2013 International Conference on Robotics, Biomimetics, Intelligent Computational Systems (ROBIONETICS)
Yogyakarta, Indonesia, November 25-27, 2013

Genetic Algorithm-based PID Parameters Optimization for Air Heater Temperature Control

Dwi Ana Ratna Wati and Rakhmat Hidayat
Department of Electrical Engineering,
University of Islam Indonesia,
Yogyakarta, Indonesia
E-mail: dwi_ana@uii.ac.id

***Abstract*— The main problem on PID controller design is tuning its parameters in order to generate optimal systems performance. This paper applies Genetics Algorithms (GA) for tuning PID controller of an air heater. PID controller is used to control the output temperature of the air heater. A process model of the air heater is defined based on its open loop step response. Using this model, an offline PID parameters optimization based on GA is done. The chromosome in GA represents PID parameters namely proportional gain (Kp), integral gain (Ki), and derivative gain (Kd). The objective functions are settling time and overshoot. The experimental results show that the step response of this GA-based PID controller has superior performance than its using Ziegler Nichols tuning.**

Keywords*— *genetic algorithms; temperature control; PID; tuning; air heater

I. INTRODUCTION

PID controller has been successfully applied in many industrial applications. This is made possible by its simple structure and design, low cost in maintenance and its effectiveness in controlling common linear systems [1]. PID controller has three parameters, namely proportional gain (Kp), integral gain (Ki), and derivative gain (Kd). These parameters need to be tuned precisely thus result in optimal systems performance. It could possibly result in bad performance or even unstable if these values are improperly tuned [2].

Soft computing is an alternative method that can be used in PID controller design and optimization [1-3]. According to [2], the use of soft computing technique proposes several advantages. First, it is possible to use a high-order process model in tuning, so the errors resulting from model reduction are avoided. Second, it is possible to consider several design criteria in a balanced and unified way. There is no need of approximation that is typical in classical tuning rules. Even though soft computing technique is often get many critics for its computationally heavy and its guarantee of convergence to optimal solution, but PID controller tuning is a small scale problem with no computational complexity issue. It is just need a couple of second to solve the problem using soft computing method. Compared to conventional tuning, this method results in a good steady state response and better performance indices [2].

A kind of soft computing is Genetic Algorithm (GA). GA is an evolutionary algorithm used to solve optimization problem. It has been successfully applied in many controller optimization problem such as fuzzy controller design [3,5] and self tuning fuzzy PID controller [4]. In GA, population of chromosomes are representation of candidate solutions. Through each iteration, their quality are evaluated by fitness function. Then selection mechanism is run to choose the best ones as parents. Parents will produce offspring by crossover and mutation mechanism. These offspring are new better solutions of the problem. This process will be repeated until the optimal solution has been found. GA provide a tool to search poorly understood and highly complex solution space [1].

Air heater has been applied in some air conditioning system, in industrial processes as in combustion and in household appliance as in clothes dryer. A controller is needed on this system to keep the output temperature as in set point. In this research, GA-based PID controller is designed and applied for controlling the temperature of an air heater.

II. GA-BASED PID CONTROLLER DESIGN

A. Air Heater Modelling

An air heater, used in this research, consists of an heating element and a blower to produce the hot or warm output air (fig. 1). A model of this air heater is needed in the PID controller design. The first step of GA-based PID controller design is system identification. In order to get the model, a system identification is done. An open loop step response of the air heater is examined using data acquisition system shown in fig. 2. A Simulink model, consisting of step input command and the data acquisition system using NI-USB 6009, is designed. This Simulink model is run to operate the air heater in open loop mode. The output step response is recorded. It is used as process model data to define the process model of a plant or process. The process model is as in (1), where K is a gain, T_d is delay time, and T_1 is rise time as shown in fig. 3. This process model then will be used as reference in the optimization of PID parameters using GA.

$$H(s) = \frac{Ke^{-sT_d}}{1 + sT_1} \tag{1}$$

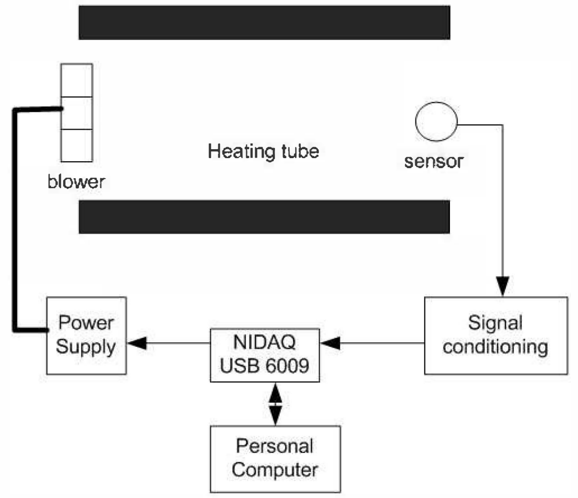

Fig. 1 Air heater system

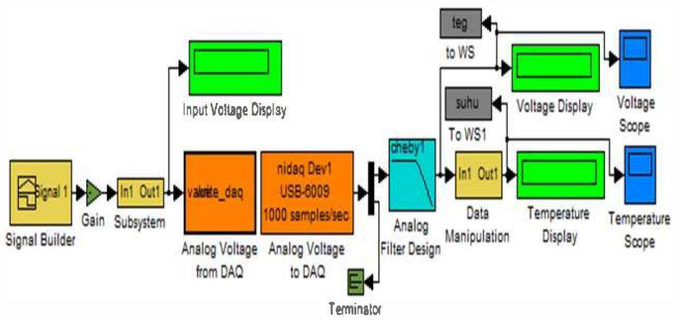

Fig 2. Simulink model for generating open loop step response

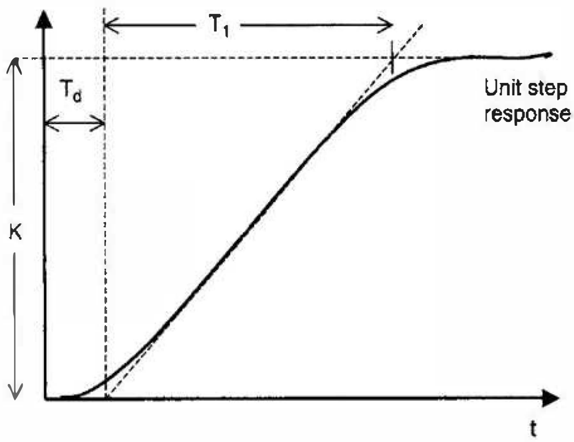

Fig 3. Open loop step response parameters

B. PID Parameters Optimization

A classical PID controller is usually expressed in time domain as :

$$u(t) = Kpe(t) + Ki\int e(t)dt + Kd\frac{de(t)}{dt} \quad (2)$$

There are three parameters of PID controller, namely proportional gain (Kp), integral gain (Ki), and derivative gain (Kd). These parameters need to be tuned properly to get the best systems performance. In practice, it is hard to design a good PID controller while multiple objectives such as short transient and high stability are to be achieved [6]. Heuristic tuning method known as Ziegler-Nichols tuning is usually chosen as a method to determine the value of Kp, Ki, and Kd [7]. However, these values still need to be re-tuned manually because its performance has not full fill the requirement. In fact, initial design of PID controller obtain by all means, needs to be re-tuned repeatedly through computer simulation until the closed loop system performance is as desired. This fact drives the development of intelligent tool that can help engineers to achieve the best performance of PID controller for all operation points.

In this research, GA-based PID parameters optimization is designed. The goal is to produce an optimal PID controller for controlling the output temperature of an air heater. The design of PID controller is done offline using a process model resulted by system identification of air heater.

The optimization problem of PID controller design is stated as in (3), where f is settling time and overshoot of step response, while Kp, Ki, and Kd are proportional gain, integral gain, and derivative gain respectively. In order to find its solution, GA is applied. The value of Kp, Ki, and Kd are encoded as chromosome in GA. The value of f is calculated based on the response characteristic of process model of the air heater.

$$Min\ f(Kp, Ki, Kd) \quad (3)$$

C. Genetic Algorithm (GA)

Genetic Algorithm (GA) was first introduced by John Holland in 1975 [8]. In GA, solution of an optimization problem is coded as a chromosome. A population of chromosome is generated initially. Through iterations, each chromosome will be evaluated its fitness value. This value corresponds to the objective function of the problem. Based on its fitness value, the best chromosomes will be chosen as parents. In the crossover and mutation operation, these parents will mate in order to result in new better offspring. The complete process involved in GA is presented on fig. 4.

In this research, binary coding chromosome is used. In order to get the value of Kp, Ki, and Kd, these chromosome are decoded into real number. Then, these number are set to Kp, Ki, and Kd on a Simulink model that consists of the air heater process model controlled by PID controller. After the simulation is run, then step response characteristic, such as settling time, and overshoot, as the objective function f, is evaluated. These value then converted into fitness value as :

$$fitness = \frac{1}{f + \varepsilon} \quad (4)$$

Based on this fitness value, roulette wheel selection is run to get best chromosomes that will be parents on crossover and mutation operation. Crossover is mechanism to copy a part of parent's chromosome string to produce offspring, while mutation is a change on a binary value of a chromosome. After crossover and mutation operation is complete, a new generation of chromosomes is built. This new generation then will be evaluated their quality based on their fitness. Next, selection, crossover and mutation operations are repeated again until the stopping condition is true.

III. EXPERIMENT RESULT AND DISCUSSION

A. Modelling Dynamic of Air Heater

The open loop step response (fig. 5) of the air heater is obtained by giving the step input to the air heater plant using Simulink model on fig. 2. Based on this graph, a process model of the air heater is defined as in (5). This process model then is used as model of air heater on Simulink model. It consists of closed loop implementation of PID controller. The step response (fig. 5) is also applied in tuning PID parameters by Ziegler Nichols method, which resulted the value of Kp = 12.2383, Ki = 0.8089, and Kd = 30.2898. The closed loop response of this controller is shown in fig. 6. It is clear that this response has high overshoot and too long settling time. Based on this response characteristics, this PID parameters are need to be re-tuned thus result in better response, especially smaller overshoot and settling time. In this research, it is applied GA on designing PID controller of air heater output temperature.

$$H(s) = \frac{7.430e^{-4,95s}}{1+50.4832s} \tag{5}$$

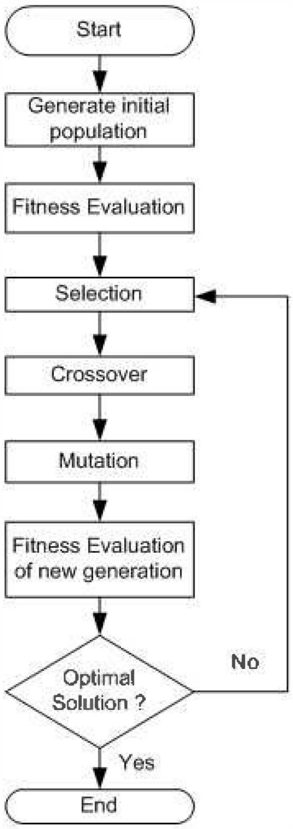

Fig. 4. Flowchart of Genetics Algorithm

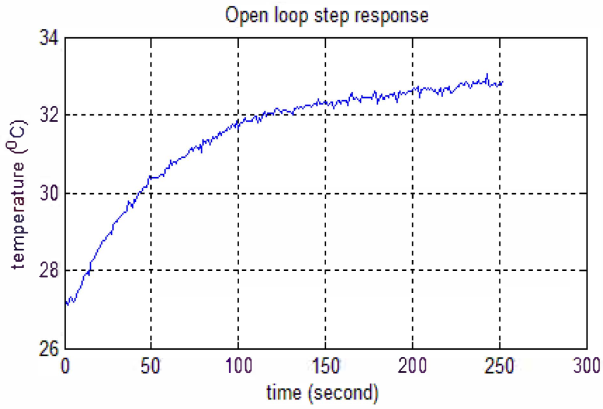

Fig. 5 Open loop step response of the air heater

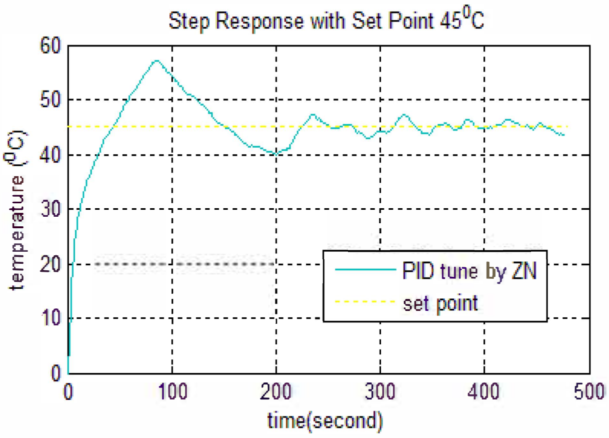

Fig. 6 Closed loop step response of the air heater with PID controller tuned by Ziegler-Nichols method

B. GA-based PID Controller Optimization

Genetic Algorithm (GA) is applied to improve the performance of the step response resulted by Ziegler-Nichols tuning which has high overshoot and long settling time. In this scheme, the absolute mode is applied. In this mode, a chromosome are decoded as the PID parameters value immediately, namely Kp, Ki, and Kd, without using the values obtained by Ziegler-Nichols tuning. These parameters then are set to PID controller in simulink model as shown in fig. 7. On each evaluation of a chromosome, this model is run to simulate the air heater system with PID controller. The step response resulted from this simulation then is evaluated its characteristics values namely rise time, settling time or overshoot. There are two kinds of objective function used in this experiment. In order to improve the settling time, the objective function is "minimize settling time", while in order to improve the overshoot, the objective function is "minimize overshoot". Table I summarizes the PID parameters resulted by GA-based PID tuning with these both objective functions. These parameters then are implemented to control real air heater plant. The step response characteristics of these implementation are calculated to determine systems performance.

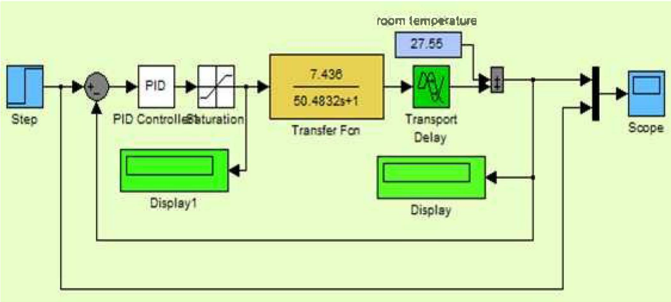

Fig. 7 Simulation model of air heater system

TABLE I. PID PARAMETERS BY GA-TUNING METHOD

	Kp	Ki	Kd
GA with objective to minimize settling time	1,0801	0,0065	0,0065
GA with objective to minimize overshoot	1,0039	0,0039	0,0039

C. *Controller Implementation on Air Heater*

The best PID controller designed with Genetic Algorithm on offline mode then is applied in the real air heater plant (fig. 8). PID controller is realized on a Simulink model as shown in fig. 9. This model generates a control signal which is sent to the air heater via NI-USB 6009, while the output temperature is read by a LM35 sensor then sent to the computer via analog input of NI-USB 6009. The actual temperature is compared to the set point in order to calculate the error signal. Based on this error signal, PID controller generates an output control signal in order to keep the temperature as close as possible to the set point.

Fig. 10 and fig. 11 show the comparison of step response between PID controller of air heater tuning by Ziegler Nichols versus PID controller tuning by GA. Fig. 10 is step response when the set point is 45^0C, while fig. 11 is step response when the set point is 55^0C. Both figures show that step response resulted by PID controller tuned by GA is better than the response of PID controller tuning by Ziegler-Nichols. The characteristic values of step responses are summarized in table II for set point of 45^0C and in table III for set point of 55^0C. The response of PID controller tuned by GA has very small overshoot compared to the response of PID controller tuned using Ziegler Nichols method. The average value of improvement on the overshoot is 86,42%, while the average improvement on settling time is greater than 50%. When using "minimize overshoot" as the objective function, there is significant change on settling time as well as in overshoot. It is better than using "minimize settling time" as the objective function. This best result of PID tuned by GA with the "minimize overshoot" as the objective function, then is examined its response on changing of the set point. Fig. 12 shows this graph on set point 40^0C, 50 ^{0}C and 60^0C. It is shown that the GA-based PID performs better than PID tuned by Ziegler Nichols on set point change tracking.

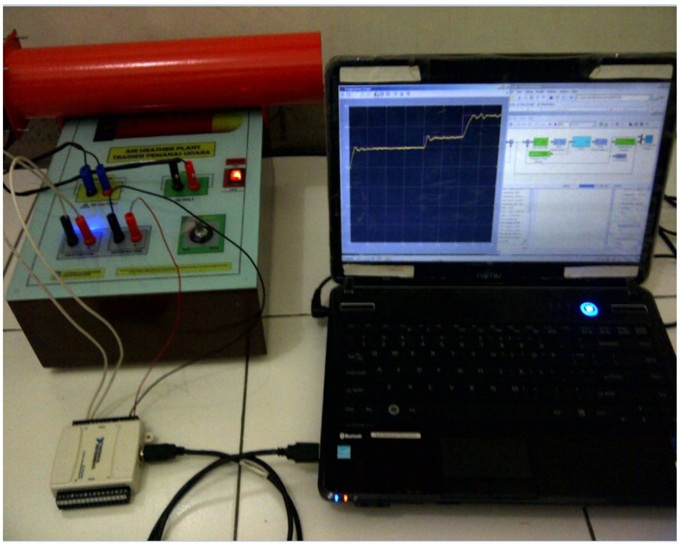

Fig. 8 Implementation on real plant

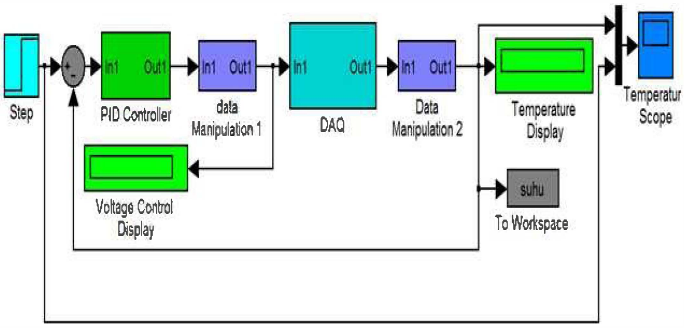

Fig. 9 Simulink model for closed loop control of air heater plant

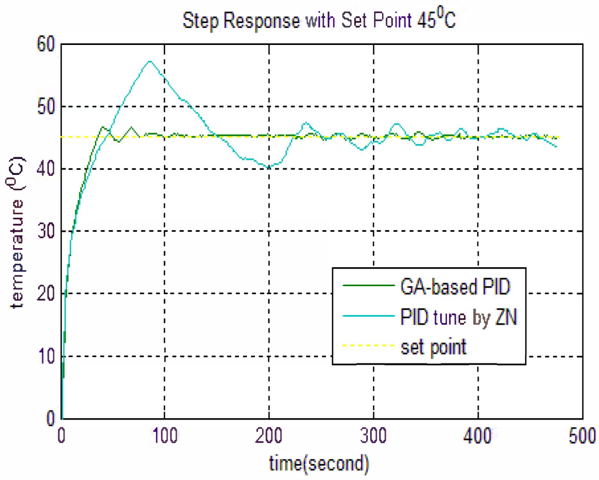

Fig. 10 Comparison of closed loop step response on the set point 45 ^{0}C

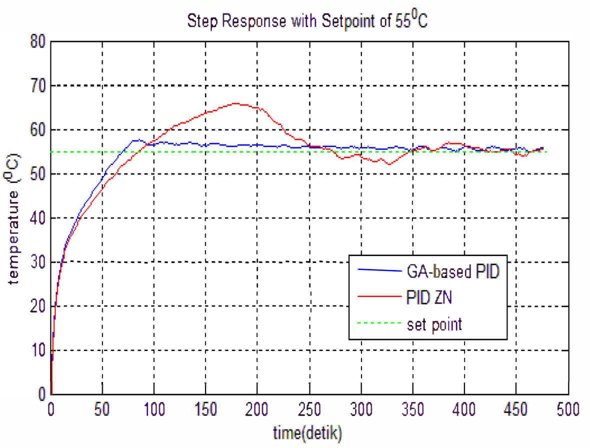

Fig. 11 Comparison of closed loop step response on the set point 55 °C

TABLE II. STEP RESPONSE CHARACTERISTICS ON SETPOINT 45°C

Tuning Method	Settling time (sec)	Rise time (sec)	Overshoot (%)
Ziegler-Nichols	undefined	27,0452	26,8190
GA with objective to minimize settling time	67,2588	24,2695	2,9033
GA with objective to minimize overshoot	49,2987	22,3713	2,1026

TABLE III. STEP RESPONSE CHARACTERISTICS ON SETPOINT 55°C

Tuning Method	Settling time (sec)	Rise time (sec)	Overshoot (%)
Ziegler-Nichols	390,2845	60,9964	19,6388
GA with objective to minimize settling time	174,9090	45,7760	4,5936
GA with objective to minimize overshoot	53,0963	44,6867	2,4083

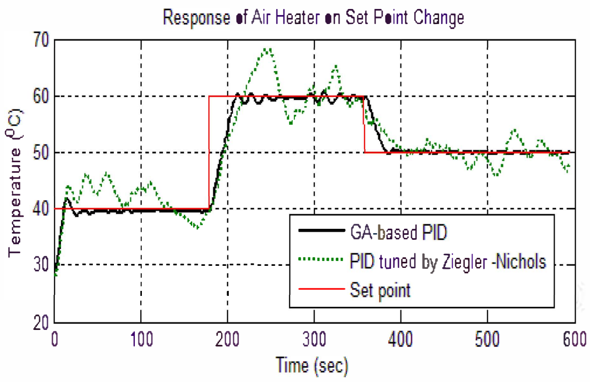

Fig. 12 Comparison of closed loop response on set point change

IV. CONCLUSION

In this research, a PID controller has been designed to control the output temperature of an air heater. GA-based optimization algorithm is used to tune and optimize the PID parameters. Firstly, the identification procedure is done in order to get the model of the air heater. Next, optimization using Genetic Algorithm (GA) is done offline using a simulation process model of the air heater plant. The PID controller optimized by GA on offline mode then is applied on the real plant. The experimental results show that the response of GA-based PID controller has superior performance than its using Ziegler Nichols tuning. A significant improvement on step response characteristics of output temperature is achieved using proposed method.

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