Faculty of Engineering

OPTIMIZATION OF PID TUNING USING GENETIC ALGORITHM

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Bachelor of Engineering with Honours

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This declaration is made on the 17 day of June 2015.

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OPTIMIZATION OF PID TUNING USING GENETIC ALGORITHM

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Thesis is submitted to

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In the Name of ALLAH, the Most Gracious, the Most Merciful

Dedicated to my beloved parents, Ku Yusoff bin Tuan Pa and

Zamilah binti Zakaria, my supervisor Mohd Farid bin Atan,

and friends who always bestow me sustainable motivations and encouragements.

Thank you very much for your support and help to finish this final year project

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ABSTRACT

Controller tuning is one of the important aspect in industry. With a good tuning method, it can ensure the quality of the process and product produce. Apart from that, it can protect the environment and help the company to reduce the cost. Genetic algorithm is one of the tuning method that increase usage and awareness in industry. By comparing the method with the conventional tuning method, the performance of tuning method by using genetic algorithm can be seen.

Keywords: *tuning method, genetic algorithm*

ABSTRAK

Aturan kawalan merupakan salah satu aspek yang penting dalam industry. Dengan kaedah aturan yang bagus, ia dapat menjamin kualiti proses dan produk yang dihasilkan. Selain itu, ia juga dapat membantu menjaga persekitaran and mengurangkan pengeluaran kos dari sesebuah syarikat. Algoritam genetic merupakan salah satu system aturan kawalan yang sedang meningkat naik dan semakin menarik perhatian industry. Dengan membandingkan prestasi aturan kawalan menggunakan algoritam genetic dengan system sedia ada, keupayaan system ini akan dapat dilihat.

Kata kekunci: *kaedah aturan, algoritamgenetik*

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Chapter 1

Introduction

1.1.Background of the Study

In process industry, the main issue arise is the method use to control the process. A process that working efficiently and safely is important to be maintain in the industries to reduce the environmental issues and control the quality of the product that being process. To ensure the controllers to work satisfactorily, they must be tuned properly. Nowadays, there are several ways to tune controller depending on the dynamics desired strength of the system. Apart from that, there had been many methods developed and refined specifically for tuning of controller in the recent years (Awouda & Mamat, n.d).

The PID controller is a common form of feedback (Astrom, 2002). It has been widely used in process industries due to their simple structure which can be easily understood and implemented in practice (Awouda & Mamat, n.d). PID controllers are frequently in control process to regulate the time domain behavior of many different types of dynamic plant (Chiha, Liouane & Borne, 2011). In process control today, more than 95% of the control loops are of PID types. The controllers come in many different forms. PID control is usually combined with logic sequential function, selectors and simple function block to produce the complicated automation system that being used for energy production, transportation and manufacturing (Astrom, 2002). Organization of sophisticated control strategies such as model predictive control usually being done hierarchielly. PID control is used at the lowest level. For PID controller to work properly, it has to be tuned which mean for different application of PID controller, a selection of PID controller parameters has to be made. In the recent surveys, it been indicated that 30% of installed controllers operate in manual, 30% of loops increase variability, 25% of loops use default setting and 30% of loops have equipment problem. the best control performance could be obtain due to the assumption that are based on first order plus time delay, however, the modern optimization techniques has made it possible to tune PID controller based on the actual transfer function of the plant to optimize the closed-loop performance (Awouda & Mamat, n.d). However, improper PID parameter tuning could lead to cyclic and slow recovery, poor robustness and the worst case scenario could be the collapse of system operation (Saad, Jamaluddin & Darus, 2012). There are many strategies have been proposed to determine the optimum setting of PID parameters. The key idea of designing a PID controller is to determine the three gains, i.e; proportional gain, K_D, integral gain, $K_{i,}$ and derivative gain, K_D of the controller (Chang, Hwang & Hsieh, 2003). The PID controller tuning method are classified into two main categories which are closed loop methods and open loops method. The closed loop tuning technique is a method that tune the controller during automatic state which the plant operating in closed loop. Meanwhile, the open loop technique refer to methods that tune the controller when it is in manual state and the plant operates in open loop (Shanrokhi & Zamarrodi, n.d). Ziegler-Nichols tuning method is the most standard one but it is often difficult to optimal PID parameters with these methods. Apart from that, the minimum error criteria method such as ITAE also has been widely used in process control. The controller tuning methods provide the controller parameters in the form of formulae or algorithms. The form of formulae and algorithms can help to ensure that the control system obtain is stable and meet the required objectives. Nowadays, evolutionary algorithm method has been studied by research to be implement as one of the control method of PID tuning. EA provide a framework for effective sampling large search spaces, and easily tailored to specific problems (Jones, n.d.).

The use of evolution as an inspiration for solving computational problems because the mechanisms of evolution which seem very well suited for some of the most pressing computational problems in many field (Melanie, 1996). Genetic algorithm is one the evolutionary computation method that has been extensively studied by most researchers in searching for optimal PID parameters due to its high potential of escaping being trapped in local minimum (Saad, Jamaluddin & Darus, 2012). Genetic algorithms is a heuristic optimization technique inspired by Darwin's theory of evolution which states that the survival of an organisms is affected by rule "the strongest species that survives" (Hermawento, n.d). In Darwin theory, it is also stated that to maintain the survival of an organism, they need to undergo the process of reproduction, crossover and mutation. The concept is then adopted to computational algorithm and used to find solution for problem and called as objective function. Solutions that generated by genetic algorithms is called as chromosome and the collection of chromosome is called population. Genetic algorithm are best used when the objective function is discontinuous, highly nonlinear, stochastic and has unreliable or undefined derivatives. The advantages of using genetic algorithms is that it can provide solutions for highly complex search space. Genetic algorithm also perform well approximately solution for all types of problems because they do not make any assumption about the underlying fitness landscape (Zvirgzdina & Tolujevs, 2013).

1.2.Problem statement

The usage of process control is crucial in process industry. This is to ensure the quality of the product that being process is based on the quality measurement that been set. Although there are many tuning method available, but not all the method is suitable for each process industry. The implementation of genetic algorithm could help in maximize the control process. This is due to the characteristics of genetic algorithm that does not make any assumption about the underlying fitness landscape or in other word the shape of the fitness function, or objective function. Apart from that, genetic algorithm also supports the multi objective optimization and it always result in an answer, which become better and better with time. The calculation by using genetic algorithm method can be run in parallel thus it increase the response time because the time required to solve the problem become shorter. Apart from that, genetic algorithm is flexible due to it fitness function that can be changed from iteration to iteration which allows incorporating new data in model if it became available.

However, the usage of genetic algorithm can cause a poor premature convergence and loss of best solution found. In this project, it concerns on the method on how to optimize the usage of genetic algorithm in PID tuning so that the best result can be obtained. To obtain such result, a suitable constraint and rules must be applied in the mathematical modelling.

1.3.Project Scope

The project will be focused to optimize the general PID tuning by using genetic algorithm. This due to the attention obtain by genetic algorithm in process controller because of the potential shown in the usage of genetic algorithm to determine the best solution in PID tuning. A study will be conducted on problem with related with controller tuning. The optimized genetic algorithm method will be compared with the common method that being used in industry nowadays.

1.4.Objective

The project is conduct to understand how genetic algorithm is use in PID tuning. In the PID tuning, it is important to obtain the best solution so that the controller will have the fastest and stable response time. To obtain that, appropriate mathematical modelling must be determine so that the PID tuning could be optimize.

Chapter 2

Literature Review

2.1. Introduction

This chapter reviewed previous research that has been done through journal, research studies and related issues which are associated with this study. Apart from that, the topic that related with optimization of PID tuning using genetic algorithm will be discusses. This chapter also will discuss about the PID tuning and the method that related and used by researchers for their studies of genetic algorithm in PID tuning.

2.2. Optimization of PID Tuning

In the recent years, the research on the optimization method of PID tuning in controller had been done widely. This due to the important role of tuning of controller in industrial. PID controller parameter consists of three separate parameters which are proportionality, integral and derivative values that denoted by k_p, k_i, and k_d (Saad, Jamaluddin & Darus, 2012). To obtain a good controller system, an appropriate setting of these parameters will improve the dynamic response of a system, reduce overshoot, eliminate steady state error and increase stability of the system (Saad, Jamaluddin & Darus, 2012). There are several method that can be used to optimize the parameters used and recent trends show that there has been drastic improvement in the tuning by using evolutionary algorithm (Mantri & Kulkarni, 2013). The transfer function of a PID controller is:

$$C(s) = k_p + \frac{k_i}{s} + k_d s \qquad (1)$$

2.3. Genetic Algorithm

Genetic algorithm is one of the evolutionary algorithm that widely study around the globe. In genetic algorithm, tuning referred to the process of selecting the control parameter using algorithm. The parameter involved including the population size, number of generations, mutation rates, inversion rates, permutation rates, selection rates, fitness function crossover probability, reproductions probability and decoding method.

2.3.1. Fitness Function

The optimization using genetic algorithm is done based on the objective function that being introduce. Objective function is introduced to evaluate fitness of each chromosome (Ohri, Kumar & Chinda, n.d). Fitness is a numeric value assigned to each member of population to provide a measure of appropriateness of each candidate solution (Al-Rawi, 2012). A fitness function must be devised for each problem to be solved (Beasley, Bull & Martin, 1993). Given a particular chromosome, the fitness function return a single numerical fitness or figure of merit, which is supposed to be proportional to the utility or ability of the individual which that chromosome represent. There are several ways to determine the fitness function such as weighted sum approach, altering objective function and pareto ranking approaches. This approach is used for multi objective optimization problem.

2.3.1.1. Weighted Sum Approach

This is the classical approach used to solve a multi objective optimization problem. This approach consign a weight w_i to each normalized objective function $z_i'(x)$ so that the problem is converted to a single objective problem with scalar function.

$$\min z = w_1 z_1'(x) + w_2 z_2'(x) + \cdots + w_k z_k'(x) \tag{2}$$

The normalized objective function is represented by $z_i'(x)$, $z_i(x)$ and $\sum w_i = 1$. The approach used is called a priori approach because the weight is expected to be provide by the user. By solving the problem using the objective function with given vector w = {w_i $w_2, \ldots, w_k$} a single solution will be obtained. However, if the user desired for a multiple solutions, the problem should be solve multiple times where for each solution, different weight combinations are used. The usage of this approach is difficult because the user need to select the weight vector for each run.

The main advantage of weight sum approach is that the method can be implemented directly. The fitness provide by using this approach is a single objective, thus it can be used with minimum modifications. Apart from that, the approach can run efficiently in computational system. However, since not all Pareto-optimal solutions can be investigated when the true Pareto font is non-convex, the usage of this approach could give a huge disadvantages. Thus, it will be very difficult to find the solutions that are evenly distributed over a non-convex trade-off surface by using weighted sum approach.

2.3.1.2. Altering Objective Function

Vector Evaluated Genetic Algorithms is the first optimization technique that used genetic algorithm to approximate Preto optimal set by a set of non-dominated solutions. This approach divided the population of P_t randomly into K equal sized sub-populations of $P_1, P_2, \ldots, P_K$. Based on the objective function z_i, a fitness value is assigned for each solution in subpopulation P_i. By using proportional selection for crossover and mutation, solution are selected from the subpopulations. Each of the new population will undergo crossover and mutation in the same by using the single objective genetic algorithm.

The approach that used in this method can be implemented easily and computationally as efficient as a single objective genetic algorithm. However, the population produce often converge to solutions that very superior in one objective, but in other objective the populations produce are very poor.

2.3.1.3. Pareto-Ranking Approach

Pareto-ranking approaches exploit the concept of Pareto dominance in evaluating fitness or assigning selection probability to solutions. The dominance rules is used to rank the population and then a fitness value is assigned to each solution based on the dominance rule. The assignation of the fitness value is not based on the actual objective function value. It is noted that all objective are assumed to be minimized, thus based on the following discussion, a lower rank corresponds to a better solution.

Golberg has proposed the first ranking technique as follow:

Step 1: Set I = 1 and $TP=P$

Step 2: identify non-dominated solutions in TP and assigned them set to F_i.

Step 3: Set $TP=TP \backslash F_i$. if $TP=\emptyset$ go to Step 4, else set $i=i+1$ and go to Step 2.

Step 4: For every solution x ∈ P at generation t, assign rank r_i (x,t)=I if x ∈ F_i.

In the procedure proposed, F_1, F_2, ...F_i are called non-dominated fronts, and F_1 is the Pareto front of population P. There also other approach that been used to rank assignment approach. Fonseca and Fleming used a considerably different approach.

$$r_2(x,t) = 1 + nq(x,t) \quad (3)$$

In equation (3), $nq(x,t)$ is the number of solutions dominating solution x at generation t. The usage of this approach will penalizes solutions located in the regions of the objective function space which are dominated (covered) by densely populated sections of the Pareto front.

2.4. Genetic Operators

In computer based evolutionary system, the term genetic operators is used to the method used to simulate nature. The decision to make during implementation of genetic algorithm is the choice of genetic operators that are to be used (Mallick & Khan, 2011). There are four common operators that being used in the optimization of PID tuning which are selection, crossover, and mutation.

2.4.1. Selection

In the nature, the selection of individuals is performed by survival of the fittest. The more one individual is adapted to the environment, the bigger its chances to survive and create an offspring and thus transfer its genes to the next population (Popov, 2005).

Genetic algorithm evaluate the fitness function to get the best individual. In genetic algorithm, parent selection is to give more reproductive changes to those individuals that are fit (Czarkowski, 2002). The original genetic algorithm used fitness proportionate selection, in which the expected value of an individual is that individual's fitness divided by the average fitness of the population (Mallick & Khan, 2011).

There are many ways used to evaluate the fitness function such as the sum of square error. The method that known and widely used in different genetic algorithm applications are Roulette wheel and tournament selection (Al-Rawi, 2012).

2.4.1.1. Roulette Wheel

Selection by roulette wheel is done by assigned each individual with a slice of a circular roulette wheel. The size of the slice is proportional to the individual's fitness. The wheel is spin based on the number of individual in the population. After each spin, the individual under the wheel marker is selected to be in the pool of parents for the next generation. The method is implemented as follows:

1) The total expected value of individuals in the population are summed and the sum is called as T.
2) The above step is repeated N number of times.

A random integer r, between 0 and T is chosen. The individuals in the population go through looping, summing the expected values until the sum is larger than or equivalent to r. the selected individual is selected if it expected value sum is over this limit.

The usage of stochastic method statistically results in the expected number of offspring for each individual. However, due to the small populations that usually related with genetic algorithms, the actual number of offspring allocated to an individual is often far from its expected value (Melanie, 1996).

2.4.1.2. Tournament Selection

Tournament selection used selection pressure as the degree to which the better individuals are favored. The individuals with the higher selection pressure are more favored compare to the individuals with lower selection pressure. This selection pressure drives the genetic algorithm to improve the population fitness over the generations.

Genetic algorithms are able to distinguish finest or near finest solutions in a wide range of selection pressure. However, if the selection pressure is too low, the convergence rate will be slow and the genetic algorithm will require more time to distinguish the optimal solution. If the selection pressure is too high, genetic algorithm prematurely converge to the solution under the optimal.

The selection pressure provide by the tournament selection is done by holding a tournament among *s* competitors, where *s* is the tournament size. The competitor with highest fitness is the winner of the *s* tournament competitors. The winner then insert into the mating pool. The mating pool will consist of the higher average fitness compare with the average population fitness due to the winner of the tournament. The different in fitness inside the mating pool will provide the selection pressure which initiatives the genetic algorithm to develop the fitness of every succeeding generation. The selection pressure can simply be increase by increasing the tournament size *s*, as the winner from a larger tournament will on average have a higher fitness than the winner of a smaller tournament.

2.4.2. Crossover

Crossover is a process which the genes are selected from the parent chromosomes and new offspring is created (Malhotra, Singh & Singh, 2011). The crossover operator divides a population into the pairs of individuals and performs recombination of their genes with a certain probability. If one point crossover is performed, one position in the individual genetic code is chosen (Al-Rawi, 2012). The process of crossover will produce new individuals, which have some part of parent's genetic material. Crossover can be performed with binary encoding, permutation encoding, value encoding and tree encoding. The crossover operation can be mathematically described as follows:

If parents are (w_{n1}, k_{f1}) and (w_{n2}, k_{f2}), then

Child 1: $w_n = r*w_{n1} + (1-r)*w_{n2}$

$K_f = r*k_{f1} + (1-r)*k_{f2}$

Child 2: $w_n = (1-r)*w_{n1} + r*w_{n2}$

$K_f = (1-r)*k_{f1} + r*k_{f2}$

Where $r \in (0, 1)$ is a random number

Here the crossover operator works with real decimal pairs instead of any coded strings.

The simplest form of crossover is single point crossover. There also other crossover variations such as dual point, multipoint, uniform, shuffle, asexual crossover, and single child crossover.

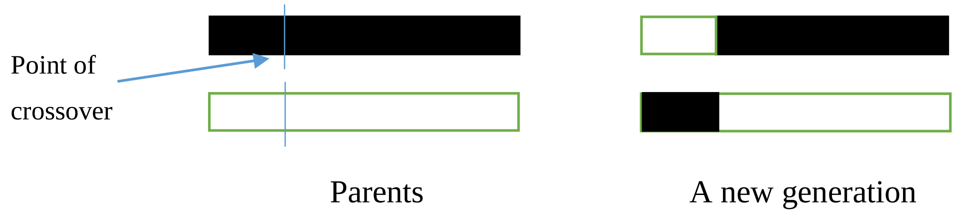

Figure 2.1: Single point crossover (adapted from Czarkowski, 2002)

2.4.3. Mutation

Mutation is the secondary operator in genetic algorithms. The operator is require because sometimes, chromosomes may lose some potentially useful genetic material. The mutation operator introduces random change into characteristics of chromosomes (Konak, Coit & Smith, n.d). Those changer are caused mainly by mistakes during the copy process of the parent's genes during the selection and crossover operation. Typically, in genetic algorithm implementation, the mutation rate is very small which often less than 1% are. Although the mutation produce in the new chromosome is not very different from the original one, mutation still plays a critical role in genetic algorithm. This due because when the mutation occur, it will reintroduces genetic diversity back into the population and assists the search escape from local optima.

2.5. Genetic Algorithm Tuning Based PID Controller

The GA had been try to be used in liquid-level control system. In the research, GA is used to search for the optimal PID parameter that will minimize the IAE value when the process is in steady state. The details of the GA that been used are given in the following. The encoding used real numbers to form chromosomes. The population size used is eight tribes. Within the tribe is three PID parameters that used to describe the