Optimized PID$^2$D$^2$ controller based on genetic algorithm for three-tank liquid level control System

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Abstract

This paper considers the optimized PID$^2$D$^2$ controller based on genetic algorithm for three tank liquid level control systems. The process control of the liquid level inside the tank is an important issue for today’s industrial processes due to the requirement of mixing the liquid components. Thus, the designing and implementation of the controllers for such a system are major problems which need to be considered. At the moment, most controllers using in the process control are basic PID controllers. However, sometimes the poor performance for the system with PID controller will be acquired; i.e., the slow settling time and high overshoot. Therefore, this paper proposes an efficient method of tuning controller PID$^2$D$^2$ parameters by using genetic algorithm (GA). According to the proposed technique in this paper, the simulation results that the improvement of the settling time and overshoot for the system is obtained by comparing with the tuning controller PID parameters based on GA and PSO techniques.

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1. Introduction

Liquid level control is one of the most important technologies in the industrial’s process which is able to determine the quality of its products, and it is one of safety system in the process. However, the liquid level system has some problem with the maximum overshoot, steady-state error and the oscillating transient response. These problems can be reduced or solved by applying the closed loop control system between outlet and inlet systems by

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PID controller or other methodology.

PID controller is a kind of widely famous tools applied in processing control in the world’s industrial which is so extensive, simple and comfortable to use. Hence, there are many factors effect to the internal parameters of PID controller, i.e., P, I and D in each plant. The advantage of using a PID controller is that it can provide the robust performance for a wide range of operating conditions by the values of $K_p$, $K_i$ and $K_d$ which are different and variable. It was very interesting from a lot of research studies related to the various optimization methods to find the optimal parameters to control the plant e.g. tuning of PID controller for liquid level tank system using intelligent techniques [1], PID tuning by genetic algorithm for double-tank liquid level control [2], and three tank system using hybrid GA-PSO algorithm [3]. However, in the studying of those researches, it is found out that there are still some techniques need to be improved for controlling the parameters to minimize the objective target.

The objective of this paper is to implement a PIDFID$^2$ controller based on genetic algorithm for obtaining the optimal parameters on the PID controller for three-tank system that is the interacting system type. A desire of the minimum overshoot, rise time, settling time and peak are obtained by minimizing the objective function which can be determined by GA function on MATLAB program. The result is then compared with the results of PID controller based on GA tuning method, PSO tuning method and hybrid GA-PSO to how that the proposed method of this paper performs better than other techniques.

2. Liquid level control

Liquid level control in this research is a type of three-tank interacting system. All tanks are laid at the same level in the horizontal line in order to stably control the flowrate of each tank. To be successful in controlling flowrate supply to the 1st tank and the outlet control level is at the 3rd tank, the target setting must be initiated to meet and the reduction of some errors is required.

![Fig. 1. Mathematical Modeling of Interacting system [3]](image)

The mathematical modeling to represent the three-tank system can be shown as follows.

$$Q_1 - Q_2 = A_1 \times \frac{d(H_1)}{dt}, Q_2 - Q_3 = A_2 \times \frac{d(H_2)}{dt}, Q_3 - Q_4 = A_3 \times \frac{d(H_3)}{dt}$$ (1)

$$Q_2 = \frac{H_2 - H_3}{R_1}, Q_3 = \frac{H_3 - H_4}{R_2}, Q_4 = \frac{H_4}{R_3}$$ (2)

Where $H_1$, $H_2$, $H_3$ are the liquid level in 1st tank, 2nd tank and 3rd tank respectively. $Q_1$ is inlet flowrate of 1st tank. $Q_2$, $Q_3$, $Q_4$ are outlet flowrate of the 1st tank, 2nd tank and 3rd tank respectively. $A_1, A_2, A_3$ are the cross section area of the 1st tank, 2nd tank and 3rd tank respectively. At the outlet of each tank, there is a control valve with resistance $R_1, R_2$ and $R_3$ of the 1st tank, 2nd tank and 3rd tank respectively.

After substituting Laplace transform transfer in equation (1) and (2), transfer function $H_1(s) / Q_1(s)$ could be written in equation (3). Based on [3], the parameter configurations are $A_1 = A_2 = 1 \text{m}^2$, $A_3 = 0.5 \text{m}^2$, $R_1 = R_2 = 2 (\text{m}/(\text{m}^3/\text{s}))$, and $R_3 = 4 (\text{m}/(\text{m}^3/\text{s}))$.

$$G(s) = \frac{H_3(s)}{Q_1(s)} = \frac{2}{4s^3 + 14s^2 + 11s + 1}$$ (3)
3. PID controller

The PID controller is simple and easy to implement. PID controllers have been used for decades. The transfer function of PID controller can be represented in (4) where $U(s)$ is the control controller output, $E(s)$ is the tracking error signal, $K_p$ is the proportional gain, $K_i$ is the integral gain and $K_d$ is the derivative gain. The proportional part of the controller reduces the error response to disturbance. The integral part of the controller eliminates the steady state error and the derivative part, provides fast dynamic response and improves the stability of the system. The optimal parameters setting of a PID depends on the plant characteristic. To design the PID controller, the three gain parameters must be selected in the closed-loop control system and provide the desired response with small or no overshoot in the step response.

$$G_c(s) = \frac{U(s)}{E(s)} = K_p + \frac{K_i}{s} + K_ds$$

(4)

4. Genetic algorithm (GA)

The genetic algorithm theory is a methodology for solving practical problems based on natural selection randomization. The basic goal to optimize the fitness function. A possible solution to specific problem is seemed as an individual. The correction of a number of individual is called a population. The current population reproduces new individuals called the new generation. The new generation is supposed to have better performance than the individual of the previous generation. GA can be applied to a number of control methodologies for improving the overall system performance. GA optimization based on PID controller can be implemented following steps below.

1. Create a population for $K_p$, $K_i$, $K_d$ values; initialization of the population of chromosomes for $K_p$, $K_i$ and $K_d$.
2. Evaluate the cost function (fitness function) for all chromosomes and run the model on MATLAB.
3. Select parent chromosomes, do crossover and mutation all three parameters and be done by automatically using the fitness function.
4. Find the best values of $K_p$, $K_i$ and $K_d$.
5. Set the iteration and compare the best values with the previous values, if the results show equal, the optimizations process is done, and then process could be stopped.
6. Compare the best values with the previous ones, if they are not equal the new population will replace and start the process again.

5. Simulation results

In this research, the transfer function of the previous conventional method [3] is applied with the simulation and parameter configurations performing on MATLAB program. Genetic algorithm is a functional tool in MATLAB to support this studying. The fitness function is a summarization of both errors and overshooting of the process.

First step: Find out the parameters with the plant’s transfer function in equation (3) which its diagram is shown in Figure 2. The PID parameters results in this step are $K_p1 = 3.29$, $K_i1 = 0.281$ and $K_d1 = 24.206$.

Second step: Tune PID by genetic algorithm (GA) again to optimize the parameters with the plant’s transfer function in equation (3) combined with the result parameters in the first GA, which its diagram is shown in Figure 2. The parameter results in this step are $K_p2 = 3.81$, $K_i2 = 1.286$ and $K_d2 = 0.934$.

Final step: Plot graphs from both previous research and new results, then check the step response from all methods in the MATLAB and compare the results and record results of each method as PID controller based on GA, PSO, GA-PSO and PID\textsuperscript{2}D\textsuperscript{2} controller based on GA in Table 3.
The results of optimized parameters $K_p$, $K_i$ and $K_d$ are shown in Table 1. There are 2 steps of GA parameters which are 1) optimizing existing plant. 2) optimizing the existing plant with the results from 1st GA.

Table 1. Optimized PID and PIDI$^2$D$^2$ Parameters

<table>
<thead>
<tr>
<th>Tuning Method</th>
<th>$K_p$</th>
<th>$K_i$</th>
<th>$K_d$</th>
</tr>
</thead>
<tbody>
<tr>
<td>PID GA</td>
<td>7.546</td>
<td>0.4594</td>
<td>9.9120</td>
</tr>
<tr>
<td>PID PSO</td>
<td>5.000</td>
<td>0.4816</td>
<td>8.000</td>
</tr>
<tr>
<td>PID GA-PSO</td>
<td>5.000</td>
<td>0.4834</td>
<td>5.905</td>
</tr>
<tr>
<td>PIDI$^2$D$^2$ GA</td>
<td>$K_{p1} = 3.29$, $K_{p2} = 3.81$</td>
<td>$K_{i1} = 0.281$, $K_{i2} = 1.286$</td>
<td>$K_{d1} = 24.206$, $K_{d2} = 0.934$</td>
</tr>
</tbody>
</table>

Table 2. Step response performance for PID and PIDI$^2$D$^2$ controllers

<table>
<thead>
<tr>
<th>Step response characteristics</th>
<th>Controller Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Plant with PID GA</td>
</tr>
<tr>
<td>Rise Time</td>
<td>0.9256</td>
</tr>
<tr>
<td>Settling Time</td>
<td>6.9148</td>
</tr>
<tr>
<td>Overshoot</td>
<td>0.7548</td>
</tr>
</tbody>
</table>

Table 2. shows step response characteristics composed of rise time, settling time, overshoot and. It could be summarized that the step response of PIDI$^2$D$^2$ based on GA optimization is more efficient than other methods such as PID based on GA, PSO and Hybrid GA-PSO for the process of liquid level control system since the characteristics of PIDI$^2$D$^2$ based on GA results shortest rise time and settling time and lowest overshoot and peak.

Fig. 3. Comparison of PID Controller for liquid level control

Figure 3 shows all the results method; through the blue line, it can obviously illustrates that PIDI$^2$D$^2$ based on GA optimization is more efficient than PID controller based on GA, PSO and Hybrid GA-PSO for the process of liquid level control system as expected result referred to this paper.

6. Conclusion

The PIDI$^2$D$^2$ controller based on genetic algorithm (GA) was designed for liquid level control system. To prove the PIDI$^2$D$^2$ controller based on GA providing the optimal solution and the best performance when compared with a basic PID controller, the step response was simulated for these comparisons. The results are shown that the percent overshoot, rise-time and settling time of the closed-loop control system which is optimized with PIDI$^2$D$^2$ controller based on GA, are better than the results from PID controller. In summary, the proposed method of PIDI$^2$D$^2$ controller is superior to the PID controller and can be a great significance in practical aspect as well.

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