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PID Controller Optimization By Soft Computing Techniques-A Review

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Abstract

PID controllers are widely used in industrial plants because it is simple and robust. So the control engineers are on look for tuning procedures. This paper gives the review of some soft computing techniques which are used for PID tuning. Soft computing techniques make easy of the tuning of parameters of controller to get desired response.

Keywords: *PID Controllers; Tuning; genetic algorithm; particle swarm optimization*

1. Introduction

As PID controller has simple configuration, easy to distinguish, and the tuning technique provides adequate performance in the massive majority of applications, the PID controller is commonly used in most industrial processes. But the parameter tuning of PID is very difficult. Basically PID controller contains of three separate parameters: proportionality, integral and derivative values are represented by k_p, k_i, and k_d. Appropriate setting of these parameters will improve the dynamic response of a system. It reduces overshoot, eliminate steady state error and increase stability of the system [1]. The transfer function of a PID controller is:

$$C(s) = \frac{U(s)}{E(s)} = k_p + \frac{k_i}{s} + k_d s \quad (1)$$

The fundamental structure of a PID control system is shown in Figure 1. Once the set point has been changed, the error will be calculated among the set point and the actual output. The error signal, $E(s)$, is used to create the proportional, integral, and derivative arrangement, with the subsequent signal weighted and summed signals are used to form the control signal, $U(s)$, applied to the plant model. The different output signal will be achieved. This different actual signal will be applied to the controller, and again the error signal will be computed. Control signal, $U(s)$, will be applied to the plant. This process will run constantly until steady-state error will reduce.

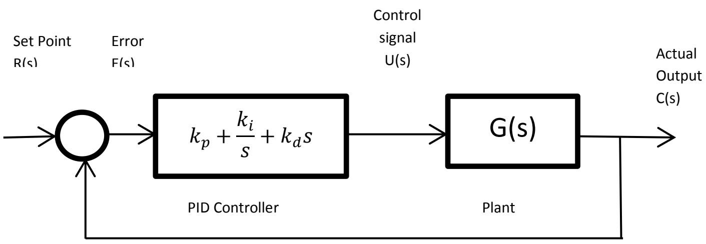

Figure 1. PID Control Structure

Proportional Term: This term increase the response as the closed loop time constant decreases with the proportional constant but does not change the order of the system as

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the output is just proportional to the input. The error or offset does not remove with the help of proportional constant. Integral term: This term eliminates the offset as it increases the type and order of the system by 1. This term also increases the system response but at the cost of constant oscillations.

Derivative term: This term mainly reduces the oscillatory response of the system. It neither changes the type and order of the system nor affects the offset.

A change in the proportionality constants of these terms changes the type of response of the system. That is why PID tuning, which is the variation of the PID proportionality constants, is of utmost importance. There have been various types of techniques applied for PID tuning. These techniques can be broadly classified as classical and computational or optimization techniques.

A. Classical Techniques

Classical techniques make certain assumptions about the plant and the desired output and try to obtain logically, or graphically some feature of the process that is then used to decide the controller settings. These techniques are computationally very fast and simple to implement. But due to the conventions made, the controller settings usually do not give the desired results directly and further tuning is required.

B. Optimization Techniques

These are techniques which are usually used for data modeling and optimization of a cost function, and have been used in PID tuning. Few examples are neural networks (computational models to simulate complex systems), genetic algorithm and differential evolution. The optimization techniques are used to minimize the cost functions. Some cost functions are as:

- Integral Absolute Error

$$\text{IAE} = \int_0^{\tau} |e(t)| \tag{3}$$

- Integral Square Error

$$\text{ISE} = \int_0^{\tau} |e(t)|^2 \tag{4}$$

- Integral Time Absolute Error

$$\text{ITAE} = \int_0^{\tau} t|e(t)| \tag{5}$$

Integral Time Square Error

$$\text{ITSE} = \int_0^{\tau} t|e(t)|^2 \tag{6}$$

Computational models are used for self-tuning or auto tuning of PID controllers. Self-tuning of PID controllers essentially sets the PID parameters and also models the process by using some computational model and compares the outputs to see if there are any process variations, in which case the PID parameters are reset to give the desired response.

2. Computational and Intelligent Optimization Techniques

There are various optimization techniques are used to optimize the parameters of PID controller. Some of them are discussed below:

A. Genetic Algorithm

Genetic algorithm (GA) is a search algorithm that explores the search space in a manner analogous to evolution in nature [6]. It uses probabilistic instructions to search for and change the potential solutions in the search space, using a cost function to analyze the fitness of solutions. GA requires the solution to be represented in a way that is analogous to genes so that the processes that bring about a change in the genes (like mutation) can be used. Usually this is done by representing the solutions in a binary format. The standard genetic algorithm is given below and flowchart of the algorithm is shown in Figure 2.

- Firstly initial solutions are randomly selected from the search space.
- Selection during each iteration a proportion of solutions is selected, based on the fitness function, for breeding the next generation of solutions. The selection is done in a probabilistic manner.
- Selected solutions are paired up and crossover and mutation operation are performed to get the next generation of solutions.
- The iterations are terminated when the termination condition (time or accuracy) is reached.

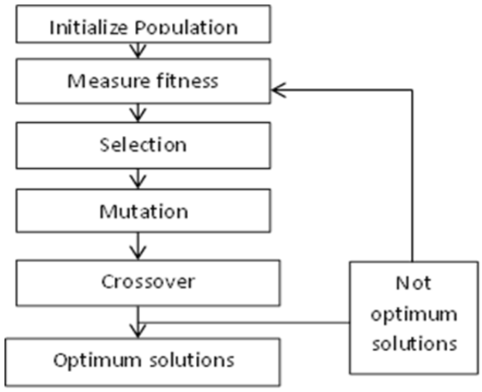

Figure 2. Flowchart of Genetic Algorithm Based Tuning

GA is very popular in PID tuning, and has gained wide applications in control systems [7]. Girishraj *et al.* [7] used GA for improving performance of a PID controller used in bioreactor and compared the performance with Ziegler Nichols, Skogestad modification [8] and IMC rule [9] and found that GA performed both in terms of overshoot, disturbance rejection, gain margin and phase margin.

The limitations of genetic algorithm in tuning a multivariable system were explored in [10]. GA has been used in position and speed control of a DC motor [11-12]. GA has been used for PID of reverse osmosis and cascade control systems tuning in [13-15] . Lot of work has been done in using GA along with other computational techniques.

B. Differential Evolution

Differential Evolution (DE) is a method for doing numerical optimization without explicit knowledge of the gradient of the problem to be optimized. The differential evolution process is originally due to Storn and Price and works on multidimensional real-valued functions which are not necessarily continuous or differentiable. Differential Evolution resolve a problem by holding a population of candidate solutions and creating new candidate solutions by combining existing ones according to its simple formulae of vector-crossover and -mutation, and then keeping whichever candidate solution has the best score or fitness on the optimization problem at hand. The optimization problem is treated as a black box that merely provides a measure of quality given a candidate solution and the gradient is so not needed. Differential evolution is used for online PID tuning also [16].

C. Evolutionary Programming

Generally, the evolutionary programming process for global optimization has some parts i.e. initialization, mutation, competition, and reproduction. Mutation is based on the current values and a Gaussian random variable. Furthermore, a quasi-random sequence is used to generate an initial population for EP [17] to avoid causing clustering around an arbitrary local optimum [17]. Evolutionary programming was used in [18] for PID tuning using IAE.

D. Artificial Neural Networks

An Artificial Neural Network (ANN), usually called 'Neural Network' is a computational model that tries to simulate the structure and functional aspects of biological neural networks. It comprises of an interconnected group of artificial neurons and processes information using a connectionist approach to computation. Usually Artificial Neural Network is an adaptive arrangement that changes its structure based on external or internal information that flows through the network during the learning phase. Though ANN can model even highly non-linear systems, it is not used in control due to limited applicability in PID controllers [19], the neural network controller has some drawbacks because of some intrinsic shortcomings of ANN theory, e.g, It is hard to define the amount of layers and the numbers of neurons per layer.

E. Fuzzy Logic

Fuzzy logic control is one of the interfaces between control engineering and artificial intelligence. The Fuzzy logic controller (FLC) associated with the conventional PID controller to adjust the parameters of the PID controller on-line according to the change of the signals error and change of the error. The FLC varies with the system being used and the PID controller parameter ranges in combination with which it is to be used. Figure 3 shows the commonly used FLC and its role in the PID tuning as described in [20].

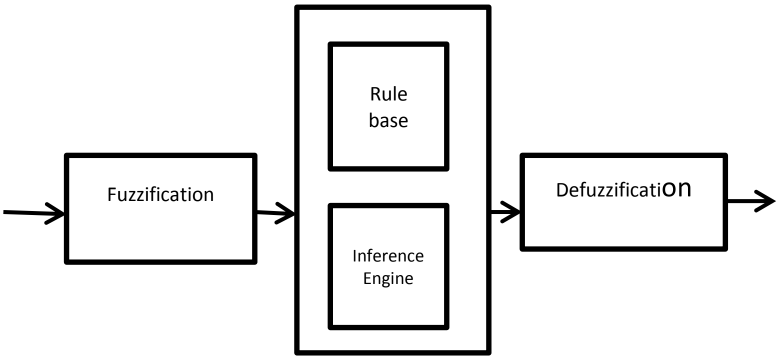

Figure 3. Basic Block Diagram for Fuzzy Control

F. Particle Swarm Optimization

Particle Swarm Optimization (PSO) is a popular optimization technique developed by Eberhart and Kennedy in 1995. In this technique, there is a population of particles which move through the solution space to find the optimal solution. In PSO method the system keeps a track of the best solution obtained till now and each individual particle keeps a track of its own individual best solution. Based on these two, each particle moves to a new position decided by a velocity and its current position. The velocity is dependent on the global and particle's best solution. As put in [21], there are so many researchers who developed the techniques to tune the parameters of controllers. If the *i*-th particle of the swarm is represented by the *D*–dimensional vector $Xi = (xi1, xi2,..., xiD)$ and the best particle in the swarm is denoted by the *gbest*. The best previous position of the *i*-th particle is recorded and represented as $Pi = (pi1, pi2,..., piD)$, and the location change (velocity) of the i-th particle is Vi =(vi1, vi2 ,..., viD). The particles are manipulated according to the equations,

$$v_{id} = w.v_{id} + c_1.r_1(p_{id} - x_{id}) + c_2.r_2.(p_{id} - x_{id})$$
$$x_{id} = x_{id} + v_{id}$$

Where d = 1, 2, . , D; i = 1, 2,., N and N is the size of population; w is the inertia weight; c1 and c2 are two positive constants and r1 and r2 are random values in the range [0, 1]. In favors of electro hydraulic servo system the flow chart of PSO is shown in Figure 4.

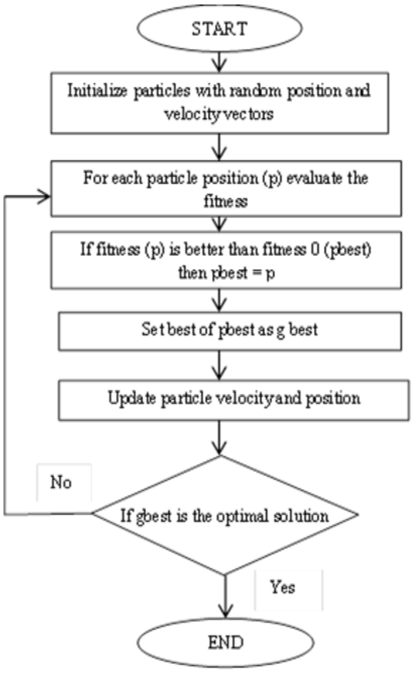

Figure 4. Flow Chart of PSO

3. Conclusion

This paper gives the literature review about soft computing techniques which are introduced by different researchers. This review article is also presenting the current status of tuning of PID controller system using soft computing techniques.

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