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GA Based Intelligent Controller for Dynamic System

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Abstract: This study deals with design of Proportional + Integral (PI) controller, GA based controller for a non-linear liquid spherical tank system. Level control of a spherical tank is a complex issue because of the non-linear nature of the tank. For each stable operating point, a first order process with Time Delay Model was identified using process Reaction Curve Method. The need for improved performance of the process has led to the development of the optimal controllers. GA is an Evolutionary algorithm that is proposed in this aspect. The performance of GA based controllers is compared with conventional controller tuned using Ziegler-Nicholas (Z-N) Method. The comparison is done based on rise time, settling time, overshoot and it was found that the GA based controller is better suited for this process.

Key words: Genetic algorithm, PI controller, dynamic system, system identification, Evolutionary algorithm

INTRODUCTION

The industrial application of liquid level control is tremendous (Mahmood and Taha, 2013) especially in refineries petroleum and chemical process industries. Usually, level control exists in some of the control loops of a process control system. An evaporator system is one example in which a liquid level control system is a part of control loop. Evaporators are used in many chemical process industries for the purpose of separation of chemical products. Level control is also very important for mixing reactant process. The quality of the product of the mixture depends on the level of the reactants in the mixing tank. Mixing reactant process is a very common process in chemical process industries and food processing industries. Many other industrial applications are concerned with level control, may it be a single loop level control or sometimes multi-loop level control. In some cases, level controls that are available in the industries are for interacting tanks. Hence, level control is one of the control system variables which are very important in process industries. Nowadays, chemical engineering systems are also at the heart of the economics. The process industries such as refineries petrol, petro-chemical industries, paper making and water treatment industries require liquids to be pumped, stored in tanks and then pumped to another tank. In the design of control system, one often has a complicated mathematical model of a system that has been obtained from fundamental physics and chemistry. The above mentioned industries are the vital industries where liquid level and flow control are essential. Many times the liquids will be processed by chemical or mixing treatment in the tanks but always the level fluid in the tanks must be controlled and the flow between tanks must be regulated. Level and flow control in tanks are the heart of all chemical engineering systems.

This study endeavors to design a system using Genetic algorithm. Genetic algorithm or in short GA is a stochastic algorithm based on principles of natural selection (Thomas and Poongodi, 2009) and genetics. Genetic Algorithms (GAs) are a stochastic global search method that mimics the process of natural evolution. Using Genetic algorithms to perform the tuning of the controller will result in the optimum controller being evaluated for the system every time. The objective of this study is to show that by employing the GA Method of tuning a system, an optimization can be achieved. This can be seen by comparing the result of the GA Optimized System against the Classically Tuned System

MATERIALS AND METHODS

Mathematical modeling: It is quite often the case that we have to design the control system for a process before the process has been constructed. In such a case, we need a representation of the process in order to study its dynamic behavior. This representation is usually given in terms of a set of mathematical equations whose solution gives the dynamic or static behavior of the process. The process considered (Ziegler and Nichols, 1942; Chidambaram, 2004; Kumar, 2010) is the spherical tank in which the level of the liquid is desired to be maintained at a constant

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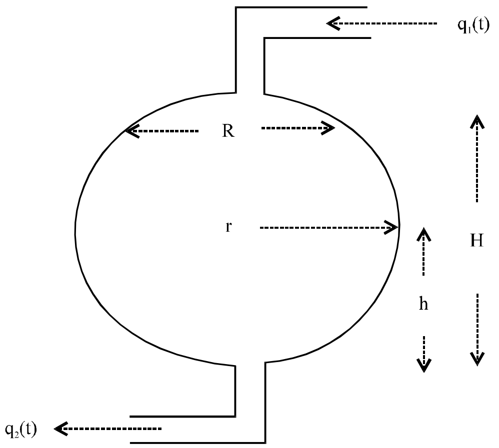

Fig. 1: Spherical tank liquid level system; q_1 = Inlet flow rate to tank (m^3/min); q_2 = Outlet flow rate to the tank (m^3/m); h = Hight of te spherical tank (m); H = Hight of the liqued level in the tank at any time 't' (m); R = Top radius of the spherical tank (m); r = Radius of the spherical tank at a particular level of height h(m)

value. This can be achieved by controlling the input flow into the tank. The spherical tank is shown in Fig. 1. Using the law of mass, rate of accumulation of mass in the tank = Rate of mass flow in-Rate of mass flow out. The level in spherical tank at any instant is obtained by making mass balance equation as indicated as:

$$\frac{dv}{dt} = q_1 - q_2 \tag{1}$$

where, V is the volume of the tank which is expressed as:

$$V = \frac{4}{3}\pi h^3 \tag{2}$$

Applying the steady state value:

$$V - V_s = \frac{4}{3} 3h_s^2 (h - h_s) \tag{3}$$

$$V(s) = 4\pi h_s^2 H(s) \tag{4}$$

$$q_2 = c\sqrt{h_s} \tag{5}$$

where, 'c' is the valve coefficient:

$$q_2 - q_2(s) = \frac{1}{2} c h_s^{-\frac{1}{2}} (h - h_s) \tag{6}$$

Table 1: The specifications of the real time

Parts name	Details
Spherical tank	Body material: SS 316
	Diameter: 500 mm
	Capacity: 200 L
Storage tank	Capacity: 200 L
	Body material: SS 316
Differential pressure transmitter	Make: AB
	Type: Capacitance
	Input: 2.5-250 mbar
	Output: 4-20 mA
Rotameter	Make: Tellien/equivalent
	Flow rate: 100-1000 LPH
	Type: Variable area
	Float material: SS 316
Control valve	Type: Pneumatic air to close
	Input: 3-15 psi
Pump	Make: Kirlosker
	Flow rate: 1500 LPH maximum
	Supply voltage: 230 V AC/50 Hz
Air regulator	Size: ¼" BSP
	Range: 0-2.2 bar
I/P converter	Make: ABB
	Input: 4-20 mA
	Output: 0.2-1 bar
V/I converter	Model: Electronic
	Input: 1-5 V
	Output: 4-20 mA
VMAT-01	Input: 8
	Output: 2
Pressure gauge	Range: 0-30 psi
	Range: 0-100 psi
I/V converter	Model: Electronic
	Input: 4-20 mA
	Output: 1-5 V

Linearizing the non-linearity in the spherical tank:

$$Q_2(s) = \frac{c}{2\sqrt{h_s}}, \quad H(s) = \frac{H(s)}{R_t} \tag{7}$$

Where:

$$R_t = \frac{2h_s}{Q_2(s)}$$

$$\begin{aligned} Q_1(s) - Q_2(s) &= sV(s) \\ Q_1(s) - \frac{H(s)}{R_t} &= s(4\pi h_s^2)H(s) \\ Q_1(s)R_1 &= (4\pi R_1 h_s^2 s + 1)H(s) \end{aligned} \tag{8}$$

$$\frac{H(s)}{Q_1(s)} = \frac{R_t}{\tau s + 1} \tag{9}$$

where, $\tau = 4\pi R_t h_s^2$. Thus, the equation gives the model of the system.

Real time system

Specification: The specification of the real time can be represented in Table 1.

Block diagram: The real time experimental system consisting of a spherical tank, reservoir and water pump,

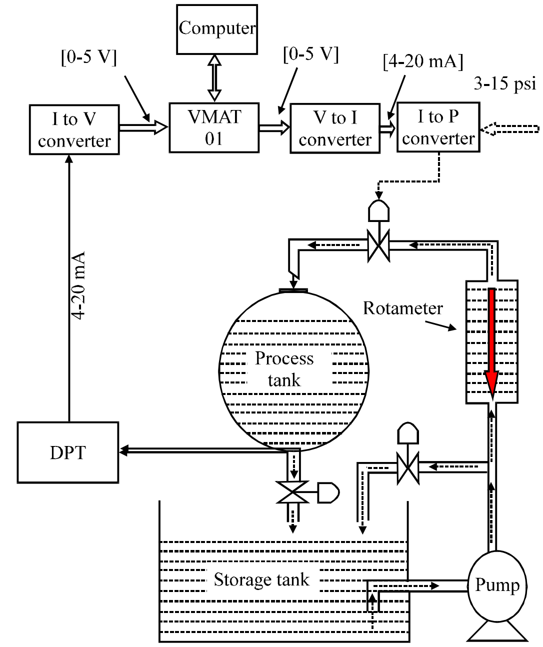

Fig. 2: Block diagram of real time system

Fig. 3 Real time implementation

current to pressure converter, compressor, Differential Pressure Transmitter (DPT), VMAT01 DAQ CARD, I/Vconverter, V/I converter and a personal computer which acts as a controller, forms a closed loop system. The block diagram of this system is shown in Fig. 2.

Hardware implementation: Figure 3 shows the real time implementation of the system. The flow rate to the spherical tank is regulated by changing the stem position of the pneumatic valve by passing control signal from computer to the I/P converter through VMAT01 DAQ CARD and V/I converter. The operation current for regulating the valve position is 4-20 mA which is converted to 3-15 psi of compressed air pressure. The water level inside the tank is measured with the differential pressure transmitter which is calibrated for 0-40 cm and is converted to an output current of 4-20 mA. This output current is converted into 0-5 V using I/V converter which is given to the controller through VMAT01 DAQ CARD. The VMAT01 USB based DAQ CARD is used for interfacing the personal computer with the spherical tank.

Black box modeling: System identification for the spherical tank system is done using black box modeling in real time. For fixed input flow rate and output flow rate, the spherical tank is allowed to fill with water from 0-40 cm height. At each sample time, the data from differential pressure transmitter, i.e., between 4-20 mA is being collected and fed to the system through the serial port RS-232 using VMAT01 interface module. Thereby the data is scaled up in terms of level (cm). Using the open loop method, for a given change in the input variable, output response for the system is recorded. Ziegler and Nichols have obtained the time constant and time delay of a FOPTD (First Order plus Time Delay) Model by constructing a tangent (Nithya *et al*., 2010) to the experimental open loop step response at its point of inflection. The tangent intersection with the time axis at the step origin provides a time delay estimate; the time constant is estimated by calculating the tangent intersection with the steady state output value divided by the model gain. Cheng and Hung have also proposed tangent and point of inflection methods for estimating FOPTD Model parameters. The major disadvantage of all these methods is the difficulty in locating the point of inflection in practice and may not be accurate. Prabhu and Chidambaram have obtained the parameters of the first order plus time delay model from the reaction curve obtained by solving the nonlinear differential equations model of a distillation column. Sundaresan and Krishnaswamy have obtained the parameters of FOPTD Transfer Function Model by letting the response of the actual system and that of the model to meet at two points which describe the two parameters τ and L. The proposed times t_1 and t_2 are estimated from a step response curve (Table 2). This time corresponds to the 35.3 and 85.3% response times. The time constant and time delay are calculated as follows:

$$\tau = 0.67(t_2-t_1) \tag{10}$$

$$L = 1.3t_1-0.29t_2 \tag{11}$$

At a fixed inlet flow rate, outlet flow rate, the system is allowed to reach the steady state. After that a step increment in the input flow rate is given and various readings are noted till the process becomes stable in the system. The experimental data are approximated to be a FOPDT. Therefore, the model for the above system is given by:

$$K_p = \frac{\text{Change in output}}{\text{Change in input}}$$

where, K_p = Proportional gain

$$\text{Transfer function} = \frac{K_p e^{-Ls}}{\tau s+1} \qquad (12)$$

Where:

Delay time (L) = $1.3\times t_1-0.29t_2$

Time constant (τ) = $0.67(t_2-t_1)$

Controller design

Design of PI controller: After deriving the transfer function model, the design of controller tuning is done using the method proposed by Skogestad. The PI controller settings are:

$$K_p = \frac{1}{K}\frac{\tau}{L+\tau_C}\tau_I = \tau \qquad (13)$$

Controller gain K_p depends inversely on model gain K. It is also reasonable that $\tau_I = \tau$ as slow processes have large values of and thus should also be large for satisfactory control. As τ_C decreases, K_p increases. This is because a quicker approach to set point requires more strenuous control action and thus there is justification for a larger value of K_p. Using the PI controller tuned values; the setup was run for the different set points in real time. Then, load disturbances at different (Bhuvaneswari *et al*., 2009; Anandanatarajan *et al*., 2005) intervals were given in the tank. The variation in the level was recorded in both the cases. The above mentioned Skogestad setting is also used to find the controller settings for different zones which are given in Table 3.

Design of GA based controller: Genetic algorithms are random search algorithms that imitate natural evolution with the Darwinian 'survival of the fittest' approach. GA's performs coding of the parameter, nor on the existence of derivatives of the unctions as needed in some conventional optimization (Jaiswal and Phandis, 2013) algorithms. In GA, population of chromosomes is formed, each representing a possible solution to the problem. The population will then undergo operations similar to genetic evolution, namely reproduction, crossover and mutation.

The components of Genetic algorithm are fitness function and genetic operator's fitness function is nothing but an objective function which is to be minimized or maximized. Selection, selects the fittest chromosomes for the next generation based on their fitness values and crossover pairs and crossover point are selected randomly and strings are swapped beyond the crossover point. Mutation of a bit involves flipping that is changing a 0-1 or vice versa if binary coding is used. Then, again the new generation is subjected to these operations till the problem is optimized. Here, in this research, the optimized tuned values are applied in real time for different set points and load change as carried in PI.

Table 2: Model parameters for different regions

Operating region	Height (cm)	K_p	τ	L
I	0-15	2.010	270.68	60.60
II	15-22	4.940	387.93	835.02
III	22-27	6.273	575.53	822.50

Table 3: PI tuning parameters for different regions

	Tuning parameters	
Region (cm)	K_P	τ_I (sec)
0-15	0.0456	0.0136
15-22	0.0290	0.0063
22-27	0.1912	0.0280

```
%Initializing the GA
Popultaion Size = 30;
Variable Bounds = [0 2; 0 0.05];
evalFn ='PI_objfun_ISE';
%Change this relevant object function
evalOps = [];
options = [1 e-6 1];
initPop = intiallizega(populations Size,varaibleBoundes,
evalFn---, evalOps, options)
```

RESULTS AND DISCUSSION

The optimized technique is applied to a real time control of a spherical tank system using VMAT01 module. The performance of the GA tuned controller is compared to Skogestad's based PI controller tuning settings. The set point is initially set at 15 cm. Then, it is varied to 22 cm and subsequently to 27 cm. For the conventional controller, set point tracking performance is characterized by lack of smooth transition between set points as well as presence of overshoots and higher rise time. The GA tuned controller performs better than conventional controller as indicated by faster transition between set points, with less oscillation as shown in Fig. 4 and 5. In Fig. 6, the performance of GA tuned controller is the best as researchers can observe the absence of both overshoots and smoother and faster transitions between set points. Table 4 gives the ISE and IAE for the different

Table 4: Performance indices of the controllers

Set point (cm)	Controllers	ISE	IAE
15	GA tuned	741.03	160.52
	PI	883.20	283.40
22	GA tuned	1954.22	356.57
	PI	2702.61	547.01
27	GA tuned	3124.45	353.30
	PI	4188.50	495.93

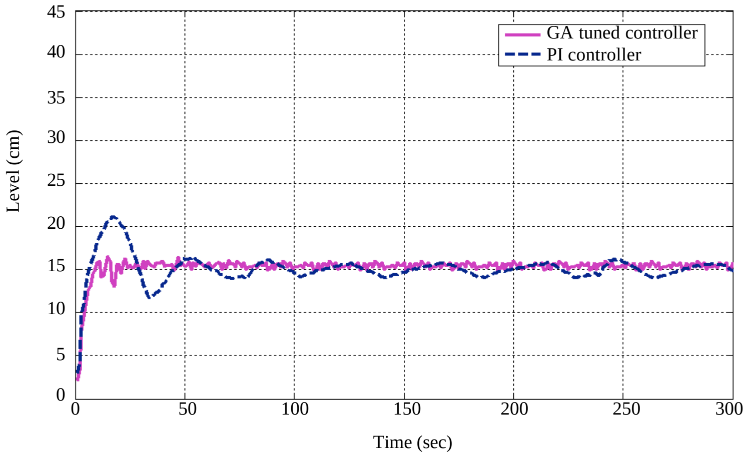

Fig. 4: Servo response for a set point 15 cm

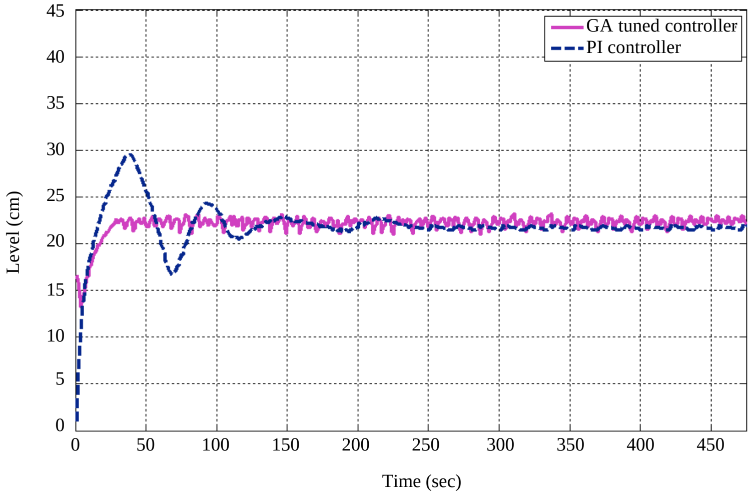

Fig. 5: Servo response for a set point 22 cm

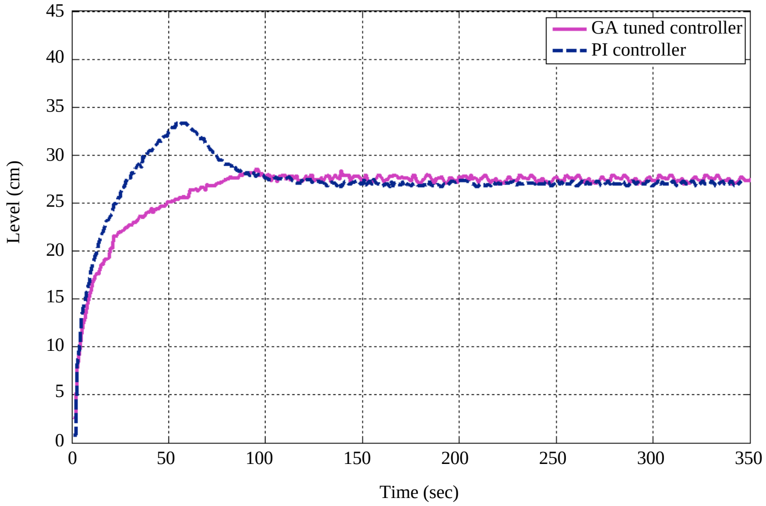

Fig. 6: Servo response for a set point 27 cm

controller types for different set points. From the Table 4, it is clear that the controller based on GA techniques minimizes the error criteria.

CONCLUSION

For non-linear processes an GA based controller is designed. Its performance is tested in real time by using the VMAT-01 module for a spherical tank level process. Comparison with a GA based controller and conventional PI controller gives testimony to the effectiveness of the GA baesd control technique in the non-linear system. Experimental results prove that the response is smooth for GA based controller compared to PI controller. It is concluded that for a non-linear system the GA based controller outperforms well when compared to conventional controller in real time using cost Effective Data Acquisition System.

REFERENCES

Anandanatarajan, R., M. Chidambaram and T. Jayasingh, 2005. Design of controller using variable transformations for a nonlinear process with dead time. ISA. Trans., 44: 81-91.

Bhuvaneswari, N.S., G. Uma and T.R. Rangaswamy, 2009. Adaptive and optimal control of a non-linear process using intelligent controllers. Applied Soft Comput., 9: 182-190.

Chidambaram, M., 2004. Applied Process Control. Allied Publishers Pvt. Ltd., Mumbai, India.

Jaiswal, M. and M. Phandis, 2013. Speed control of DC using genetic algorithm based PIC controller. Int. J. Adv. Res. Comput. Sci. Software Eng., 3: 247-253.

Kumar, S., 2010. Modeling and implementation of LabVIEW based non-linear PI controller for a conical tank. J. Control Instrum., 1: 1-9.

Mahmood, A.K. and H.H. Taha, 2013. Design fuzzy logic controller. Int. J. Environ. Sci. Eng., 1: 23-26.

Nithya, S., N. Sivakumaran, T.K. Radhakrishnan and N. Anantharaman, 2010. Soft computing basd controllers implementation for non-linear process in real time. Proceedings of the World Congress on Engineering and Computer Science, Volume 2, October 20-22, 2010, San Francisco, USA.

Thomas, N. and P. Poongodi, 2009. Position control of DC motor using genetic algorithm based PID controller. Proceedings of the World Congress on Engineering, Volume 2, July 1-3, 2009, London, UK., pp: 1-4.

Ziegler, G. and N.B. Nichols, 1942. Optimum setting for automatic controllers. Trans. ASME, 64: 759-768.