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Real Time Implementation of Enhanced Nonlinear PID Controller for a Conical Tank Process

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ABSTRACT

Level is one of the most important parameter that has to be monitored and controlled in any process industry. Conical tanks are widely used in many industries due to its shape which provides easy discharge of water when compared to other tanks. Moreover, liquid level control of a conical tank is still challenging for typical process control because of nonlinearities. Since PID control is the workhorse of almost 90% of the industries, an Enhanced Nonlinear PID (EN-PID) controller is proposed which exhibits the improved performance than the conventional linear fixed-gain PID controller, by incorporating a sector-bounded nonlinear gain in cascade with a conventional PID control architecture. To achieve the high robustness against noise, two nonlinear tracking differentiators are proposed to select high-quality differential signal in the presence of measurement noise. The main advantages of the proposed EN-PID controller lie in its high robustness against noise and ease of implementation. And in the proposed technique a EN-PID is designed and tuned using the Bee colony optimization (BCO) technique. The BCO algorithm is based on the model that is obtained from the communicative behavior of the honey bees. Simulation results performed on a conical tank level process are presented to demonstrate the performance of the developed EN-PID controller.

Keywords

Bee Colony Optimization, Conical Tank Level Process, Nonlinear PID

1. INTRODUCTION

Nonlinear PID control is the emerging control mechanism in process industries [1,2]. The main feature of nonlinear PID controller is that it can be easily designed using wiener model as cited by P.K.Bhaba. Although linear fixed-gain PID controllers are often adequate for controlling a nominal physical process, the requirements for high-performance control with changes in operating conditions or environmental parameters are often beyond the capabilities of simple PID controllers [3]. In order to enhance the performance of linear PID controllers, many approaches have been developed to improve the adaptability and robustness by adopting the self-tuning method, general predictive control, fuzzy logic and neural networks strategy, and other methods. Amongst these approaches, nonlinear PID (N-PID) control is viewed as one of the most effective and simple method [6]. The bee colony optimization algorithm is inspired by the behaviour of a honey bee colony in nectar collection. This biologically inspired approach is currently being employed to solve continuous optimization problems [4, 5]. The paper deals with the description of the conical tank level process and also it involves the function of various components required for the conical tank level process. Open loop data is generated and the input-output characteristics is analysed. An attempt has been made to design an Enhanced nonlinear PID controller for the conical tank by BCO based optimization technique.

2. CONICAL TANK PROCESS DESCRIPTION

The Experimental setup and the schematic diagram of the conical tank system is shown in the figure 1 & 2 respectively. The process consists of a process tank, submersible pump, two differential pressure transmitter, overhead sump, inlet valve and outlet valve and interfacing card.

Fig 1 Experimental set up

The proposed system consists of two conical tanks, which measures 50cm in height and in the top end diameter is 40cm, the tapering end is 14cm. It consists of differential pressure transmitter for measuring the pressure and gives in terms of milliamps. The two tanks are connected through an interacting pipe with valves. It has a reservoir to store water and this is supplied through the pumps to the tanks. The process tank is in the shape of an inverted cone fabricated from a sheet metal. Provisions for water inflow and outflow are provided at the top and bottom of the tank respectively. The height of the process tanks are 50 cm, the top radius is 40 cm and bottom radius is 14 cm. The Tullu 80 pump is used for discharging the liquid from the storage tank to Tank1. The inflow to the Tank1 is proportional to the speed of the pump. The pump discharges water at a rate of 800 liter/hour and has 6500 rpm.

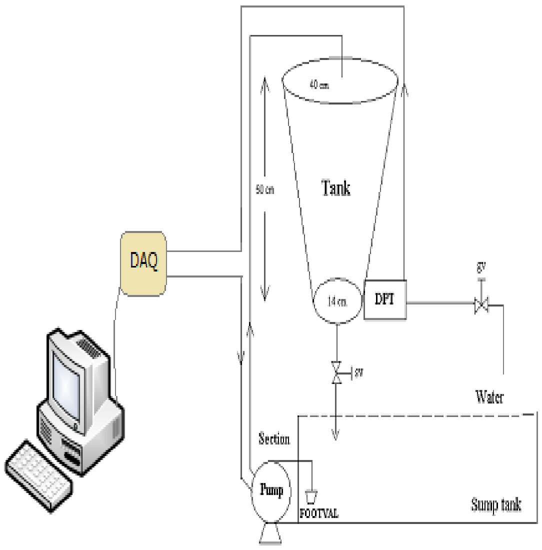

Fig 2. Conical tank system set up diagram

Gauge pressure is used for liquid level measurement hydrostatic, which uses pressure head. This process is equal to liquid height above the sensor multiplied by the specific gravity of the liquid. It is independent of the volume or vessel shape. In open vessel a pressure transmitter mounted near the bottom of tank will measure the pressure corresponding to the high-pressure side of the transmitter. The low-pressure side is vented to the atmosphere. A thin transparent tube made of plastic is provided externally to view the actual level of the liquid in the tank. A graduated scale placed parallel to the tube indicates the current level. Gate valves, one at the outflow of the tank1 and the other at the outflow of the tank2 are connected to maintain the level of water in the tanks. Clockwise rotation ensures the closure of the valve, thus stopping the flow of liquid and vice versa. A 25-pin male connector is used here to interface the hardware setup with the PC. The electrical output generated from the potentiometer is first converted into a digital value before applying it to the computer. A solenoid value is used to drain the water from the conical tank constantly at a constant rate to the storage tank. Otherwise if it is not kept at a optimum position, the water will reach a top position for lesser pump speed or will reach a lower position for a lot higher pump speed. To cover the entire range of the set up, this valve position should be kept properly.

The triggering circuit consists of the following modules:

i. Zero crossing detector(ZCD)

ii. Ramp generator

iii. Comparator and

iv. Astable controlled oscillator

Figure 3 shows the block diagram of the Thyristor trigerring circuit.

1.Zero Crossing Detector

This transforms the synchronizing signal into a square signal. The ZCD is constructed using opamp. The negative voltage pulses are removed by using diode at the output of the ZCD.

2. Ramp Generator

This is designed using a transistor and a RC charging network. The generated ramp signal is given to a comparator.

3. COMPARATOR

A comparator, as its name applies, compares a signal on one output of an op-amp with a known voltage called the reference voltage on the other input.

In the simplest form, it is nothing more than an open loop op-amp circuit. With two analog inputs and one digital output, the output may be (+) or (-) saturation voltage, depending on which input is larger.

In this circuit, the comparator is used to compare the ramp with a d.c voltage Vc which varies between 0 to 5 volts. The output of the comparator is used for triggering the thyristor.

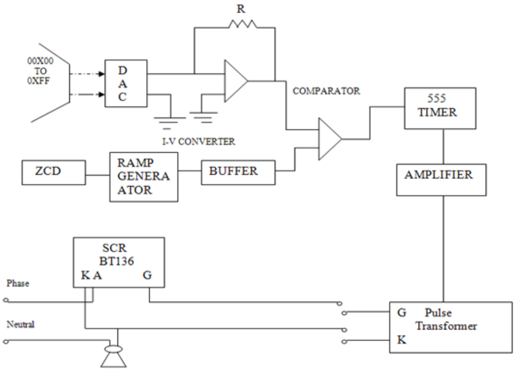

Fig 3 Block diagram of thyristor triggering circuit

4. OSCILLATOR

The main function of this is to generate alternating current or voltage waveform. More precisely, an oscillator is a circuit that generates a repetitive waveform of fixed amplitude and frequency without any external signal. In the triggering circuit this is required to produce a high frequency switching, so as to reduce thyristor gate dissipation. The pulse amplification is done by separate driver circuits and then fed to the isolation transformer.

Based on the error value, the controller generates a hexadecimal equivalent of the voltage that is to be applied to the submersible pump. this digitized value is then applied to an eight-bit digital to analog converter(DAC) followed by a current to voltage converter with an output voltage range(0-5)v .this voltage signal is compared with the reference voltage using a comparator circuit.

Table 1 Generated data for Inflow rate 15% and 30%

Inflow rate - 15%		**Inflow rate - 30%**	
Time (Secs)	Level (%)	Time (Secs)	Level (%)
5	2.71	7	4,5
10	3.2	12	5.71
30	3.83	25	6.33
40	4.31	50	6.8
50	4.6	75	7.52
100	5.01	100	7.95
150	5.07	300	9.01
200	5.07	400	9.04

The output of the comparator is applied to an Astable oscillator. The main function of this oscillator circuit is to generate alternating current (or) voltage waveform. More precisely, this circuit generates a repetitive waveform of fixed amplitude and frequency without any external signal. In the triggering circuit this is required to produce high frequency switching so as to reduce thyristor gate dissipation. The pulse amplification is done separately using driver circuit and then fed to the pulse transformer.

3. DATA GENERATION AND PROCESS MODELING BY CONVENTIONAL TECHNIQUES

The data is generated using the open loop method. Traditional methodology for optimizing and tuning PID loops rely on ‘open-loop’ tests, whereby the loop is placed in manual mode and the controller output is moved, usually in a step-wise fashion.

3.1. Steps Involved In Open Loop Data Generation

1. Initially the pump is turned on and its speed is adjusted in the manual mode.
2. Then in the automatic mode, the LABVIEW software is logged in.
3. The flow rate is measured using the rotameter.
4. Set point for various flow rates are given via the software.
5. The process is allowed to reach the steady state.
6. The data generated is stored in the excel sheet.
7. Finally the response for various inflow rates is obtained from which K, τ and θ can be determined.

Open loop data are generated in the conical tank system by varying the inflow rate and noting down the respective level. Table 1 shows the sample data generated for an inflow of 15% and 30%. Figure 4 and 5 shows the response of the conical tank for an inflow rate of 15% and 30%.

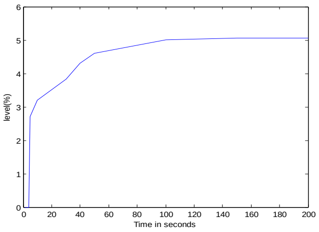

Fig 4 Response for inflow rate 15%

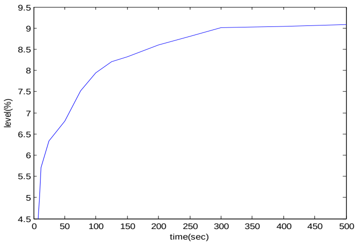

Fig 5 Response for inflow rate 30%

3.2. Process Input-Output Characteristics

The input to tank is varied in steps from minimum to maximum and the corresponding steady state levels in the tank are noted. Finally the obtained data are plotted. Table 2 shows the steady state characteristics of the tank with input flow to the tank in percentage and level of the tank in cm.

From the Input-output characteristics shown in figure 6, it is clear that the process is non-linear. So for the design of the controller, the process tank is modeled into five linear.

Table 2. Steady state characteristics for the tank

Input to Tank in %	Level in Tank in cm
15	2.89
30	5.18
40	7.44
60	20.08
75	25.8
95	40.08

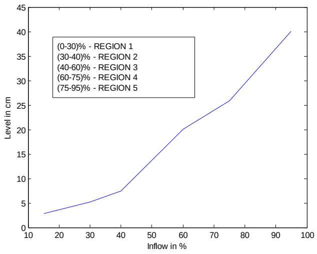

Fig 6 Inflow and level in tank

4. ENHANCED NONLINEAR PID FOR CONICAL TANK LEVEL PROCESS

Proportional-integral-derivative (PID) controllers have been the most popular and the most commonly used industrial controllers in the past years. The popularity and widespread use of PID controllers are attributed primarily to their simplicity and performance characteristics. In order to enhance the performance of linear PID controllers, many approaches have been developed to improve the adaptability and robustness by adopting the self-tuning method, general predictive control, fuzzy logic and neural networks strategy, and other methods . Amongst these approaches, Nonlinear PID (N-PID) control is viewed as one of the most effective and simple method for industrial applications . Nonlinear PID control may be any control structure of the following form:

$$u(t) = K_p(.)e(t) + K_i(.)\int e(\tau)d\tau + K_d(.)e(t)$$

Where $K_p(.)$, $K_i(.)$ and $K_d(.)$ are time-varying controller gains, which may depend on system state, input, or other variables, and u(t) and e(t) are the system input and error, respectively. Figure 7 shows the block diagram of the nonlinear PID controller.

The enhancement of the controller is achieved by adapting its response based on the performance of the closed-loop control system. When the error between the commanded and actual values of the controlled variable is large, the gain amplifies the error substantially to generate a large correction to rapidly drive the system output to its goal. As the error diminishes, the gain is automatically reduced to prevent excessive oscillations and large overshoots in the response. Because of this automatic gain adjustment, the N-PID controllers enjoy the advantage of high initial gain to obtain a fast response, followed by a low gain to prevent an oscillatory behavior.

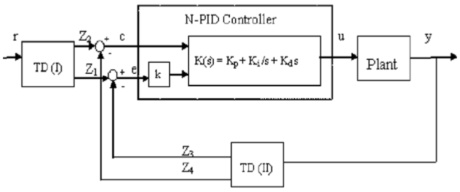

Fig 7 Block diagram for Nonlinear PID Controller

- Nonlinear tracking differentiator, TD(I) is referred to as the following system: given a reference signal r(t), the system provides two signals Z_1 and Z_2, such that $Z_1 = r(t)$ and $Z_2 = \dot{x}(t)$.
- Similarly TD(II) provides the output y(t) as two signals
  $Z_3 = y(t)$ and $Z_4 = \dot{y}(t)$ respectively.

The error e(t) is given by $Z_1 – Z_3$ and the nonlinear gain is introduced to act on error.

The proposed enhanced nonlinear PID (EN-PID) controller consists of a sector-bounded nonlinear gain k(e), a linear fixed-gain PID controller expressed by $K(s) = K_p + K_i/s + K_d s$, and two nonlinear tracking differentiators (TDs) where k_p, k_i, and k_d are proportional, integral and derivative gains, which can be determined by the Ziegler–Nichols criterion. The nonlinear gain k(e) is a sector-bounded function of the error e(t), and acts on the error to produce the ‘‘scaled’’ error f(e) = K(e).e(t). Using the high-quality differential signal selected by the developed TDs, the following enhanced nonlinear N-PID control law is developed as

$$u(t) = \left[K_p + K_i\int_0^t dt + K_d\frac{d}{dt}\right].f(e)$$

$$u(t) = K_p\,[k(e).e(t)] + K_i\left[\int_0^t k(e).e(t)\right]dt + K_d\,[k(e).c(t)]$$

where e(t) and c(t) are expressed as, respectively,

$$e(t) = Z_1 - Z_3$$
$$c(t) = Z_2 - Z_4$$

- Nonlinear systems, where EN-PID control is used to accommodate the nonlinearity, usually to achieve consistent response across a range of conditions.
- Linear systems, where EN-PID control is used to achieve performance not achievable by a linear PID control, such as increased damping, reduced rise time for step or rapid inputs, improved tracking accuracy, and friction compensation.

5. BEE COLONY OPTIMIZED ENHANCED PID CONTROLLER FOR CONICAL TANK LEVEL PROCESS

The Bees algorithm is developed to obtain the optimal controller parameters such as K, K_p, K_i and K_d Then it is implemented in EN-PID controller to obtain the response. Figure 8 shows the block diagram of the EN-PID controller optimized using bee colony technique. The Bees algorithm is developed to obtain the optimal controller parameters such as K_P, K_I, K_D and K.

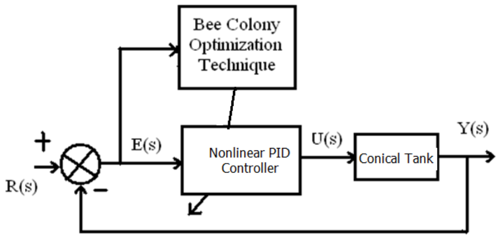

Fig 8 Block diagram of Non-linear PID controller using Bee colony optimization technique

5.1Performance Index

In this section, the feedback controller design is formulated as an optimization problem and the solution is sort through steps of Ant Colony Optimization (ACO). The technique uses ACO to tune the PID parameters online for a minimum ITAE for each region separately. Due to the variety of PID control law permutations, it is necessary to specify a minimum set of attributes that is PID controller is assumed to be of non-interacting form as defined below:

$$G_c(s) = K_p + K_i \frac{1}{s^{\lambda}} + K_d s^{\mu}$$

By suitable transformation of the parameters this form is converted to interacting form. Minimizing the following error criteria generates the controller parameter

$$ITAE = \int_0^T |r(t) - y(t)| \;\; t \;\; dt$$

where r(t) = reference input, y(t) = measured variable
At first, the bee, i.e. the PID parameters are randomly initialzed. The fitness function is defined as 1/ITAE. Smaller the fitness function, the better performance of the system response with the specified PID parameters.

5.1. Algorithm: Bee colony Optimization for EN-PID controller tuning

1. Intialize the population of solutions $x_{i,j}$
2. Evaluate the population
3. Cycle =1
4. Repeat
5. Produce new solutions (food source positions) $\nu_{i,j}$ in the neighbourhood of $x_{i,j}$ for the employed bees using the formula $\nu_{i,j} = x_{i,j} + \phi_{ij}(x_{i,j} - x_{k,j})$ where k is the solution in the neighbourhood of I, ϕ is a random number and evaluate them
6. Apply the greedy selection process between x_i and ν_i
7. Calculate the probability values P_i for the solutions x_i by means of their fitness values using the
   $$P_i = \frac{fit_i}{\sum_{i=1}^{SN} fit_i}$$
   The fitness values of solutions are calculated as
   $$fit_i = \left\{ \begin{matrix} \dfrac{1}{1+f_i} & \text{if } f_i \ \geq 0 \\ 1+\text{abs}(f_i) & \text{if } f_i \ < 0 \end{matrix} \right\}$$
   Normalize P_i values into [0,1]
8. Produce the new solutions (new positions) ν_i for the onlookers from the solutions x_i, selected depeding on Pi and evaluate them
9. Apply the greedy selection process for the onlookers between ν_i and x_i
10. Determine the abandoned solution (source) if exists and replace it with a new randomly produced solution x_i for the scout using
    $x_{ij} = \min_j + \text{rand}(0,1)*(\max_j - \min_j)$
11. Memorize the best food source position (solution) achieved so far
12. Cycle = cycle +1
13. Until cycle = Maximum cycle Number

The termination criterion can be in two was: either by ending the program when objective function value reaches a reasonably low value or after a finite number of iterative steps. In the present case, the program was terminated after 45 iterations.
The table 3 shows the optimal controller parameters that can be applied for the non-linear controller, obtained using Bee Colony Optimization technique.

Table 3 Optimal controller parameters for non-linear controller

K	K_P	K_I	K_D
8.5931	7.1525	3.1027	8.7562

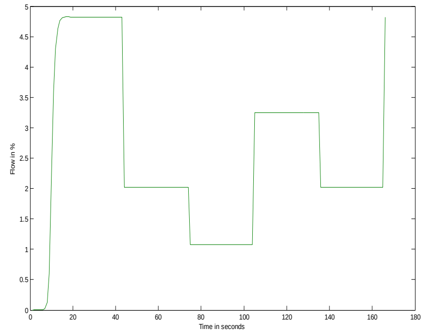

Fig 9 Response of enhanced non-linear PID controller

6. CONCLUSION

The open loop data is generated by varying the flows and measuring the respective levels. The I/O characteristics is plotted for the process and piecewise linearization is done. The EN-PID controller model is developed and implemented in the process for non-linear control. The Bee colony optimization algorithm is developed and implemented in MATLAB to give optimal values of K, K_p, K_i and K_d. Finally the BCO tuned EN-PID controller is implemented in the real time process.

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