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Research Article

Performance Optimization of PI Controller in Non Linear Process using Genetic Algorithm

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Abstract

*Recently, through the use of soft computing techniques fine tuning of PID controller parameters are carried out for non linear process. In this paper the Genetic Algorithm (GA) optimization technique, is successfully applied for tuning PI controller used in conical tank level process and hence to minimize the integral time absolute error (ITAE)***.** *A conical tank level process is represented as first order plus dead time transfer function. It is obtained by deriving mathematical differential equation and implemented in MATLAB. The main objective is to obtain a minimum rise time, minimum setting time, stable and controlled system by tuning the PI controller using Genetic Algorithm optimization technique. The incurred value is compared with the adaptive tuning techniques like gain scheduling and is proved better. The obtained simulation results demonstrate that this GA-based PI tuning approach is really a potential method gives minimum rise time (T_r), minimum settling time (T_s) and reduces the ITAE.*

Keywords: *Non linear Process, PI Tuning, Adaptive Controller, Genetic Algorithm*

1. Introduction

In the control strategy literature, there is number of tuning methods are available for fine tune the parameter of PID controllers. Among them, a method utilized by most of the researchers is the Ziegler-Nichols (Ziegler J. G.and Nichols N. B, 1942)ultimate-cycle tuning method. For a wide range of practical applications, this tuning method works well to get adequate settings of classical PID controllers. But, sometimes this method is laborious and time-consuming, particularly for processes with non linear dynamics or larger time constants.The system identification technique(Astrom K. J andHagglund T.1984) exploits a pattern recognition method to match the output or error signal with the user requirement and adjust the parameter of the PID controller to their expected values. So, some new control techniques have been developed. The relay feedback technique(C. C. Hang, K. J. Astrom and W. K. Ho,199l)uses a relay with hysteresis instead of the PID controller to drive the open-loop system into closed loop self-oscillations, and then measures the amplitude and frequency of the self-oscillations which are used to tune the PID controller.

As a matter of fact, the PID parameters are obtained through the above-mentioned approaches must be retuned before being implemented in the process under control in real time environment. For this reason, a number of new techniques were emerged such as neural network and fuzzy logic which mimic the functioning of the human intelligence process.However the implementation of these techniques is quite complicate(Asriel U. Levin and Kumpati S. Narendra,1996 , Simon Fabri and Visakan Kadirkamanathan,1996) .An adaptive algorithm is proposed for PID controllers based on a theory of adaptive interaction(Lin F., Brandt R.D., and Saikalis G.).

In recent years, the interest of most researchers moves towards optimization techniques. Genetic algorithm is the most powerful optimization technique that they can be easily incorporated in PID tuning. Genetic algorithms are inspired by Darwin's theory about evolution. Genetic Algorithm is implemented as computer simulation with a setofsolutions, described by chromosomes calledpopulation. A new population is formed by from old population. To an optimization problem motivated the new population better than the old one. New solutions are selected according to their fitness; the more suitable they are the more chances they have to reproduce. The above is repeated until the condition is satisfied. It is hence one of the most developing controller tuning techniques (Rathikarani D., Sivakumar D. and Anita Janet Mary S ,2007) and proved by number of researchers(GirirajKumar S. M., Sivasankar R., Radhakrishnan T. K, Dharmalingam V and AnantharamanN.2008).An application of adaptive control technique highly influenced in non linear systems to achieving better results (Ravi V.R., Thyagarajan T,2011,Aravind P., ValluvanM, Saranya M2013). In this paper,results obtained by the proposed method are found better than the adaptive techniques in various aspects. For

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the reason of effective draining facility,conicaltank is preferred in industries but its shape non linearand is a complex issue to maintain a liquid level at desired value. It has non linear structure which leads the liquid in the tank rises with respect to the inclination angle through which the tank is designed. So effective control isessential. The objective of the paper is to use the GA algorithm in order to improve the performance of the conical tank level process has led us to develop a optimal controller. The development of the mathematical model for the conical tank level process is discussed in section 2. The tuning results of adaptive control techniques are discussed in section 3. Section 4 and 5 deals with the explanation of the GA and its implementation. The comparative analysis and results are given insection 6.Based on the results is given in Section 7 conclusions arrived.

2. Mathematical Modeling

The conical tank system shown in Figure1 is a system with nonlinear dynamics. Its nonlinearity is described by the differential equation(Ravi V.R., Thyagarajan T,2011). It is derived according to law of conservation of mass,
Inflow rate - Outflow rate = Accumulation

$$\mathrm{Fin} - \mathrm{Fout} = \frac{d}{dt}[\text{Total Volume} - \text{Cap Volume}]$$

(1)

Total volume of the conical tank is $= \frac{1}{3}\pi r^2 H$

Cap Height =h_c

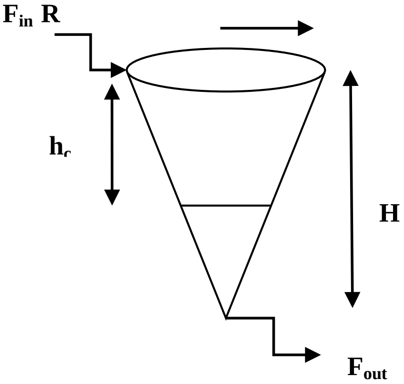

Figure1 Schematic of Conical Tank

Table-1 Operating Parameters

S.no	Parameter	Description	Value
1	R	Top radius of the cone	19.25cm
2	H	Total height of the tank	73cm
3	F_{in}	Maximum Inflow rate	111.11cm^3/s
4	K	Valve Coefficient	55cm^2/s

By solving equation 1 we get,

$$\frac{dh}{dt} = \left(\mathrm{Fin} - \beta\sqrt{h}\right) * \frac{1}{A} \qquad (2)$$

Where, A = $\frac{1}{3}\pi r^2$ h

The equation [2] describing the mathematical model for single conical tank level control, this equation is implemented in MATLAB Simulink. The basic method of identifying the system is step response method. A step change in inlet flow rate represents a process as first order transfer function with dead time,.

$$G(s) = \frac{K_p e^{-\tau_d(s)}}{\tau s+1} \qquad (3)$$

Where K is the process gain; τ is the first order time constant; τd is the dead time (1 sec).Due to the non-linearity in the shape of the conical tank, a single range response cannot cover the entire range. So, full range of conical tank is sliced into different regions by introducing step change at various ranges. Four responses were obtained for0-1.44cm as model-1, 1.44-5.76cm as model-2, 5.76-12.83cm as model-3 and 12.83-23.04 cm as model-4 with process gain 0.0218, 0.0654, 0.109, 0.155 and time constant 0.041, 0.24, 1.97, 11.75 respectively.

3. Adaptive Control Technique

In the early 1950's research in adaptive control was started in autopilot design for high-performance aircraft. Adaptive controldeals with complex systems that have unpredictable parameter deviations and uncertainties (Ravi V.R., Thyagarajan T.,2011). In this paper gain scheduling adaptive control technique is considered to proceed for PI tuning.

3.1 Gain Scheduling Method

It is an open-loop adaptive control technique(Aravind P., Valluvan M., Saranya M.2013). Gain scheduling (GS) is a very effective way of controlling system whose dynamics changes with operating condition. At each operating point controller parameters were obtained in terms of process parameters. The proportional (K_p) and integral gain(T_i) values are obtained.

$$\mathbf{K_p = \frac{\tau}{R}\,;\ T_i = \tau} \qquad (4)$$

3.2 GA Based PI Controller

The GA is a global search algorithm based on the evolutionary ideas of natural selection and natural genetics. The searching route is related to the natural advancement of biological creatures in which consecutive generations of organisms are given birth and raised until they themselves are able to procreate. In GA algorithms, the fittest among a set of artificial creatures with string structures can survive and form a new generation together with those which are produced through some structured randomized data. GA efficiently make use of historical information to speculate on new search populations with gradually improved behaviors.

Generally, GA consists of three primary operators: reproduction, crossover and mutation. Given an optimization problem, simply GA encode the parameters concerned into finite bit strings, and then run iteratively using the three operators in a random manner but based on the fitness function evolution to perform the basic tasks of copying strings, exchanging portions as well as changing some bits of strings, and decode the solutions to the problemfrom the last pool of mature strings. Figure 2 shows the flow chart of genetic algorithm program

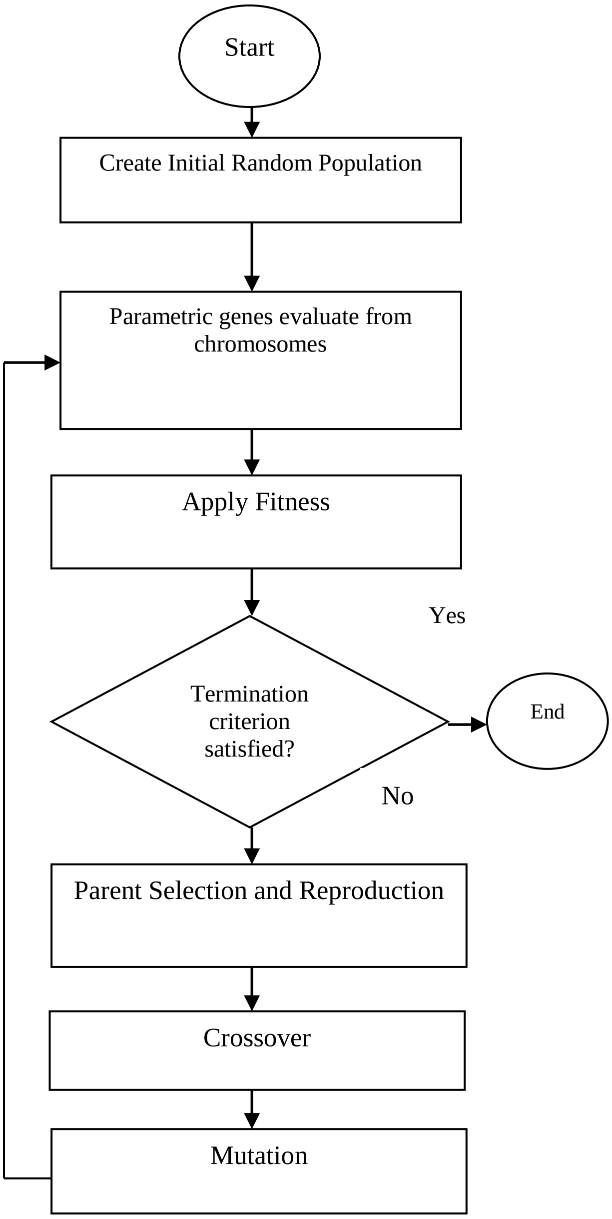

Figure2 Flow chart of Genetic Algorithm Programming

3.3 Reproduction

In the reproduction phase each value of chromosomes is evaluated. Just like in natural evolution, a fit chromosome has a higher possibility of being selected for reproduction. This is one of the reasons for the reproduction operation to be sometimes known as the selection operator.

3.4 Crossover

In reproductive phase no strings is formed , new strings are created in this operator by exchanging information among strings of the mating pool. In crossover operations switches certain parts of the two selected strings from the previous generation to capture the good parts of old chromosomes.

4. Implementation of GA

The optimal values of the PI controller parameters Kp, Ki are found using GA. All possible sets of controller parameter values are chromosomes whose values are adjusted so as to minimize the objective function, which in this case is the error criterion (GirirajKumar S. M., Sivasankar R., Radhakrishnan T. K., Dharmalingam V. andAnantharaman N**,**2008).

4.1 Selection of GA parameters

Tostart up with GA, predefining certain parameters need to be defined. It includes the population size, bit length of chromosome, number of iterations, selection, crossover and mutation types etc. Selection of these parameters decides to a great extent the ability of designed controller.

4.2 Performance Indices for the Algorithm

The performance of a controller is best evaluated in terms of integral of time absolute error criterion. A number of such criteria are available and in the proposed work, controller's performance is evaluated in terms of:Integral of Time multiplied by Absolute Error

(ITAE) criterion, given by:

$$\mathbf{I_{ITAE}} = \int_0^{\mathbf{T}} \mathbf{t}|\mathbf{e}(\mathbf{t})|\mathbf{dt} \quad (5)$$

5. Termination Criteria

Optimization algorithm will automatically terminate execution either when the number of iterations gets over or with the attainment of acceptable fitness value. Fitness value, in this case is nothing but reciprocal of the magnitude of the objective function, since we consider for a minimization of objective function. In this paper the termination criteria is considered to be the attainment of acceptable fitness value which occurs with the maximum number of iterations as 100.For each iteration the best among the 100particles considered as potential solution are chosen Therefore the best values for 100 iterations for four models are sketched and shown in figure3, figure4, figure5 and figure6 with respect to iterations.

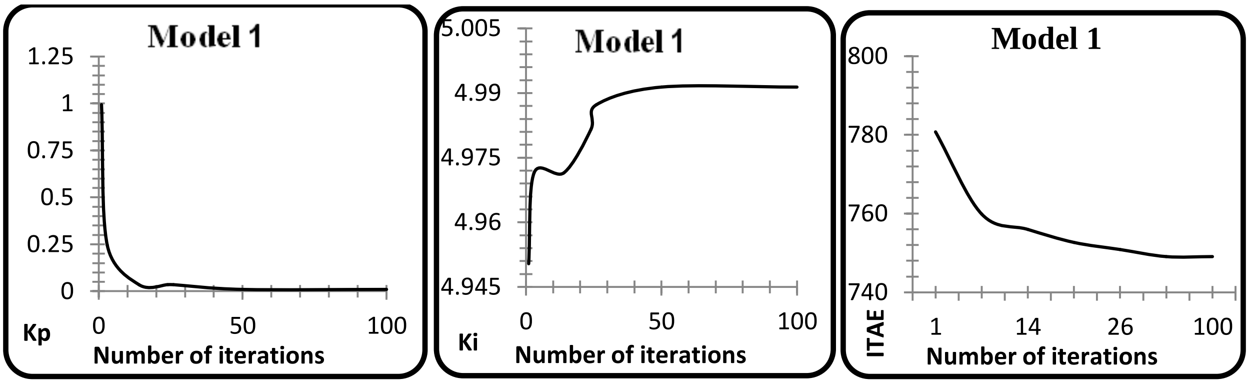

Figure3 Best solutions of Kp , Ki and ITAE response for 100 iterations(model 1)

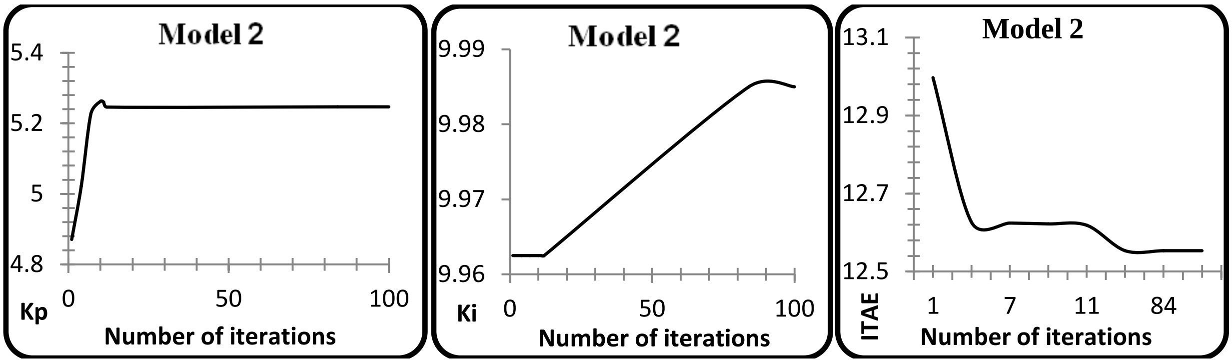

Figure4 Best solutions of Kp , Ki and ITAE response for 100 iterations(model 2)

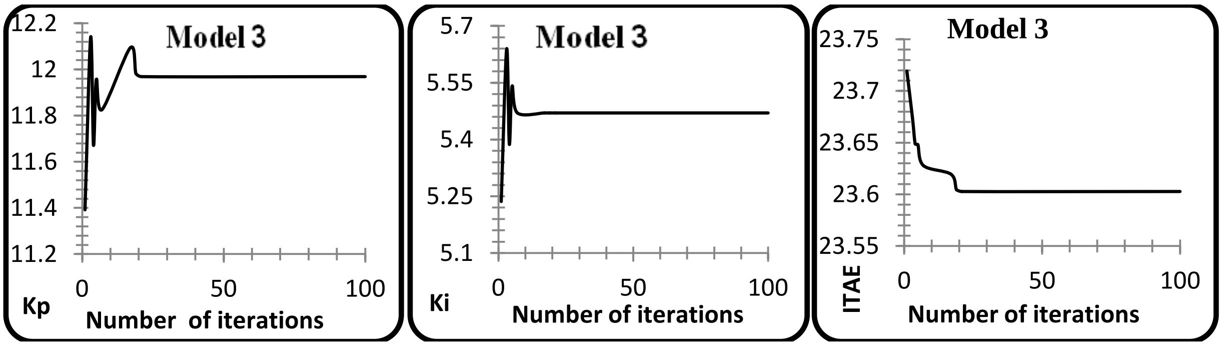

Figure5 Best solutions of Kp , Ki and ITAE response for 100 iterations(model 3)

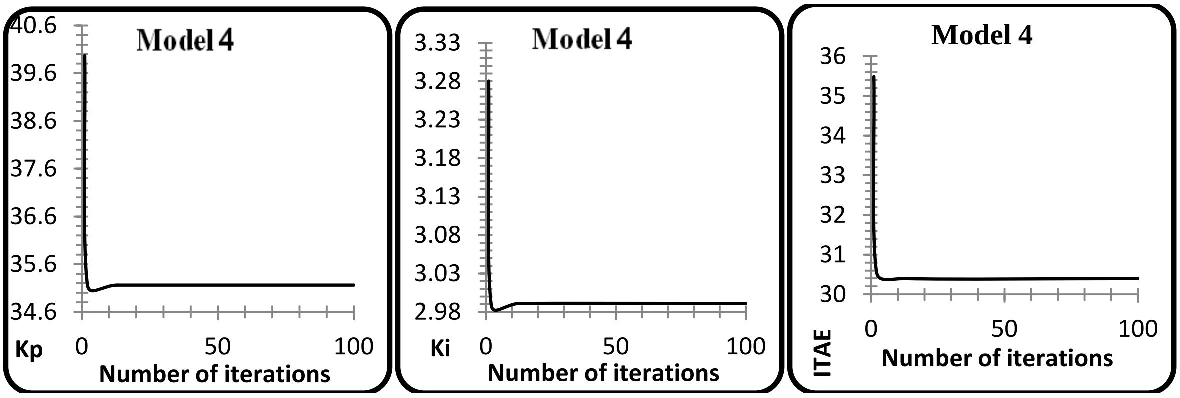

Figure 6 Best solutions of Kp , Ki and ITAE response for 100 iterations(model 4)

7. Results and Comparison

The simulation responses for GA algorithm based PI control scheme and gain scheduling adaptive control scheme were tested at various operating points. The simulated responses were obtained for multi step inputs .

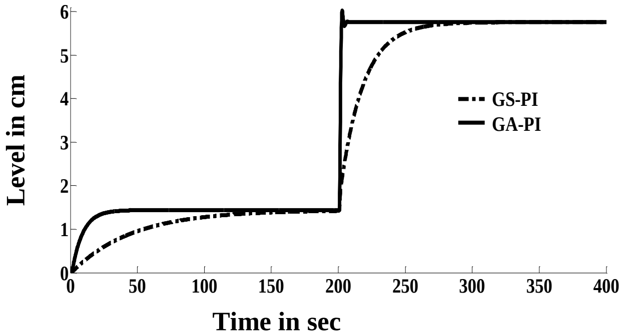

Figure7 Simulated response model 1 and 2 for setpoint change

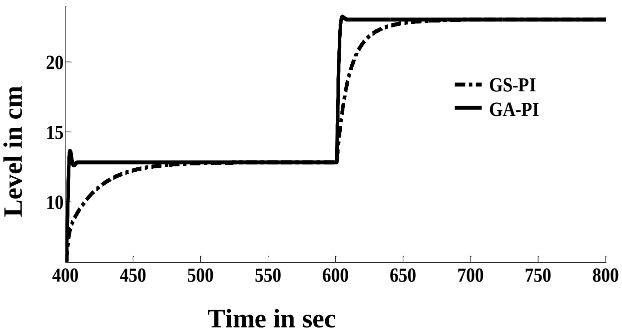

Figure8 Simulated response model 3 and 4 for setpoint change

Table-2 Tuned Gain Values of Controller

Sl No	Model	GS		GA	
		Kp	Ki	Kp	Ki
1	1	0.1509	0.9934	0.0097	4.9914
2	2	1.358	0.9069	5.2467	9.985
3	3	3.6379	0.5176	11.968	5.47
4	4	7.586	0.5314	35.162	2.991

Table-3 Comparison of Time Domain Specifications

Setpoint (cm)	Performance	GS	GA
1.4	Peak overshoot (%)	-	-
	T_r (sec)	125	65
	T_s(sec)	125	65
5.7	Peak overshoot (%)	-	6.25
	T_r (sec)	107	2
	T_s(sec)	107	11
12.8	Peak overshoot (%)	-	11.88
	T_r(sec)	148	2
	T_s(sec)	148	12
23	Peak overshoot(%)	-	1.95
	T_r(sec)	120	04
	T_s(sec)	120	11

At first, the mathematical model of conical tank level process is derived in terms of differential equation and an open loop response is obtained by performing step test in Matlab. The process is identified and closed loop control performances of various PI controllers were studied and results are presented in figure7 and figure8 for four regions. It is clear from the response the PI value which was obtained by the GA algorithm gives better performance than gain scheduling method in various perspectives. GA based Controller enables the process to reach the set value in minimum time and attains steady state.

Analysis shows that the design of proposed controller gives a better the performance by means of minimum rise time, minimum settling time and satisfactory over a wide range of process operations.

Conclusion

The objective of this work is successfully accomplished by implementing optimization technique in the process. The performances of the control schemes for four regions areanalyzed. The results in figure7 and figure 8 and table 3are clearly favor to GA based PI control scheme.It can be concluded that the tuned controller parameters based on GA optimization technique can yield a better performance than gain scheduling adaptive controller with lowest settling time, rise time and peak overshoot. The performance index in terms of integral of time absolute error criterion of the controller using GA algorithmis proved to be less than the gain scheduling control technique. The performances of controller are analyzed in time domain and are tabulated in table 3.

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