Experimental Validation of Adaptive Control Techniques for Conical Tank System

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Abstract. A nonlinear system is one whose behavior cannot be described by first-degree equations. The conical tank is an example of a nonlinear system often employed in industry, where maintaining the liquid level is critical. A level that exceeds the tank's maximum capacity may disrupt reaction equilibrium or cause valuable or hazardous substances to leak. If the level is too low, the consecutive processes may have a poor representation. As a result, liquid level control is a critical responsibility in process industries. As a result of its nonlinear behavior and continuallyvarying area of cross section, maintaining the level of liquid in a conical tank turns into a difficult operation. The main goal is to design a control mechanism for a conical tank system that will keep the level constant at the desired value.The conical tank system is first modelled for different height ranges and a conventional proportional controller is accustomed for initial controller implementation and then, two types of adaptive controller namely Gain scheduling controller and Model Reference Adaptive Controller (MRAC) are employed. The system's output is obtained by implementing the control algorithms and their performances are analyzed. It was observed that MRAC when implemented produced a better response compared to gain scheduling controller.

Keywords: Conical tank, Non linear, Adaptive control, Gain scheduling controller, MRAC.

1 Introduction

Conical tank has a continuously shifting cross sectional area, and so is non-linear in nature. Ascontrol theory mostly gets to handle with linear processes, controller design is a difficult issue for industries that use non-linear processes. Liquids must be pumped, tanked, and later transferred to the next stage in the process industries. The liquid will most likely be treated in the tanks through chemical or mixing treatment, so its level must continuously be monitored. Control of level in a conical tank is a critical and typical duty in process industries.

The level of liquid is maintained in tanks by managing the inflow. The manipulated variable is the inlet to the tank, while the control parameter is the level in the tank.A Gain scheduling controller [1] changes the parameter of controller based on the operating condition of the process. It is better to make up for the known nonlinearities of the process.

Another method is Model Reference Adaptive Control (MRAC) [2], which uses adaption mechanism such that it will adjust the controller parameters in order to optimize (maximize or minimize) the objective function's value (criterion).

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The paper is formulated as follows: In section 2, the mathematical modelling of the system is done. In section 3, the controller is designed. In section 4, the results are given showing the recommended method's effectiveness. Conclusion is presented in section 5.

2 Conical Tank System and its Modeling

As it facilitates ease of discharge, the conical tank is widely utilised in the process industries. Conical tank level control is difficult because the area of cross sectional of the tank is constantly changing. The suggested system consists of a 60-centimeter-high conical tank with a top end diameter of 40 centimetres and a tapering end diameter of 15 centimetres. A differential pressure transmitter is present for sensing pressure and providing milliamp output. It has a reservoir for storing water, which is then tanked via the pump. The amount of water that enters the tank is related to the pump's speed. The gauge pressure, which takes into account the pressure head value, is used to determine the liquid level. The output is calibrated to correspond to the actual liquid level in the conical tank [3].

Level is considered as the control parameter and the inlet to the tank is considered as the manipulated parameter to determine the model of the conical tank mathematically. The rate at which the liquid flows to the tank is F_{in}, the rate at which the liquid flows out of the tank is F_{out}, the area of cross section of the tank is A, H is the depth of the conical tank, Ris the maximum radius of the conical tank, h is the level to which liquid is accumulated in the tank, r is the radius corresponding to the liquid in the tank, and k is the valve coefficient.

Persuanat to mass balance equation,
Liquid accumulation rate = rate of inflow–rate of outflow

$$F_{in} - F_{out} = A\frac{dh}{dt} \quad 1)$$

$$F_{out} = k\sqrt{h} \quad 2)$$

The system is represented as,

$$\frac{Y(s)}{U(s)} = \frac{c}{\tau s + 1} \quad 3)$$

Where Y(s) = change in height
U(s) = Change in inlet flow.

$$\tau = \frac{2}{\beta} hs^{5/2} \quad 4)$$

$$c = \frac{2\alpha}{\beta} hs^{1/2} \quad 5)$$

$$\alpha = \frac{1}{\pi(\frac{R}{H})^2} \quad 6)$$

$$\beta = k\alpha \quad 7)$$

$$k = \frac{1}{x} \quad 8)$$

$$x = \frac{\sqrt{h}}{Fout} \qquad 9)$$

Using these equations, the process tank was modelled for various height ranges.

3 Controller Design

Gain Scheduling Controller

The dynamics of a process are known to alter with the process's operating conditions in numerous instances. The recognized nonlinearities [4], [5] will be one source of change in dynamics. The parameters of the controller can then be changed by monitoring the process's operating circumstances. Gain scheduling is the name given to this concept since it was initially designed to handle just changes in process gain. It is based on measurements of process parameters and is an effective approach to correct for changes in process parameters or known process nonlinearities. It's a fantastic method for minimizing the effects of parameter changes. It is capable of compensating for both static and dynamic nonlinearities [6]. As depicted in Fig 1, it can be thought of as a system in which feedback controller gain is manipulated using the compensation incorporated in the feed forward loop. Finding proper scheduling variables is a major challenge in this controller. This is usually done based on a thorough understanding of the systems' physics.

The controller settings under a variety of operating situations are determined using an appropriate design approach once the scheduling variables have been decided. When a PID controller is employed, the controller parameters are determined at each operational point using Cohen coon method of tuning and they are scheduled. Once the gain scheduled controller is put in line for control to be implemented, the PID gains are chosen automatically based on the operating conditions at that particular instant, thus leading to a better control [7], [8].

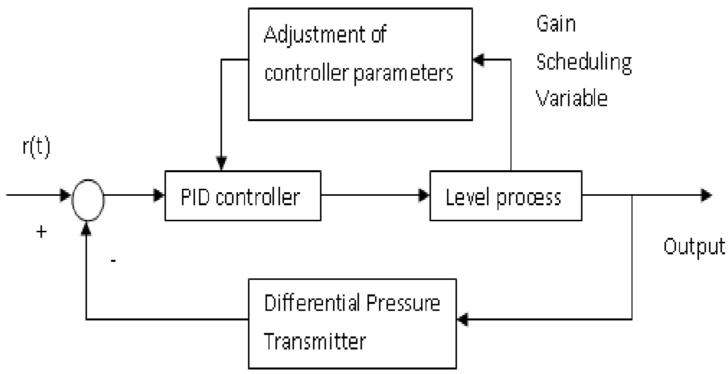

Fig 1. Block schematic of gain scheduling controller

4 Model Reference Adaptive Controller

MRAC stands for Model Reference Adaptive Control and is a self-adaptive control system. The MRAC is made up of two loops. The inner loop is a feedback control loop like any other. The adaptation mechanism and a feedback loop are both included in the outer loop. [9].

In MRAC, a thorough understanding of the plant and the performance standards it must achieve allows the designer to create a model, referred to as the reference model that represents the closed loop plant's desirable attributes. The reference model is chosen in order to get the desired trajectory. The tracking error is the departure of the plant output from the expected trajectory, which is calculated by comparing the plant output with the reference model output. The closed loop plant consists of a plant and a controller, as well as an adjustment technique for generating controller parameters estimations on-line [9]. The adjustment process tunes the controller parameters automatically such that the closed loop plant output, $Y_p(t)$, closely resembles the reference model output, $Y_m(t)$, as shown in Fig 2.

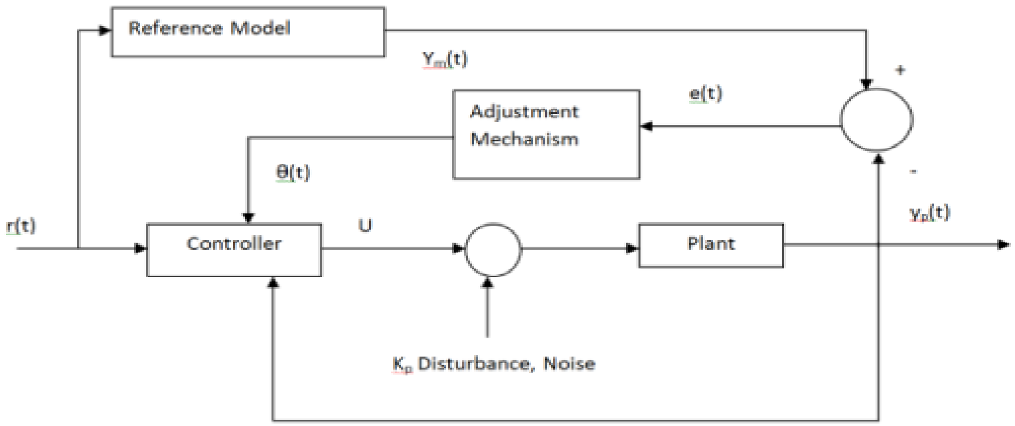

Fig 2. Block schematic of model reference adaptive controller

The reference model's parameters and structure are specificities based on control performance criteria [10]. The MRAC system's adjustment mechanism is built using an adaptive control rule known as the MIT rule, which makes an attempt to diminish the cost function and is characterized as follows:

Tracking error:

$$Y_p - Y_m \quad (10)$$

The cost function:

$$J(\theta) = \frac{1}{2} e^2 (\theta) \quad (11)$$

Controller law:

$$U = \theta(t) * r(t) \quad (12)$$

Update rule:

$$\frac{d\theta}{dt} = -\gamma \frac{\delta J}{\delta \theta} \quad (13)$$

$$\frac{d\theta}{dt} = -\gamma e \frac{\delta e}{\delta \theta} \qquad (14)$$

where, the model error is denoted by the e, the controller parameter vector is θ , the control signal is U(t), the command signal is r(t), the tuning parameter is γ, and the adjustable parameter is θ. The sensitivity derivative of the error with regard toθ is represented by the component ∂e/∂θ.

5 Results and Discussions

The open loop data of level was acquired using DAC card, at various operating conditions and their transfer functions were obtained as shown in Table 1.and the response is shown in Fig 3.

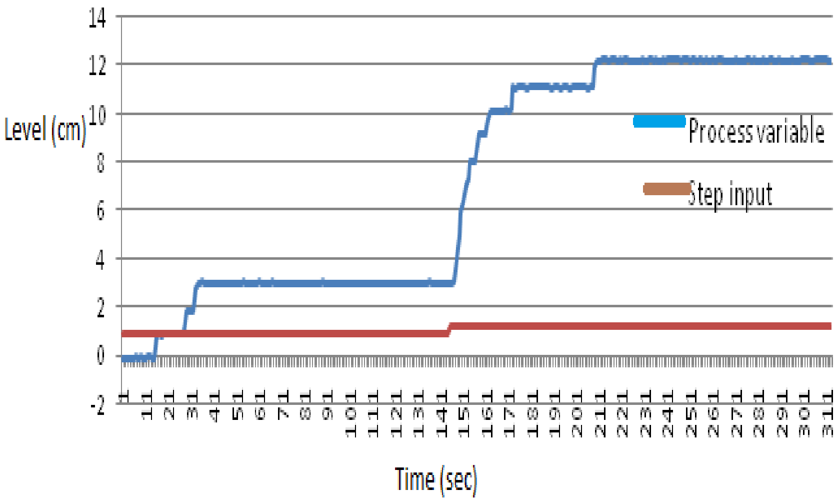

Fig 3. Open loop response of the system

Table 1. Transfer function for various operating ranges

Height range(cm)	Transfer function
0-15	$\frac{2.767}{13s+1}e^{-16s}$
15-25	$\frac{4.85}{49s+1}e^{-16s}$
25-35	$\frac{6.538}{198s+1}e^{-16s}$
35-45	$\frac{7.67}{368s+1}e^{-16s}$

45-55	$\frac{8.571}{457s+1}e^{-16s}$

The operating regions were chosen such that it covers the entire height of the actual tank. The controller parameters were tuned using Cohen coon method and the gains for different operating points were calculated. Then the gain scheduling controller was designed and the response was obtained for single set point as shown in Fig 4. and the servo tracking response was also obtained as shown in Fig 5. It was noted that the system has some offset and takes a reasonable time to settle. But the overshoot and undershoot were negligible.

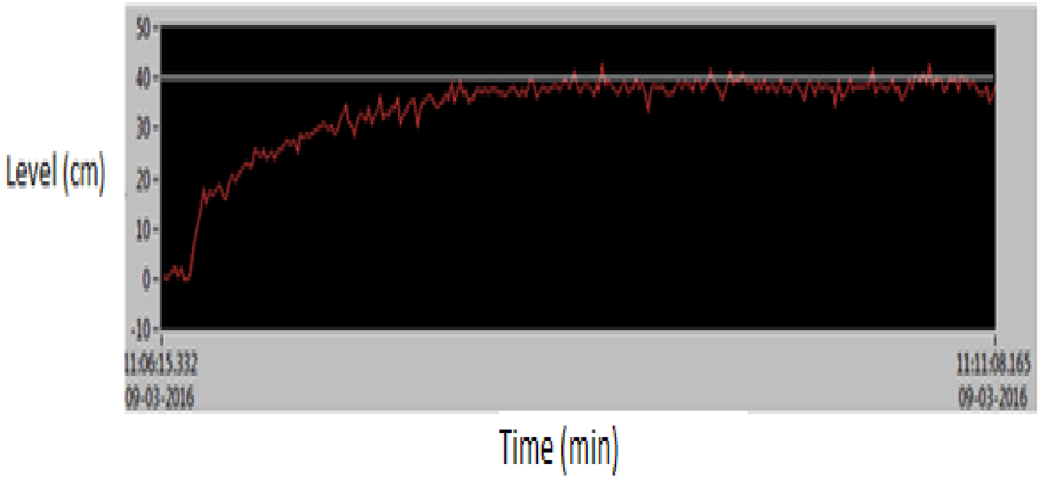

Fig 4. Response of system with gain scheduling controller for step change in input

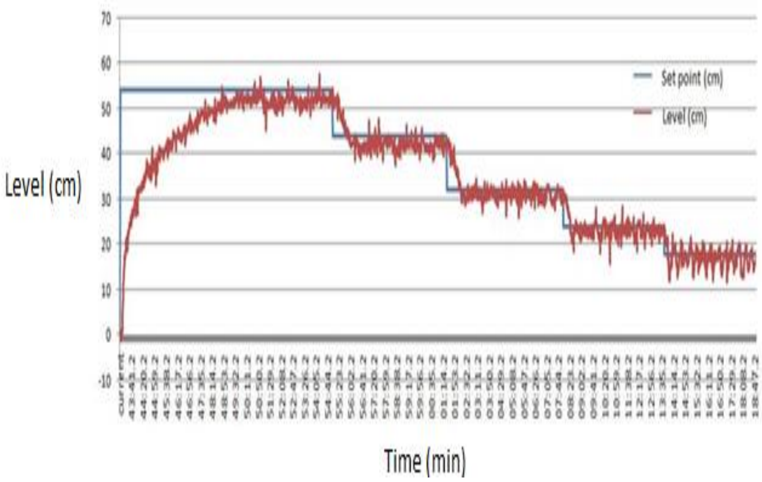

Fig 5. Servo Response of system with gain scheduling controller

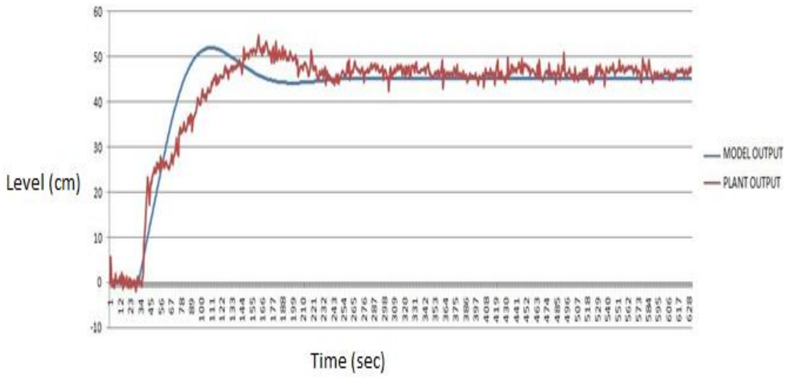

Fig 6. Response of system with model reference Adaptive controller

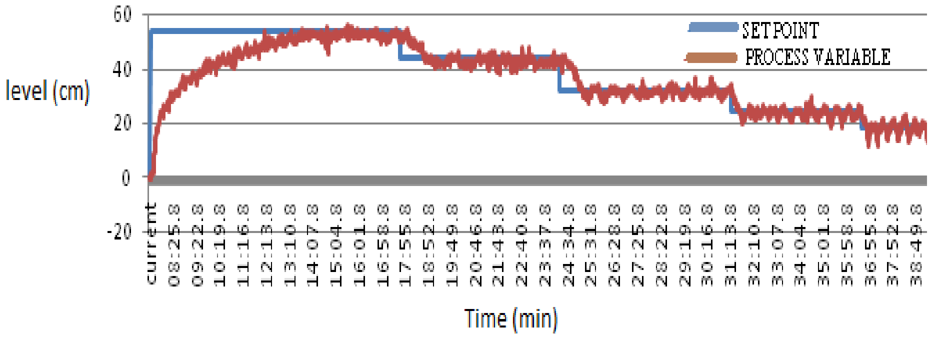

Fig 7. Servo Response of system with model reference adaptive controller

MRAC was implemented and the responses were obtained. It is noted from the response graphs shown in Fig 6. and Fig 7., that the settling time is less compared to Gain scheduling controller, overshoots, undershoots and offset are almost negligible.

From Fig 8. it is very clear that MRAC exhibits very quick rise in level, which means a faster response rate, less delay, quick settling, with minimum oscillations and offset. Table 2 gives the numerical comparison of the performances of the controllers.

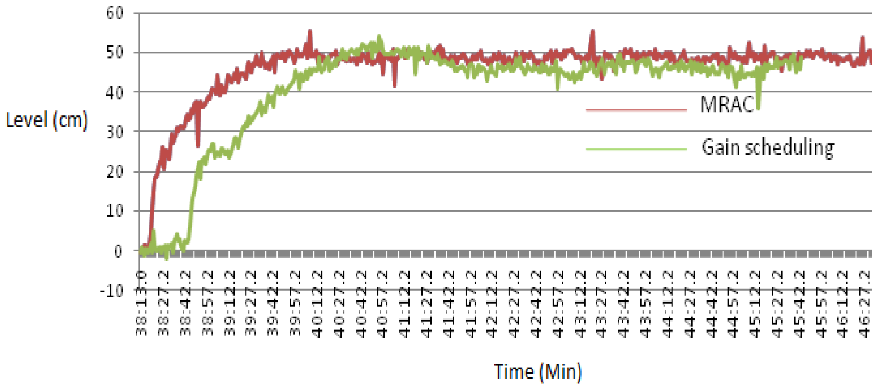

Fig 8. Comparison of gain scheduling controller and MRAC

Table 2. Comparison of controllers

S.No:	Parameters	Gain Scheduling Controller	MRAC
1	Rise Time (min)	5.1	1.2
2	Settling Time (min)	7.3	2.1
3	Steady State error (cm)	2.5	1.3

Conclusion

Conical tank being a highly non linear process, controlling the level of the tank becomes very difficult because the system has varying dynamics. This makes it essential to design controllers with different parameter values at different operating points. So, instead of a conventional PID controller, here gain scheduling controller and a Model Reference Adaptive controller were designed and their performance were compared and it is noted that MRAC outperforms gain scheduling controller.

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