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# Intelligent Control of Non Linear Tank Level System

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**Abstract**–*Conical tank system is widely used in industries due to easy flow of liquid, it is very difficult to analyze the behavior of such system as a linear system due its cross sectional area. There are different intelligent techniques used with this system to remove the non-linearity present in the system by which it can operate as linear system. So this paper considers the intelligent control technique named Genetic Algorithm (GA) to optimize the performance & response of the system and remove the non-linearity. GA is used to analyze the good dynamic behavior of interacting and non-interacting conical tank system. Genetic algorithm has great advantage for such type of system which also considered in this paper.*

**Keyword:** *Genetic algorithm (GA), Two tank interacting conical tank system (TTICS), IAE, ITAE, ISE.*

## 1. INTRODUCTION

Due to the wide scope in process industries like petroleum industries, colloidal mills, pharmaceutical and chemical industries, RO plants, biodiesel processing and reactor tanks, it is a very challenging task to address the non linearities in the flow control of conical tank level system, due to its shape of the cross sectional area. For entire drainage of fluids, a conical bottomed cylindrical tank is utilized in the process industries, where its non-linearity is probably more at the bottom. The drainage efficiency may be advanced further if the tank is completely conical. However constant flow in the tank system makes it highly non-linear and therefore the liquid level manage in such structures is difficult.

Hence there are different intelligent control techniques to control liquid level of tank level system which was used by many researchers. R J Rajesh and *et.al.* Proposed ANNDIC (Artificial Neural Network Direct Inverse Control) method in 2015, this method consider with inverse of the output of the system is directly applied to the Neural Network, with the help of learning process result can be found. Shuchi Singh and Sakshi Bangia proposed LABVIEW based controlling of two tank level system in 2016, this type of method can evaluate the controlled height of liquid level by some mathematical formulation which practiced on LABVIEW experimental setup. PSO (particle swarm optimization) based technique is proposed by S. Srinivasan and *et.al.* in 2017, PSO is a intelligent control technique by which input is controlled by controller in the form of particles, and then the parameters of particles are further optimized. Some other technique like Cohen & Coon method, L. M. method, ANN method etc. were also proposed by the researchers.

In this paper, intelligent control technique i. e. Genetic algorithm (GA)is used to tune the gains of PI controller which is used with conical tank level system. Genetic algorithm is used to optimize the non-linearity present in the conical tank level system. Level control may be either interacting or non-interacting [2].

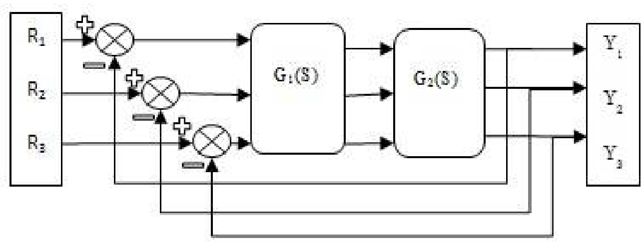


**Fig. 1: Multivariable system[3, 4, 5]**

System which have multiple number of inputs and multiple number of outputs, such systems are known as MIMO (Multi input multi output) system [1, 2]. MIMO system evaluation is more difficult than SISO (single input single output) system regulation [3]. MIMO system shown in Fig. 1[3, 4, 5]

The whole paper consists with six sections, which divides in this manner that section 1 gives the literature survey of the system, and under section 2&3 mathematical process of the system and introductory of experimental setup of the system respectively are taken, section 4 gives the description of tuning of PI controller mutually the implementation of introduced intelligent technique i. e. Genetic Algorithm(GA). Also paper contains steps of simulation of process in section 4. Results of MATLAB Simulink model of the system are considered in section 5. And finally, section 6 gives thefinal appearance or performance and under section 7 references are taken.

## 2. MATHEMATICAL MODELING AND PROCESS DESCRIPTION

In this process the liquid level in the tank required to be occurring repeatedly[6]. This can be experienced by controlling of inflow rate of the tank. The manipulated parameter of the tank is inflow rate and the controlled parameteris liquid level in the tank. The schematic diagram of SISO conical tank is shown in Fig. 2 [6] which is given below:-

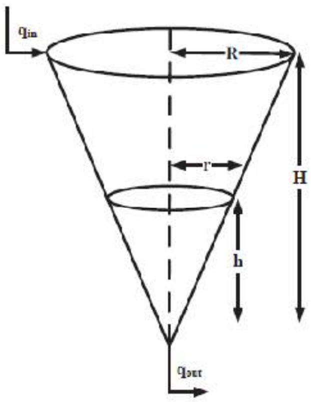


**Fig. 2: Single conical tank system[6]**

The mathematical modelling of single conical tank is as follows. [9]

According to mass balance equation,

Rate of flow= Inflow rate – Outflow rate

$$\frac{dV}{dt} = q_{in} - q_{out} \quad \text{Eq. 1}$$

$$q_{out} = \frac{h}{R_V} \quad \text{Eq. 2}$$

Here $q_{in}$ and $q_{out}$ are input flow rate and output flow rate respectively.

The volume of single conical tank level system is:-

$$V = \frac{1}{3} r^2 \pi h \quad \text{Eq. 3}$$

Where,

V= volume of conical tank H= maximum height of conical tankh = height of liquid level of tank r = radius of tank at liquid level R= maximum radius of conical tank $R_v$= valve resistance

Using Eq. 2 & Eq. 3,

The Eq. 1 can be written in the form of Eq. 4

$$\frac{dh}{dt} = \frac{1}{\pi h^2 \beta^2}\left(q_{in} - \frac{h}{R_V}\right) \quad \text{Eq. 4}$$

Where,

$$\beta = \frac{R}{H} = \frac{r}{h} \quad \text{Eq. 5}$$

Here $\beta$ represents the ratio of radius of the tank to the corresponding height of the conical tank. The ratio remains constant throughout the tank. Eq. 4 is used to design the MATLAB Sim link model of conical tank level system.

## 3. EXPERIMENTAL SETUP

Setup of two tank interacting conical tank system (TTICS) consist by two identical conical tanks, the diagram of experimental setup given in Fig. 3[7].

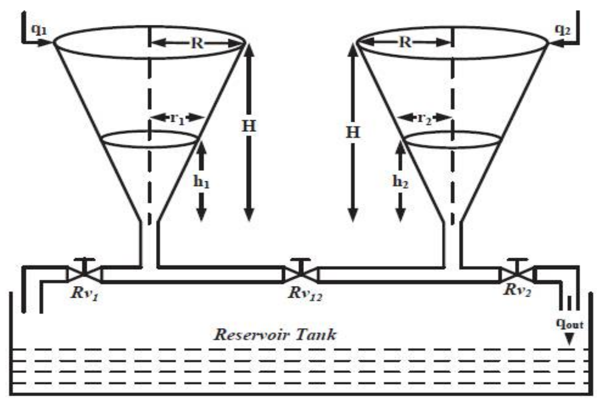


**Fig. 3: Schematic for experimental setup for interacting conical tank[7]**

Here, $q_1$ = input flow rate in tank 1$q_2$ = input flow rate in tank 2$q_{out}$= outflow rate H = maximum height of both tanks R = radius of both tanks$r_1$= radius of liquid level of tank 1$r_2$=radius of liquid level of tank 2$h_1$= height of liquid level of tank 1$h_2$= height of liquid level of tank 2$R_{v1}$= valve resistance of tank 1$R_{v2}$= valve resistance of tank 2 $R_{v12}$ = valve resistance between tank 1 &2

**Table 1: Parameters of interacting conical tank system[9]**

| Parameters | Description | Value |
|---|---|---|
| R | Maximum radius of both tanks | 20cm |
| H | Maximum height of both tanks | 60cm |
| $q_1$, $q_2$ & $q_{out}$ | Inflow rates & outflow rate | 440LPH |
| $R_{v1}$ | Valve resistance | (1/50)s/cm$^2$ |
| $R_{v2}$ | Valve resistance | (1/50)s/cm$^2$ |
| $R_{v12}$ | Valve resistance | (1/35)s/cm$^2$ |

The two tanks are interconnected with manually operated controller valve i. e. $R_{v12}$. It has two outflow valves $R_{v1}$ and $R_{v2}$ for tank (1) and tank (2) respectively that further are operated manually. Here $h_1$and $h_2$ are considered as liquid levels for tank 1 and tank 2 respectively. $q_1$ and $q_2$ are manipulated fluid flow parameters. Table1 [9] shows all parameters of the conical tank system with inflow and out flow rates. To evaluate responses of the interacting tank its mathematical design is necessary.

The mathematical modelling of two input two output (TITO) conical tank system is similar as SISO system, so the liquid levels i. e. $h_1$& $h_2$ respectively are given as below:-

$$\frac{dh_1}{dt} = \frac{1}{\pi h_1^2 \beta^2}\left(q_1 - \frac{h_1 - h_2}{R_{V12}}\right) \qquad \text{Eq. 6}$$

$$\frac{dh_2}{dt} = \frac{1}{\pi h_2^2 \beta^2}\left(q_2 + \frac{h_1 - h_2}{R_{V12}} - \left(\frac{h_2}{R_{V2}}\right)\right) \qquad \text{Eq. 7}$$

The mathematical expression of the interacting tank is given in Eq. 6 and Eq. 7 respectively. These equations are derived similarly as derived for single input single output system under section 2 of this paper. Control of interacting tank is repetitious and complicated compared to the controlling part of single conical tank. The level of second tank is controlled irrespective of the level in first conical tank in interacting tank system. By using differential equations for this system the input-output characteristics are generated using random input values. These characteristics are irrelevant with system behavior. To reduce this irregularity from the system, optimization is required with the help of PI tuning and genetic algorithm.

## 4. PI TUNING&IMPLEMENTATION OF CONTROL TECHNIQUE

### 4. 1) PI CONTROLLER TUNING

Tuning of PI controller involves the adjustment of $K_p$& $K_i$ to achieve the optimal parameter of the system. Each term has its own advantages and disadvantages, the proportional controller is used for process stability, but there may present some offset. To reduce the offset errors integral controller is used. Tuning of PI controller is done by many different methods like Ziegler Nichols method, Cohen coon method, but this paper introduce technique i. e. Genetic Algorithm, which is used to achieve optimal solution and best gain values of PI controller for the given system, and to achieve better time domain response and steady state response of the system. The error is defined as the desired response of the system in which the level has to meet and the actual response of the system which is being tuned by technique.

### 4.2) IMPLEMENTATION OF INTELLIGENT CONTROL TECHNIQUE (G A)

The intelligent control technique named as genetic algorithm which is used to optimize the error in the close loop system with help of tuning the gains of PI controller. Genetic algorithm is a computerized search and optimization technique. It is a part of evolutionary algorithm. The basic concept of genetic algorithm is to simulate process in natural system which is necessary for evolution. It is widely used in structural engineering problems, neural networks, image processing system etc. There are three important aspects in genetic algorithm i. e.

1. Definition of objective function.
2. Definition of implementation of genetic representation.
3. Definition of implementation of genetic operators.

The process used for applying genetic algorithm is that :-

There is a space for all feasible solutions, all feasible solutions are marked by its fitness value, then these feasible solutions are called as population for genetic process. Then genetic is applied to design a new population by its best value from set of previous population. At the time of applying genetic process, PI controller reduce three types of problems i. e. Reproduction, Crossover & Mutation. The advantages of genetic algorithm are easy to understand, modular, separate from application, supports multi-objective optimization, flexible for building blocks for hybrid applications. The disadvantages are it takes more computational time, it is slower than other techniques.

Fig. 4 shows the block diagram of working of GA using PI controller with the conical tank level system. And Fig. 5 shows the simulated model diagram of two tank cinocal tank level system using PI controller.

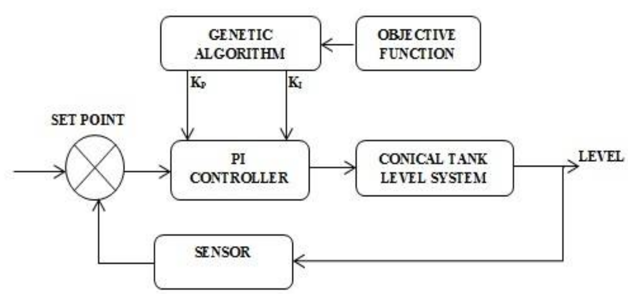


**Fig. 4 Block diagram of GA- PI for two tank conical tank level system**

There are three different types of error which addressed by the controller. [8]

A. ISE
B. IAE
C. ITAE

All the parameter require a secure experiment to be analyzed on the system (i. e. a fixed set point or disturbance change) and the integrals are calculated over a stable time duration (in theory to infinity, but usually until a time long enough for the responses to settle). Performance of the system formulated in Table 2. [8].

ISE integrates the square of the error over time. ISE will control large errors more than smaller ones (since the square of a large error will be much bigger). Control systems which are designed to minimize ISE will tend to remove large errors rapidly, but will allow small errors continue for a long duration of time. Often this leads to fast responses, but with considerable, low amplitude, oscillation.

IAE integrates the absolute error over time. It doesn't add weight to any of the errors in a systems response. It tends to produce slower response than ISE optimal systems, but usually with less sustained oscillation.

ITAE integrates the absolute error multiplied by the time over time. What this does is to weight errors which exist after a long time which are significantly more stiffly than those at the beginning of the response. ITAE tuning produces systems which settle much more faster than the other two tuning methods. In the last of this is that ITAE tuning also produces systems with stagnantly initial response (necessary to avoid sustained oscillation).

**Table 2: Performance of PI controller [8]**

| Name of the criterion | Formula |
|---|---|
| Integral of squared error (ISE) | $ISE = \int_0^\infty e(t)^2 \, dt$ |
| Integral of absolute error (IAE) | $IAE = \int_0^\infty \lvert e(t) \rvert dt$ |
| Integral of time weighted absolute error (ITAE) | $ITAE = \int_0^\infty t \lvert e(t) \rvert dt$ |

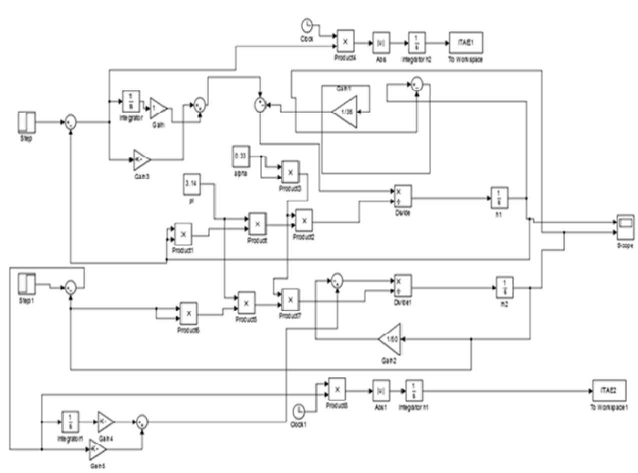

**Fig. 5: Simulink model of two conical tank level system using with PI controller**

## 5. SIMULATION RESULTS

The response of close loop interacting conical tank system is much better than the single conical tank system.

First, genetic algorithm is applied for maintaining the liquid level of tank 1 i. e. $h_1$. After applying genetic algorithm, the parameters of the performance of PI controller is mentioned in the Table 3.

### ITERATIONS FOR LIQUID LEVEL ($h_1$)

**Table 3: Performance of interacting conical tank system**

| Resulted liquid level | $K_p$ | $K_i$ | ITAE | |
|---|---|---|---|---|
| | | | Min | Max |
| $h_1$ | 1. 4894 | 8. 6844 | 1 | 432. 62 |

Here, table 3 shows the tuned gains of PI controller i. e. $K_p$& $K_i$ and the ITAE range for the liquid level $h_1$. Hence resulted liquid level response is shown in Fig. 6, which quit saturated at the optimized reference level of 30cm in 5 seconds.

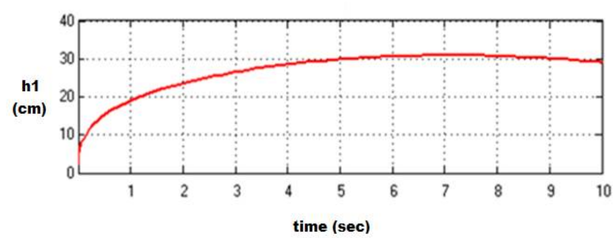


**Fig. 6: Response of interacting conical tank system using GA with single input**

Secondly, after evaluating the performance of PI controller using genetic algorithm for optimizing the liquid level for tank 1 i. e. liquid level $h_2$, then genetic also applied to the second tank for optimizing the liquid level of tank 2 i. e. liquid level $h_2$. The evaluated performance of PI controller using genetic algorithm for the second tank liquid level is given in Table 4.

### ITERATIONS FOR LIQUID LEVEL ($h_2$)

**Table 4: Performance of interacting conical tank system**

| Resulted liquid level | $K_p$ | $K_i$ | ITAE | |
|---|---|---|---|---|
| | | | Min | Max |
| $h_2$ | 6. 5788 | 10 | 1 | 442. 13 |

In, Table 4 shows the tuned gains of PI controller which is also introduce for liquid level $h_2$, that’s why the maximum range of ITAE is little bit better than the ITAE range for liquid level of tank1. Hence Fig. 7 shows the response of the liquid level $h_2$and also the liquid level $h_1$ which is almost saturated at the optimized reference level of 30cm in 6 seconds.

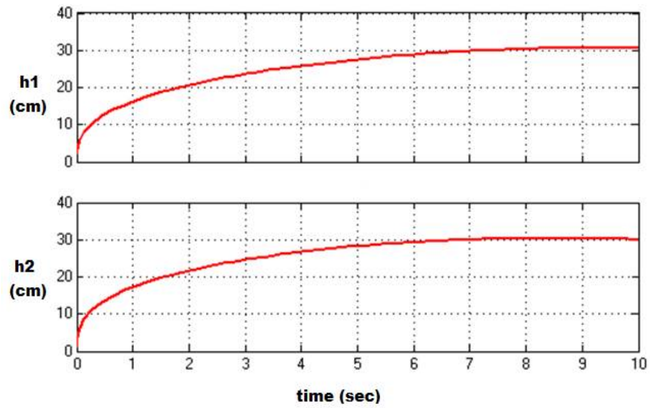


**Fig. 7: Response of interacting conical tank system using GA with dual input**

## 6. CONCLUSION

In this paper, Genetic Algorithm is implemented on the conical tank system, which moves the system into stable& saturated system and gives better performance, from simulation result it can be observed that detailed servo and regulatory performance analysis for non-linear system have been covered which convert into linear system. After using Genetic Algorithm a good dynamic behavior of interacting and non-interacting conical tank system can be realized. The future work of this project is that to implement the PSO with neural network controller's i. e. neural network internal model controller (NNIMC) etc.

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