PERFORMANCE OPTIMIZATION AND COMPARISON OF VARIABLE PARAMETER USING GENETIC ALGORITHM BASED PID CONTROLLER

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ABSTRACT

The performance optimization and comparison of variable parameter nonlinear PID (NL-PID) and Genetic Algorithm (GA)[1] based PID controller is achieved in this paper. In the proposed method, an error function depending on the system input and output is created and a nonlinear PID controller is designed by using the defined error[2]-[5] function. The nonlinear PID controller changes its own parameters over time according to the output response. Genetic algorithm based PID controller performance is compared with the NL-PID controller[7] and Ziegler-Nichols PID controller. Simulation results show that the effects of the PID controllers; nonlinear GA based and Ziegler-Nichols.

Keywords - Genetic Algorithm, Variable parameter PID, Ziegler-Nichols method and Gaussian error function.

I. INTRODUCTION

PID control schemes based on the classical control theory have been widely used for various industrial control systems for a long time [1]. Generally, it is simply to determine parameters and easy to apply them. Thus, PID controller is the most common form of feedback. The controllers consist of in many different forms.

Nonlinear Proportional-Integral-Derivative control (NPID control)[2-10] is a nonlinear control construction in which the controller gains are modulated according to system state, input, error or other variables. By modulating the controller gains it is possible to achieve:

1. Increased damping,
2. Reduced rise time for step input
3. Improved tracking accuracy
4. Friction Compensation.

Genetic Algorithm (GA) is a stochastic global search method that mimics the process of natural
evolution. The genetic algorithm starts with no knowledge of the correct solution and depends entirely on responses from its environment and evolution operators (i.e. reproduction, crossover and mutation) to arrive at the best solution. By starting at several independent points and searching in parallel, the algorithm avoids local minima and converging to sub optimal solutions.

In this way, GAs have been shown to be capable of locating high performance areas in complex domains without experiencing the difficulties associated with high dimensionality, as may occur with gradient decent techniques or methods that rely on derivative information.

In this study, GA based PID parameters and NL-PID parameters allied to change of error are analyzed and nonlinear functions of Proportional (P), Integral (I) and Derivative (D) depending on error and GA-PID parameters are presented respectively.

II. DESIGN OF PID CONTROLLER, PERFORMANCE INDICES AND GENETIC ALGORITHMS

A general body of a PID control system is shown in Fig.1, where it can be seen that in a PID controller, the error signal e(t) is used to generate the proportional, integral, and derivative actions, with the resulting signals weighted and summed to form the control signal u(t) applied to the plant model.

![Figure 1. A typical PID control system](image)

Figure 1. A typical PID control system

A. PID Controller Design Methods

Despite there are many design methods for PID controllers, the most widely used design methods in the literature are Ziegler-Nichols rules, Chien-Hrones-Reswick PID tuning algorithm, Cohen-Coon tuning algorithm, Wang-Juang-Chan tuning formulae.

The Ziegler-Nichols[3] design method which was presented in mid-20th century is the most popular methods used in process control to determine the parameters of a PID controller. One of the important specialties of this system guarantees the stabilities.

PID control consists of three types of control, Proportional, Integral and Derivative control.

Proportional Control:
The proportional controller output uses a ‘proportion’ of the system error to control the system. However, this introduces an offset error into the system.

Integral Control:
The integral controller output is proportional to the amount of time there is an error present in the system. The integral action removes the offset introduced by the proportional control but introduces a phase lag into the system.

Derivative Control:
The derivative controller output is proportional to the rate of change of the error. Derivative control is used to reduce/eliminate overshoot and introduces a phase lead action that removes the phase lag introduced by the integral action.
Continuous PID Controller:
The three types of control are combined together to form a PID controller with the transfer function.

Discrete PID Controller:
This project proposes to use a PID controller that is tuned online. To facilitate the real time aspect of this, a discrete PID controller must be used. The PID controller will be discretised using the Trapezoidal Difference method.

Trapezoidal Difference Method:
The trapezoidal difference method is the most popular method for discretizing a PID controller. The trapezoidal difference method maps a stable continuous controller to a stable discrete controller.

![Figure 2. Unit response of the designed system](image)

B. Genetic Algorithms

A GA is an optimization technique in which the solution space is searched by generating a population of candidate individuals to find best values [11]. This process is similar to natural evolution of biological individuals. These are generally having global search capability, better robustness and not depending on initial conditions. These algorithms present excellent global optimization points to solve system optimization problem.

Generally, GAs consist of three fundamental operators: reproduction, crossover and mutation

Reproduction:
During the reproduction phase the fitness value of each chromosome is assessed. This value is used in the selection process to provide bias towards fitter individuals. Just like in natural evolution, a fit chromosome has a higher probability of being selected for reproduction.

An example of a common selection technique is the ‘Roulette Wheel’ selection Method

Crossover:
The crossover operations swap certain parts of the two selected strings in a bid to capture the good parts of old chromosomes and create better new ones. Genetic operators manipulate the characters of a chromosome directly, using the assumption that certain Individual’s gene codes, on average, produce fitter individuals. The crossover probability indicates how often crossover is performed.

There are two stages involved in single point crossover:
1. Members of the newly reproduced strings in the mating pool are ‘mated’ (paired) at random.
2. Each pair of strings undergoes a crossover as follows: An integer k is randomly selected between one and the length of the string less one.

Swapping all the characters between positions k+1 and L inclusively creates two new strings.

Mutation:
Using selection and crossover on their own will generate a large amount of different strings. However there are two main problems with this:
1. Depending on the initial population chosen, there may not be enough diversity in the initial strings to ensure the GA searches the entire problem space.
2. The GA may converge on sub-optimum strings due to a bad choice of initial population.
C. Performance Indices

In order to select the best controller, we define a cost function. The cost function mainly derives on how the controller reacts to a given disturbance. There are many of cost functions. In fact, we can define in infinitive criterion. It is a quantitative measure of the performance of a system and is chosen so that emphasis is given to the important system specifications. There are many type of performance indices is described in literature.

A performance index[5-7] is criterion measures that are based on the integral of some function of the control error and on possibly other variables (such as time).

For example, IAE integrates the absolute error over time. It does not 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.

The Integral of the Square Error (ISE) penalizes for large errors more than for small errors. It tends to eliminate large errors quickly [11].

III. PROPOSED METHODS

Considering the above classical methods, they present poor robustness, high overlapping, late rise time etc. Thinking of fixed parameters causes this result in steady state and temporary state. In defiance of these explanations, better system response is occurred when the PID parameters are looked into depending on error function owing to they are variable. Correspondingly, system responds better than traditional PID controller methods when the PID fixed parameters determine with genetic algorithms based on objective functions or designing them as a nonlinear form.

Considering the step response of a common control system we need to decrease overlapping and oscillation, accelerate the system response and initialize the steady state error. For these conditions the parameters can be analyzed like this way.

The proportional gain (K_p) contribute to accelerate system response, decrease the settling time however increase the oscillation and in the large values system becomes unstable. It is benefitted from “error function” (also called Gaussian error function It) to determine NL-PID variable coefficients (see in Fig.3).

![Error Function](image)

Figure 3. Error Function

IV. SIMULATION RESULTS

The control methods mentioned above was examined with the classical common method Ziegler – Nichols and comparison of some results can be seen on Table I. These methods and Z-N PID values were compared to some criterion and implementing methods values were better than Ziegler – Nichols method.

The designed model is shown in Fig. 4. For this simulation two different plants model tested. The coefficients (a_i, b_i, c_i) shown in the Table I were obtained for the application. Steady state error and performance indices were measured via the block diagram and system response curves were figured for both. Two kind of plant was used in this paper which is third order process and fourth order system. Output responses and changing of NL-PID parameters were showed in Fig. 5.
Under the conditions shown in Fig 5 of this experiment, it can be seen that the ISE and MSE objective functions perform almost identically, having a smaller rise time, smaller overshoot and bigger settling time than the other controllers. Each of the genetic algorithm-tuned PID controllers outperforms the Ziegler-Nichols tuned controller in terms of rise time and overshoot but only the ITAE and IAE functions outperform it in terms of settling time. The MSE objective function was chosen as the primary performance criterion for the remainder of this project due to its smaller rise time and smaller overshoot than any other method in conjunction with a slightly faster compile time due to there being just one multiplication to be carried after the error has been calculated. This is coupled with the fact that MSE has been a ‘proven measure of control and quality for many years’ makes it the ideal performance criterion for this project.

<table>
<thead>
<tr>
<th>Plant</th>
<th>ISE</th>
<th>IAE</th>
<th>$e_{ss}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZN PID</td>
<td>3.153</td>
<td>5.075</td>
<td>-.0041</td>
</tr>
<tr>
<td>NL PID</td>
<td>2.783</td>
<td>4.012</td>
<td>-.0325</td>
</tr>
<tr>
<td>GA PID</td>
<td>2.012</td>
<td>3.001</td>
<td>-.0115</td>
</tr>
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Table I. Comparison Value between Implement Methods
V. CONCLUSION

In spite of the fact that controllers designed by the Ziegler-Nichols rules give a good performance, they create poor robustness and high exceeding. It is obvious that in case of few parameter changes of the plant led to decline of the performance of the conventional PID controller drastically. The coefficients of GA-PID parameters were set with idea of the objective function, called mean square error (MSE).

The methods presented gave lower exceeds, short settling time and better performance indices than that of classical form for the third and fourth order systems. Especially, genetic algorithm which converge the minimal points used to obtain the best PID controller parameters. The main advantage of it was to find optimal points of PID parameters and as it seen in the graphics, GA-PID results were the best ones in the plants. However the GA designed PID is much better in terms of the rise time and the settling time.

REFERENCES