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Genetic Algorithm Tuning Based PID Controller for Liquid-Level Tank System

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Abstract- **This paper presents a design of PID controller for liquid-level tank system. The controller is tuned online by Genetic Algorithm (GA). The liquid-level tank system has limitations and it is difficult to control optimally using only PID controller as the parameters of the system are changing constantly. For this reason the strategy of online GA tuning is used in this work. Genetic algorithm has been shown to be capable of locating high performance areas in complex domains without experiencing the difficulties associated with high dimensionality or false optima as may occur with gradient decent techniques. By using the reproduction , crossover and mutation to create the new population for other parameters, it can continuously control the liquid – level tank system until the preset iteration number is reached. Finally, the best PID parameters can be obtained using this approach. Simulation results indicate that the performance of the PID controlled system can be significantly improved by tuning with GA method.**

Keywords- **PID controller, PID tuning, parameter optimization, genetic algorithm, liquid-level tank.**

I. INTRODUCTION

Owing to the requirement of industrial manufacturing processes, the liquid tank level control system is applied to many processing fields. For example, the raw materials stock of chemical works, the mixture raw materials of lithification process, the mould casting process, and the steam generator of nuclear power plants…etc., involve liquid level control to a certain extent. Conventionally, the linear PID control schemes are employed to have control of the liquid level for a number of liquid tank systems. However, as regards the high-precision control, it is insufficient to use linear PID controllers [1].

The implement a PID controller, three parameters (the proportional gain, K_p; the integral gain, K_i; the derivative gain, K_d) must be determined carefully. Many approaches have been developed to determine PID controller parameters for single input single output (SISO) systems. Among the well-known approaches is the Ziegler-Nichols (Z-N) method, the Cohen-Coon method, integral of squared time weighted error rule (ISE), integral of absolute error rule (IAE), internal-model-control (IMC) based method, gain-phase margin method [2].

Several new methods from an artificial intelligent approach, such as GA, fuzzy logic, the applications of GAs have expanded into various fields. With the abilities for global optimization and good robustness, and without knowing anything about the underlying mathematics, GAs are expected to overcome the weakness of traditional PID tuning techniques and to be more acceptable for industrial practice. In the previous work, it has been shown that GAs gives a better performance in tuning the parameters of PID controllers than the Z-N method does [3].

II. PID CONTROL ALGORITMS WITH POSITION AND INCREMENTAL FORM

The PID control law could be represented in two forms, positional form and incremental form.
Assume:

$$e(t) = yd(t) - yp(t) \tag{1}$$

$$e(n) = \text{sample}\,\{e(t)\} \tag{2}$$

$$r(n) = e(n) - e(n-1) \tag{3}$$

$$a(n) = r(n) - r(n-1) \tag{4}$$

The continuous-time linear PID controller in position form is described by the following expression:

$$u(t) = K\left(e(t) + \frac{1}{T}\int_0^1 e\,(\tau) \quad d\tau + Td\,\frac{de(t)}{dt} \right) \tag{5}$$

Where *e(t)* is the error signal defined in equation (3), with time *t*, being continuous instead of discrete. *K* is again, T_i is integration time, and T_d is derivative time. The corresponding discrete-time position form is:

$$u(n) = K\left(e(n) + \frac{T}{T_i}\sum_{i=0}^{n} e(i) + \frac{T_d}{T}\,r(n) \right)$$
$$= Ke(n) + \frac{KT}{T_i}\sum_{i=0}^{n} e(i) + \frac{KT_d}{T}\,r(n)$$

$$= K_p\ e(n) + K_i \sum_{i=0}^{n} e(i) + K_d r(n) \qquad (6)$$

Where r(n) is the rate signal defined in (3) and T is the sampling period, K_p , K_i *and* K_d are the proportional gain, integral gain and derivative gain of the PID controller, respectively [4]. The above PID control algorithms are in position form because they directly compute the controller output itself. The PID controller is often used in the incremental form, in which the controller calculates change of the controller output [4]. Note that at sampling time *n-1*,

$$u(n-1) = K_p e(n-1) + K_i \sum_{i=0}^{n} e(i) + K_d r(n-1). \qquad (7)$$

Hence, the incremental form of the PID controller corresponding to equation (6) is:

$$\Delta u(n) = u(n) - u(n-1) = K_p r(n) + K_i e(n) + K_d a(n)$$
(8)

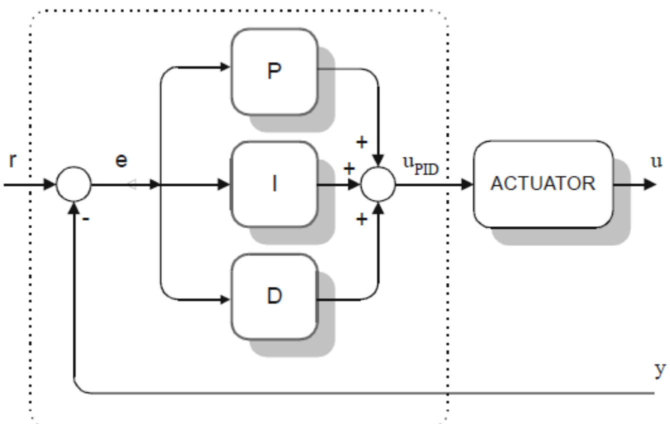


Fig. (1): Structure of PID controller

III. GENETIC ALGORITHM

A GA is an intelligent optimization technique that relies on the parallelism found in nature; in particular its searching procedures are based on the mechanics of natural selection and genetics. GAs were first conceived in the early 1970s by Holland. GAs are used regularly to solve difficult search, optimization, and machine-learning problems that have previously resisted automated solutions [5]. They can be used to solve difficult problems quickly and reliably. These algorithms are easy to interface with existing simulations and models, and they are easy to hybridize. GAs include three major operators: selection, crossover, and mutation, in addition to four control parameters: population size, selection pressure, crossover and mutation rate. Population-based optimization methods are addressed also. This paper is concerned primarily with the selection and mutation operators [5]. There are three main stages of a genetic algorithm; these are known as *reproduction*, *crossover* and *mutation*. This will be explained in details in the following section.

A. 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, as shown in Figure 2.

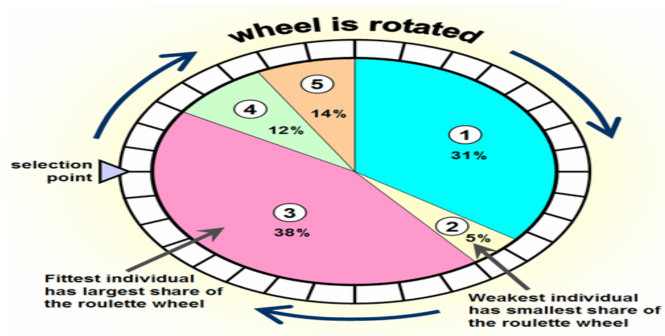


Fig.(2): depiction of roulette wheel selection

Each individual in the population is allocated a section of a roulette wheel. The size of the section is proportional to the fitness of the individual. A pointer is spun and the individual to whom it points is selected. This continues until the selection criterion has been met. The probability of an individual being selected is thus related to its fitness, ensuring that fitter individuals are more likely to leave offspring. Multiple copies of the same string may be selected for reproduction and the fitter strings should begin to dominate, There are a number of other selection methods available and it is up to the user to select the appropriate one for each process. All selection methods are based on the same principal that is giving fitter chromosomes a larger probability of selection [5]. Four common methods for selection are:

1. Roulette Wheel selection
2. Stochastic Universal sampling
3. Normalized geometric selection
4. Tournament selection

B. Crossover

Once the selection process is completed, the crossover algorithm is initiated. The crossover operations swaps 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 individuals gene codes, on average, produce fitter individuals. The crossover probability indicates how often crossover is performed. A probability of 0% means that the offspring will be exact replicas of their parents and a probability of 100% means that each generation will be composed of entirely new offspring. The simplest crossover technique is the Single Point Crossover. 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, [*1,L-1*]. Swapping all the characters between positions k+1 and L inclusively creates two new strings.

More complex crossover techniques exist in the form of Multi-point and Uniform Crossover Algorithms. In Multi-point crossover, it is an extension of the single point crossover algorithm and operates on the principle that the parts of a chromosome that contribute most to its fitness might not be adjacent. There are three main stages involved in a Multi-point crossover.

1. Members of the newly reproduced strings in the mating pool are 'mated' (paired) at random.
2. Multiple positions are selected randomly with no duplicates and sorted into ascending order.
3. The bits between successive crossover points are exchanged to produce new offspring.

In uniform crossover, a random mask of ones and zeros of the same length as the parent strings is used in a procedure as follows.

1. Members of the newly reproduced strings in the mating pool are mated (paired) at random.
2. A mask is placed over each string. If the mask bit is a one, the underlying bit is kept. If the mask bit is a zero then the corresponding bit from the other string is placed in this position.

Uniform crossover is the most disruptive of the crossover algorithms and has the capability to completely dismantle a fit string, rendering it useless in the next generation. Because of this Uniform Crossover will not be used in this project and Multi-Point Crossover is the preferred choice.

C. 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 Genetic Algorithm searches the entire problem space.
2. The Genetic Algorithm may converge on sub-optimum strings due to a bad choice of initial population.

These problems may be overcome by the introduction of a mutation operator into the Genetic Algorithm. Mutation is the occasional random alteration of a value of a string position. It is considered a background operator in the genetic algorithm The probability of mutation is normally low because a high mutation rate would destroy fit strings and degenerate the genetic algorithm into a random search. Mutation probability values of around 0.1% or 0.01% are common, these values represent the probability that a certain string will be selected for mutation i.e. for a probability of 0.1%; one string in one thousand will be selected for mutation. Once a string is selected for mutation, a randomly chosen element of the string is changed or mutated.

IV. LIQUID-LEVEL TANK SYSTEM

Liquid level control systems are commonly used in many process control applications to control, for example, the level of liquid in a tank. Figure 3 shows a typical liquid level control system. Liquid enters the tank using a pump, and after some processing within the tank the liquid leaves from the bottom of the tank. The requirement in this system is to control the rate of liquid delivered by the pump so that the level of liquid within the tank is at the desired point. In this paper the system will be identified from a simple step response analysis. A constant voltage will be applied to the pump so that a constant rate of liquid can be pumped to the tank. The height of the liquid inside the tank will then be measured and plotted. A simple model of the system can then be derived from this response curve. After obtaining a model of the system, a PID controller tuning by GA will be designed to control the level of the liquid inside the tank as shown in figure 3 [6].

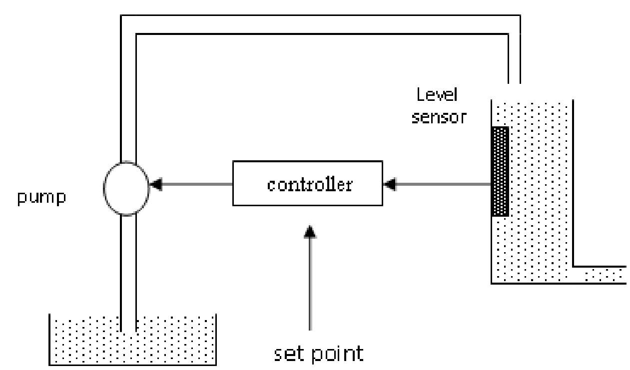


Fig.(3): A typical liquid level control system

V. THE TRANSFER FUNCTION OF THE SYSTEM

The transfer function of this liquid-level system was obtained from the most popular of the empirical tuning methods, known as the PCR method, developed by Cohen-Coon (Stephanopoulos, 1984). Cohen-Coon observed that the response of most processing units to an input change had a sigmoid shape, which can be adequately approximated by the response of a first-order system with dead time.

$$G(s) = \frac{K\, e^{-t_d s}}{Ts+1} \qquad (9)$$

Where K is the process static gain, t_d is the process dead time and t is the process time constant. From the approximate response of the reaction curve in the liquid-level system, it is easy to estimate the values of these three parameters [3].

VI. SIMULATION TEST RESULTS

In this method, the GAs is used to search for the optimal PID parameters that will minimize the IAE value when the process is in steady state. Therefore, the parameter tuning problem of a PID controller using GAs can be considered by selecting the three parameters K_p,k_i and k_d such that the response of the plant will be as desired as shown in Figure 4. The details of the GAs used in this paper are given in the following. The encoding used real numbers to form chromosomes. The population size used here is eight tribes. The tribe is composed of three PID parameters, which used to describe the liquid-level control system. Because we do not know what PID value is the best value for the system, we gave the system many tribes, composed of random PID values around the values obtained from the Cohen-Coon method in the beginning. The fitness function is calculated from the IAE, which will minimize the IAE value when the process is in steady state as shown:

$$\text{Fitness function} = \int_0^t |e|\,dt \qquad (10)$$

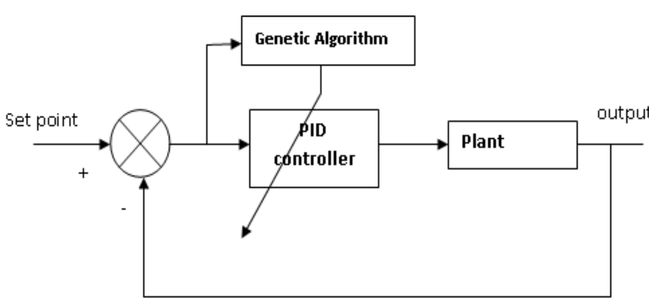


Fig.(4):Block diagram of the proposed GA method for parameter tuning of PID controllers

Therefore, the GAs work in this paper as follows (i.e., also shown in Figure (5):

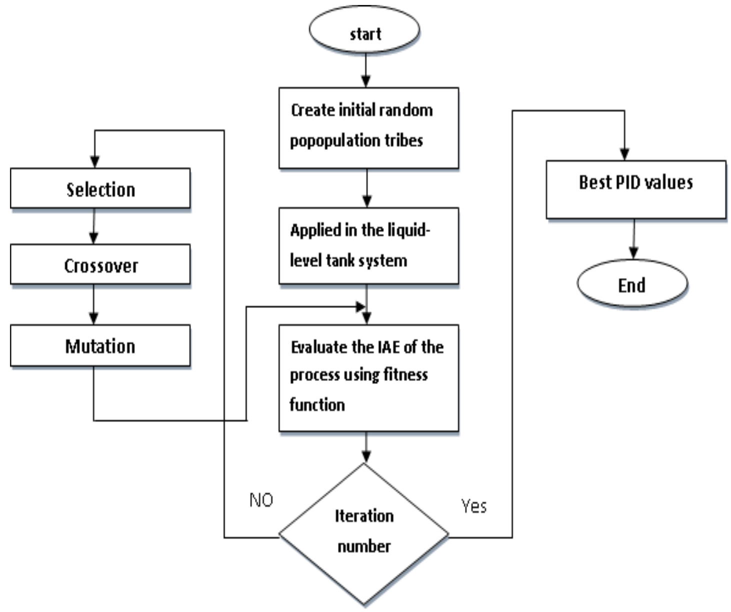
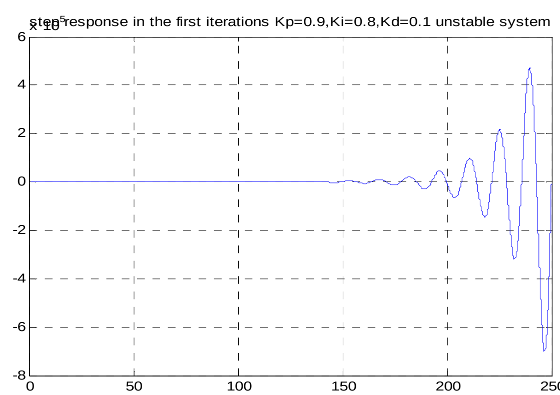
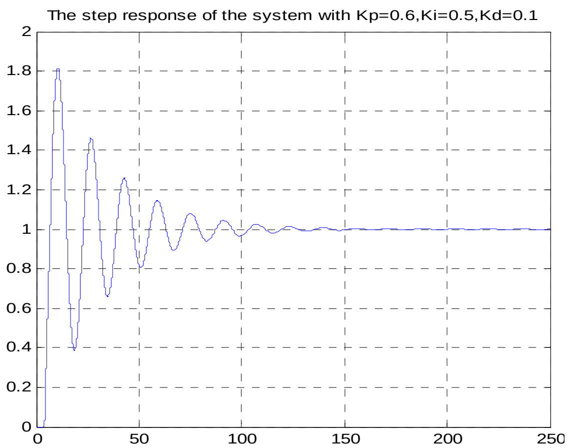


Fig.(5):Flowchart of PID tuning

The proposed GA system has been simulated using MATLAB program. At the earlier iterations ,the PID parameters obtained are yet optimum .The system is unstable and overshoot as shown in Figure (6, a,b). After more than 50 iterations, the parameters would converge towards better solutions and finally achieving optimal system response with minimal IAE as shown in Figure (7, a,b,c)



(a)



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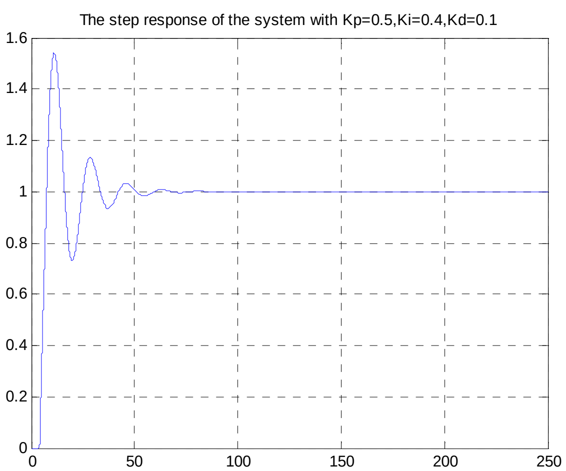

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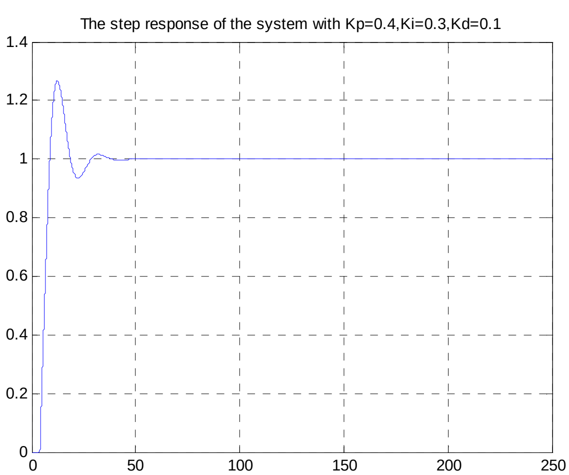

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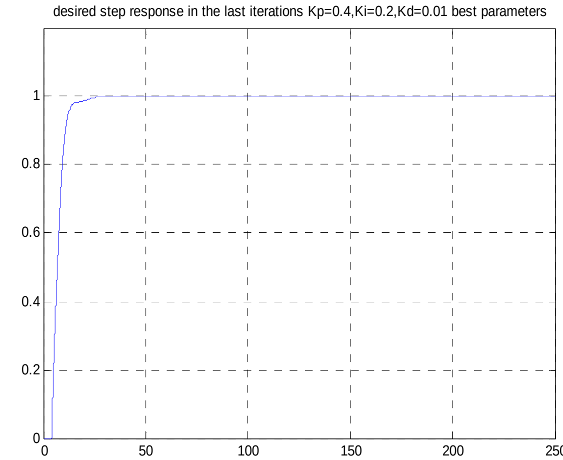

(c)

Fig.7 (a,b,c): The optimum PID parameters to control the liquid-level tank system.

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