Tuning of PID Controller for Air Conditioning Unit Based on Adaptive Genetic Algorithm

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ABSTRACT: *PID control is widely used in air conditioning system. The algorithm is simple but has a long response time, and the adjustment is not flexible. In this paper, we propose a method of optimizing PID controller parameters based on adaptive genetic algorithm. Specifically, the fitness function with penalty terms is added to the classical genetic algorithm and adaptive crossover and mutation factor genes to make the PID parameters converge to global optimum quickly. In addition, the method can prevent overshoot and improve stability effectively. Simulation results indicate that our method achieved a 83% reduction in regulation time of response of an air-conditioning unit compared with the original PID system. The method can be used for online tuning of PID parameters as well.*

Categories and Subject Descriptors:
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General Terms:
Video Frame Processing, Content Processing

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1. Introduction

The energy consumption for building operation in China accounts for over 25% of the total social energy cost, and the proportion used for air conditioning is more than 50%. As a result, there are broad research interests in managing and operating air conditioning equipments efficiently to reduce the energy consumption. Referring to the control theory, an air conditioning unit is a typical multi-inputs/ outputs system with features of nonlinearity, time-dependency and large time-delay, which is difficult to control.

PID control is one of the most widely used strategies in industrial process control. Early engineering applications of air conditioning control system were mainly based on PID adjustment. The algorithm is simple, but it has a long response time. Adjustment to the algorithm is not flexible resulting a poor fitness to the time-dependent variation of air conditioning parameters. PID controller parameters optimization is crucial since it directly affects the effectiveness of control and is closely related to the safety and economic operation of the whole system.

In this paper, we employed adaptive genetic algorithm to obtain the global optimal PID parameters [1] for air conditioning units. As a result, the control system of central air conditioning can be optimized and overshoot can be prevented. Moreover, regulation/response time is reduced.

2. Mathematical Modeling of Air Conditioning System

To guarantee the maximum use of energy, most of the air conditioning systems mix a certain proportion of outdoor

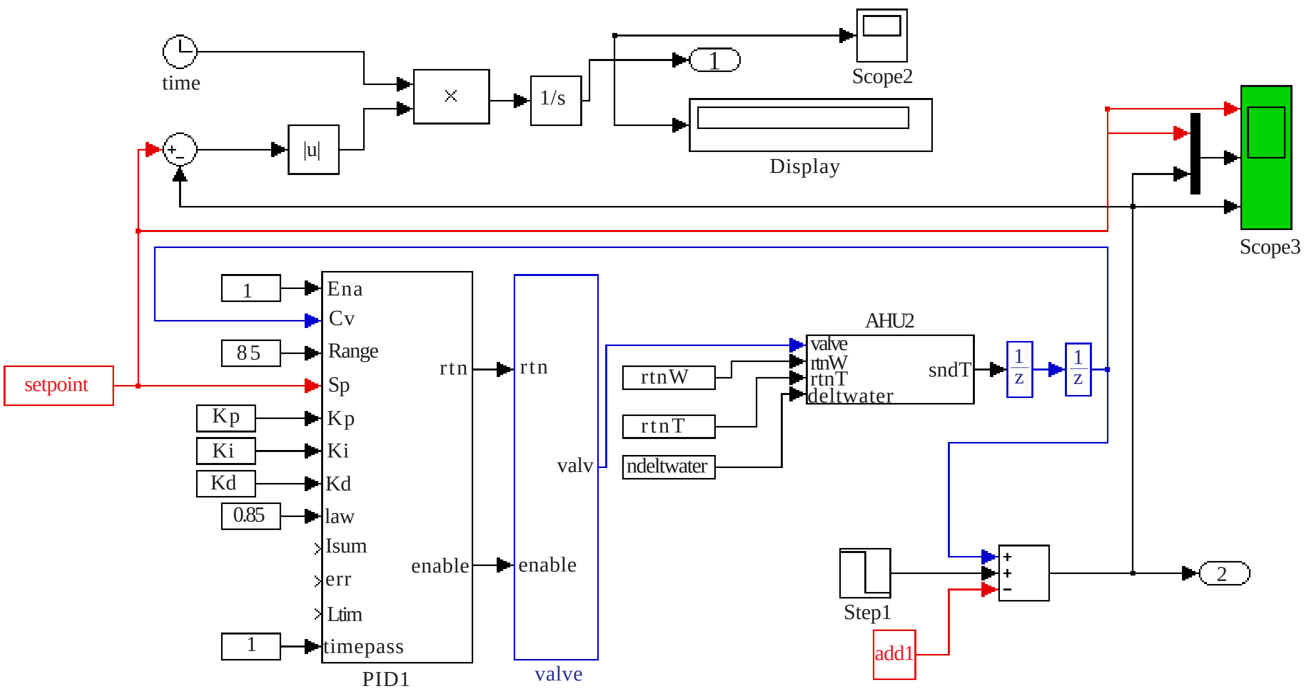

Figure 1. Integrated simulation model of air conditioning system

and indoor air in the air mixing channel. The mixed air is then delivered to the air-handling equipments through air supply systems. Therefore, the air conditioning system modeling [2] include the room cooling load model, surface cooling coil model, air mixing model, etc. The simulation and modeling are performed mainly focusing on the summer working condition, so the humidification model and heater model are not considered here. The integrated simulation model of air conditioning system is shown in Figure 1.

3. PID Parameter Optimization Based on Adaptive Genetic Algorithm

There are many methods for PID parameters optimization such as indirect optimization, gradient method, hill climbing method, etc. Genetic algorithm [3] is an efficient approach for getting the optimal global solution without any initial information. In adaptive genetic algorithm, probabilities of crossover (*pc*) and mutation (*pm*) can be automatically varied according to the fitness values of the solutions.

The control system is displayed in Figure.2 while the flow chart of PID parameter optimization is shown in Figure.3.

3.1 Encoding and decoding of parameter

The way to describe the feasible solution in genetic algorithm is to transfer the feasible solution of a certain question from its solution space to the search space that can be dealt with by genetic algorithm. This transfer method is called encoding. Usually, a number of parameters are encoded to substrings, and then the substrings are spliced to form chromosome chains. Binary coding is the most common coding method in genetic

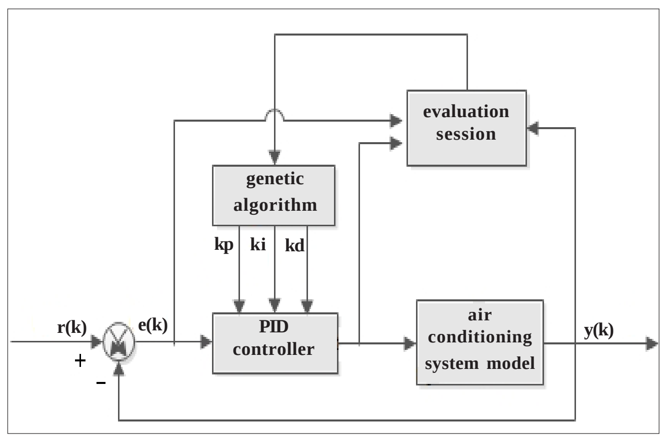

Figure 2. System block diagram of optimization of PID control based on genetic algorithm

algorithm. Due to its simplicity and variety of encoding forms, we adopt binary coding method and use three parameters (Kp, Ki, Kd) to approach optimization. Considering both sufficient search space and search efficiency, each parameter is expressed in ten bit unsigned binary code. Three parameter strings are connected together in the order of Kp, Ki, Kd to form a sample of length 30. Here we define the ranges of the parameters as $Kp \in [0, 3]$, $Ki \in [0, 3]$, and $Kd \in [0, 1]$. The parameters are calculated according to the following formulas:

$$Kp = MinX1 + \frac{y1}{2^{10}}(MaxX1 - MinX1) \quad (1a)$$

$$Ki = MinX2 + \frac{y2}{2^{10}}(MaxX2 - MinX2) \quad (1b)$$

$$Kd = MinX3 + \frac{y3}{2^{10}}(MaxX3 - MinX3) \quad (1c)$$

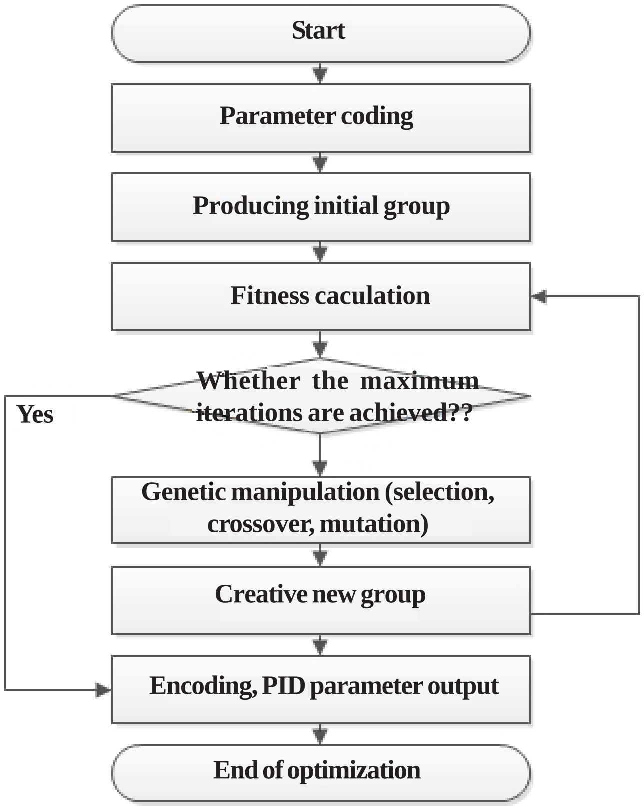

Figure 3. Flow chart of optimization of PID parameters based on genetic algorithm

*Min X*1, *Min X*2, *Min X*3 are the minimum values of *Kp*, *Ki*, *Kd*, respectively. *Max X*1, *Max X*2, *Max X*3 are the maximum values of these three parameters. *y*1, *y*2 and *y*3 denote three 10 bit unsigned binary codes.

3.2 Selection of the fitness function

In order to obtain satisfactory dynamic characteristics of the transient process, the integral of time multiplied the absolute value of error is used as the parameter to select the minimal target function. To avoid massive data control, the squared term for input control is added into the target function. The optimal index J is calculated as

$$J = \int_0^{\infty} (w_1 \,|\, e(t) \,|\, + w_2 u^2(t))\, dt \qquad (2)$$

where $e(t)$ represents the systematic error, $u(t)$ is the output of the controller, and w_1 and w_2 are the weights.

In addition, a penalty term is added to Equation (2) to prevent overshoot. As soon as an overshoot happens, it will become a term of the optimal index. So if $e(t) < 0$, the optimal index will be:

$$J = \int_0^{\infty} (w_1 \,|\, e(t) \,|\, + w_2 u^2(t) + w_1 \,|\, e(t) \,|)\, dt \qquad (3)$$

Where w_3 is a weight and $w_3 >> w_1$.

The fitness function f is defined as $f = \frac{1}{J}$ · The hereditary algebra $G = 50, w_1 = 0.999, w_2 = 0.001, w_3 = 100$ are determined according to the real condition.

3.3 Operator of adaptive genetic algorithm [4]

①Selection operator

Selection operator is used in genetic algorithm to perform natural selection procedure among individuals of groups. When carrying out the selection, fitness is the main principle. Those individuals with higher fitness will have higher possibility to be inherited to the next generation, while others with lower fitness will have lower possibility to be inherited. The possibility of being selected for each individual is positively related to its fitness. If the size of a group is represented by M, fitness of the individual I is Fi, so its possibility of being selected can be described as:

$$Pi = \frac{Fi}{\sum_{i=1}^{M} Fi} \qquad (4)$$

② Crossover operator [5]

After the individuals have been selected to reproduce the next generation, the same positions of two individuals are selected randomly to make them exchange with the crossover possibility Pc. This process represents the random exchange of information, aiming at creating new combinations of genes, that is, to produce new individuals. Generally, the empirical range of Pc is 0.50~0.99. In order to prevent the local optimization of the early group evolution and make Pc change automatically with the fitness, the formula is:

$$Pc = \begin{cases} Pc_1 - \dfrac{(Pc_1 - Pc_2)(f_{max} - f')}{f_{max} - f_{avg}}, & f \geq f_{avg} \\ Pc_1, & f < f_{avg} \end{cases} \qquad (5)$$

Wherein, $Pc_1 = 0.9$, $Pc_2 = 0.6$, f_{max} is the maximum fitness value in the group, f_{avg} is the average fitness value of each generation, f' is the higher fitness value of the two selected individuals that are about to experience crossover exchange.

③ Mutation operator

Referring to the principle of gene mutation in biogenetics, mutation happens to some positions of some individuals with the possibility of Pm. The mutation possibility Pm is in accord with the situation of extremely less biological mutation. Mutation operation is to replace the genes at some genetic loci with other alleles at the same genetic loci in the individual chromosome code strings so as to form a new individual. Usually, the empirical range of Pm is 0.0001~0.1. To avoid the local optimization of the early group evolution and to make Pm change automatically with the fitness, the formula can be described as:

$$Pm = \begin{cases} Pm_1 - \dfrac{(Pm_1 - Pm_2)(f_{max} - f')}{f_{max} - f_{avg}}, & f \geq f_{avg} \\ Pm_1, & f < f_{avg} \end{cases} \qquad (6)$$

Wherein, $Pm_1 = 0.1$, $Pc_2 = 0.001$, f_{max} is the maximum fitness value in the group, f_{avg} is the average fitness value of each generation, and f is the fitness value of those individuals that are about to mutate.

4. P Analysis of Simulation Results of PID Tuning Parameters Based on Adaptive Genetic Algorithm

4.1 The connection between the adaptive genetic algorithm and air conditioning model

The simulation model includes the adaptive genetic algorithm and air conditioning system model. The adaptive genetic algorithm creates .m file on MATLAB in form of code, systematic error $e\ (t)$ is the input value and the outputs are Kp, Ki and Kd; The air conditioning system model is built on the Simulink. Three algorithm optimized parameters Kp, Ki and Kd are the inputs while $e\ (t)$ is the output. They are connected by pid_ga function to realize the data flow and calculation, as is shown in Figure.4.

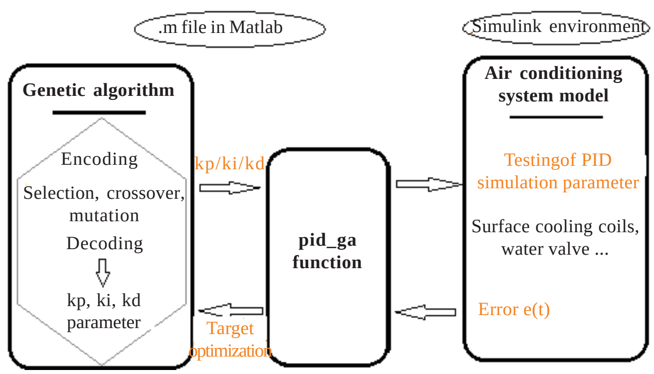

Figure 4. Connection diagram of adaptive genetic algorithm and air conditioning model

The final optimal PID parameters are: $Kp = 2.9268$, $Ki = 0.4600$, $Kd = 0.9756$.

4.2 Simulation results and analysis

Figure. 5a (Control performance of data acquisition) shows a comparison between the set temperature and the real air temperature, demonstrating the advantages and flaws of original control method for controlling the operation of air conditioning system in real condition. Curve 1 represents the set temperature, and curve 2 is the real air temperature. By comparing the difference we can notice that the real air temperature can follow the set temperature in some way, but the control strength and static/dynamic characteristics are relatively poor. When the set temperature decreases from 36°C to 31°C for the first time at around time point 100, the air temperature output has not shown a downward trend until 300 time points delay, and reaches the set value after approximately 700 time points, which reconfirms the large delay of the system. From 3200 to 4000, the real air temperature stops following the trend of set value and a large deviation can be observed. Figure. 5b (Control performance of PID) depicts the difference between the output air temperature of the surface cooling coils and the real collected air temperature. Curve 1 shows the set temperature, curve 2 is the real air temperature, and curve 3 stands for the output air temperature of the model. From the comparison, it is clear that under the control of PID controller model, the simulation of output air temperature in the surface cooling coils is perfectly in accord with the real condition, which can exactly reflect the real output situation of the surface cooling coils for the system under the PID control strategy of field controller. This model is of excellent accuracy.

Figure. 5c (Control performance of PID based on Genetic Algorithm) demonstrates the control characteristics of air conditioning system after the optimization of PID controller performed by classical genetic algorithm operation. Curve 1 is the set temperature, 2 is the real air temperature and 3 is the classical genetic algorithm optimized PID control output curve. From this figure, it can be observed that the introduction of genetic algorithm has speeded up the response of system. When the set temperature changes,

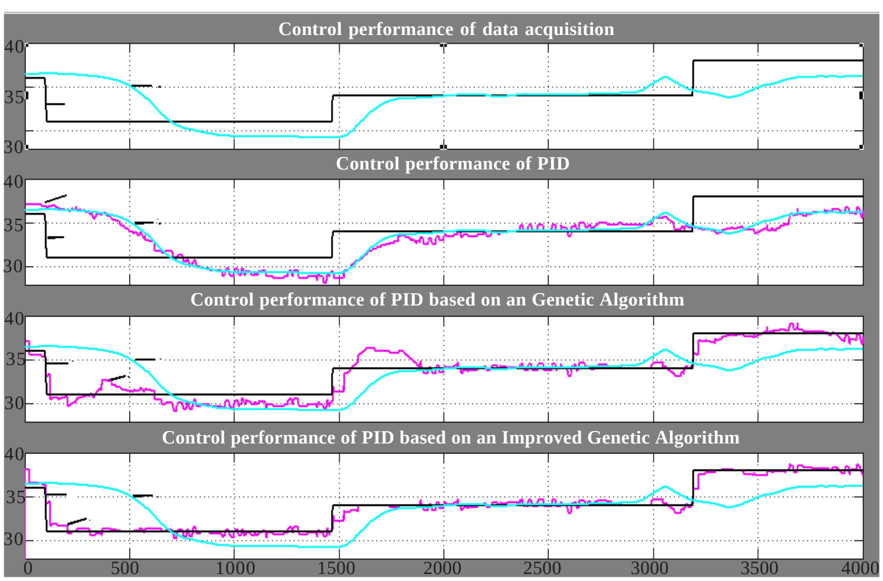

Figure 5. Simulation results figure of air conditioning PID optimization control

the response rate of output air temperature shows a significant improvement. The original system needs nearly 700s to get close to the set value while it only takes 200s after applying the genetic algorithm. The adjusting time is reduced by around 83%. For the original system, the downward trend occurs after 300 time points delay, while after the genetic algorithm is introduced, the following feature has been largely improved. But from the time point 1500 to 2000, there is great overshoot existed with the value of nearly 2°C. And the system is instable in the later stage and small scale fluctuations do exists.

Figure. 5d (Control performance of PID based on Adaptive Genetic Algorithm) shows the control characteristics of air conditioning system after the optimization of PID controller via adaptive genetic algorithm operation. Curve 1 is the set air temperature, curve 2 is the real air temperature, and curve 3 is the adaptive genetic algorithm optimized PID control output. From this figure, it can be concluded that after the introducing adaptive genetic algorithm, both the systematic adjusting and delay time have kept the advantage of the classical genetic algorithm with a reduced time of approximately 83% and excellent following feature. Also, overshoot has been effectively avoided and static error has been better eliminated.

5. Conclusion

Air conditioning unit is a typical nonlinear, time-dependent system with large delay time. Adaptive genetic algorithm is a global optimizing method and its results are usually not influenced by the initial values.

Considering the features of the central air conditioning unit, the present paper has built a model of central air conditioning unit control system. After simulating and modeling, the method of using adaptive genetic algorithm to realize the optimization of PID controller parameters for air conditioning system, conforming the apparent advantages of genetic algorithm in efficiently and effectively optimizing parameters. It also effectively helps to solve the problem of large delay time. The systematic output air temperature shows a good following feature to the set temperature. It is facile to find the optimal condition with relatively high efficiency.

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