\frac{0.68\,e^{-0.70s}}{1.5s+1}$	$\frac{0.50\,e^{-0.50s}}{1.1s+1}$	0.53	1.56	2.45	4.91	2.37	27.4	22.04	84.83
$\frac{0.18\,e^{-0.22s}}{0.78s+1}$	$\frac{0.10\,e^{-0.14s}}{0.60s+1}$	0.03	0.12	0.61	1.59	0.11	2.36	4.07	28.11
$\frac{0.09\,e^{-0.30s}}{0.30s+1}$	$\frac{0.07\,e^{-0.10s}}{0.25s+1}$	0.03	0.06	0.83	1.60	0.21	1.19	8.89	37.8

Table 3: Comparison of integral error criterion for set-point (SP) change and Load Disturbance (LD) of different operating region

Time Domain Specifications

Comparison of time domain specifications for set-point change and Load Disturbance

Conditions		Rise time	Settling time	overshoot	peak	Peak time
Set point change	$\frac{0.68\,e^{-0.70s}}{1.5s+1}$	0.5714	6.9500	250	7	1
Load Disturbance		0.5964	7.204	325	7	1

Table 4: Time Domain Specifications

full overview of the MRAC scheme employing the MIT rule, as well as performance evaluations using SIMULINK simulations are shown in results. Table 1 compares the results of the MIT system for various adaption gain values. Table 2 compares error criterian and the same error criterion for servo, regulatory operitons are compared in table 3 and table 4 gives details about time domain specifications.The MIT rule is used in a variety of situations in this paper. The choice of adaption gain is critical and is influenced by signal levels. As a result, the MIT rule with normalisation may make the plant follow the model as closely as feasible for suitable amounts of adaptation gain, as illustrated in this study.

Conclusion

Based on the findings, it is obvious that modified MIT rule based model reference adaptive control produces better outcomes than basic MIT rule based model reference adaptive control. As a result, the created control scheme might be used in real time in the future, and other sophisticated control strategies could also be used on this non-linear system.

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