A modified Genetic Algorithm using SVM for PID Gain Optimization

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Abstract: : Genetic algorithm is well known for stochastic searching method in imitating natural phenomena. In recent times, studies have been conducted in improving conventional evolutionary computation speed and promoting precision. This paper presents an approach to optimize PID controller gains with the application of modified Genetic Algorithm using Support Vector Machine (SVMGA). That is, we aim to explore optimum parameters of PID controller using SVMGA. Simulation results are given to compare to those of tuning methods, based on Simple Genetic Algorithm and Ziegler-Nicholas tuning method.

Keywords: Genetic Algorithm, Support Vector Machine, SVMGA, PID control.

1. Introduction

Genetic Algorithm is well known as a useful tool for finding the optimal solution in mathematically complex systems through probable and experimental methods. The initiative for genetic algorithm had been launched by several biologists in 1950, but it was only until 1975 that a breakthrough occurred in the development of computer algorithm by *Holland.*[2] In general, despite its weakness in the theoretical background, Genetic Algorithm exhibits outstanding functional outcomes in experiments. In addition, Genetic Algorithm has the ability to search the optimal solution with only object function even when background information or additional data is unavailable. Such characteristics render Genetic Algorithm to solve complex problems that conventional algorithm solutions have run up against.

One of the most recently developed experimental methods, Support Vector Machine (SVM) is considered to be an algorithm endowed with high performance.[8] Widely applied in function regression and classification problem, this method is likely to converge to global optimal solution. In addition, SVM's internal structure, which is needed to learn, is automatically determined. Until now, we have suggested the modified Genetic Algorithm using SVM and we have presented its better performance than conventional method. This paper applied the algorithm mentioned above to the real system, PID controller. Despite its long history, it has been a popular solution widely used in modern industries because of its operational convenience and simplistic internal structures. As we use the modified Genetic Algorithm using SVM in PID controller, optimization has been achieved through tuning each gain parameter.

2. Modified Genetic Algorithm using Support Vector Machine (SVMGA)

2.1. Support Vector Machine (SVM)

2.1.1 Support vector learning method

Support Vector Machine is a new learning method that has been shown excellent performance in pattern classification and function regression problems. This method is used widely as a tool for speech recognition, image processing, statistical processing and many other fields rigorously.

Support vector learning method has Multi-layer perceptron (MLP) with one hidden layer and it has Radial basis function (RBF) network, so we get profits as the following features.

- The number of hidden nodes can be determined automatically.
- It has no problem that converges the local minimum having a gradient descent method etc., so we can easily search the global minimum with this method.
- It is excellent in generalization capability, because its induction procedure is explained by statistical learning theory.
- Support vector means some data that decide optimal separating plane(or hyperplane) among training data.

2.1.2 Optimal separating hyperplane

Pattern classification problem's purpose which has two classes is to search a boundary that can divide the classes. Training data is given as following:

$$(x_1, y_1), (x_2, y_2), \cdots, (x_m, y_m), \tag{1}$$

where m is the number of data,$x \in R^n$ is input data, and $y \in \{-1, +1\}$ is output data. Training data are made up of subsets of $y = +1$ and $y = -1$. If these two subsets are linearly separable, they can be separable by the following hyperplane:

$$\langle w, x \rangle + b = 0, \tag{2}$$

where w is a weight vector and b is a bias. That is,

$$\begin{aligned} \langle w, x_i \rangle + b > 0 \quad \text{for} \quad y_i = +1 \\ \langle w, x_i \rangle + b < 0 \quad \text{for} \quad y_i = -1, \end{aligned} \tag{3}$$

and these equations can be rewritten again as following:

$$y_i(\langle w, x_i \rangle + b) \geq 1, \quad i = 1, 2, \cdots, m. \tag{4}$$

There are many hyperplanes satisfying the equation (**??**). Among them, to find the optimal separating hyperplane, we define margin that distance between separating hyperplane and the nearest data from that hyperplane. The hyperplane which has a maximal margin becomes the optimal separating hyperplane. Support vector learning algorithm aims at finding this optimal separating hyperplane. To find this optimal separating hyperplane is represented to solve the following optimal problem.

$$\begin{aligned} &\min \frac{1}{2}||w||^2 \\ &\text{s.t.} \quad y_i(\langle w, x_i \rangle + b) \geq 1, \\ &\qquad i = 1, 2, \cdots, m. \end{aligned} \tag{5}$$

Equation (??) can be only applied to separate two classes perfectly. If they are not perfectly separable, input data in other class is penalized. So we select the optimal hyperplane that margin is maximized and penalties are minimized at the same time. That is, as we add to the new variable, the penalty term, the equation (??) is changed as following:

$$\begin{aligned} &\min \frac{1}{2}||w||^2 + C\sum_{i=1}^{m} \xi_i \\ &\text{s.t.} \quad y_i(\langle w, x_i \rangle + b) \geq 1 - \xi_i, \\ &\qquad \xi_i \geq 0, \quad i = 1, 2, \cdots, m, \end{aligned} \tag{6}$$

where C is regularization positive constant.

2.1.3 Kernel method

In general, pattern classification problem is the majority in cases having a nonseparable hyperplane. To solve these cases, we use kernel method. If we use this method, separable hyperplane can be found by mapping to feature space from input space.

$$K(x_i, y_i) = \langle \Phi(x_i), \Phi(y_i) \rangle, \tag{7}$$

where K is a kernel function. RBF network, MLP network, polynomial function are used by representative kernel functions for mapping to feature space.

2.2. Genetic algorithm

A fundamental structure of genetic algorithm is that among individuals which is made up of one generation, some individuals which are adapt in environment and which are had a high fitness value can be alive with high probability. So, these individuals make offsprings for next generation using genetic operator - reproduction, crossover, and mutation etc. As this procedure do repeatedly, individuals converge a optimal solution gradually. In 1975, genetic algorithm was arranged and systemized by *Holland.*[2] After that, people have been vigorous to research about genetic algorithm and evolutionary computation. As a result, to find more suitable algorithm than conventional algorithm, various topics were occurred. The important topics of genetic algorithm are diversity problem, selection pressure, representation of solution parameter, genetic operator, search strategy, etc.

2.3. Modified simple genetic algorithm using SVM

We would get exacter results than common method and improve computation speed applying SVM's method in conventional genetic algorithm.[16] In other words, in case of simple genetic algorithm, basically, it has procedures - crossover and mutation - to produce offsprings. We adopted SVM in this procedures. Among reproducing individuals, they are reordered by fitness value. Weak individuals among them cannot be participated to operation. Also, criteria learning by SVM makes separating hyperplane. With this separating hyperplane, each individuals which is ending operation - crossover and mutation - is classified to some individuals that is expected GOOD and other individuals that is expected BAD. Only individuals that is expected GOOD are participated in next generation, so can diminish in load of whole plant and speed up evolutionary computation and search a exact solution.

Modified Simple Genetic Algorithm using SVM
Set k=0;
Create an initial population $P(k)$;
Evaluate $P(k)$;
While ⟨ the termination conditions are not met ⟩
  Set k=k+1;
  Generate training data and do SVM;
  Reproduce mating pool $\bar{P}(k)$ from $P(k-1)$
    using roulette wheel selection;
  Crossover $\bar{P}(k)$ to form a tentative population $\tilde{P}(k)$;
  Mutate $\tilde{P}(k)$ to form the new population $P(k)$;
  Adopt the SVM criterion
    (Classify GOOD and BAD individuals);
  Evaluate P(k);
End while
Output the solution;

The first data evaluating populations become SVM's training data. That is, x_is are gene value in equation (1) and y_is are output data which are determined by fitness value . Classifier created by training data is applied for individuals about finishing genetic operation and it decides whether each individual takes part in next generation or not. Finally, the evolutionary speed can be improved because BAD genes are weeding out and only selected GOOD genes are able to participate in next generation.

3. Tuning the PID Controller

3.1. PID Control

Despite its long history, PID controller is still widely used in the industry for its simplistic features and characteristics of tuning parameters, making it easy to calculate the controller tuning constants. The performance of PID controller depends on three principle parameters, i.e., proportional gain(K_P), integrate gain(K_I), derivative gain(K_D), and the optimization of system is determined in according to how the controller tuning constants are being adjusted. *Ziegler* and *Nichols* first developed a systematic PID tuning method for the optimization of PID controller in the 1942.[13] Recently, research studies regarding optimization through evolutionary methods are constantly conducted in offline spheres. *Wang* first studied Genetic Algorithm in a system that neutralized pH, establishing optimal tuning with Simple Genetic Algorithm (SGA).[12] Figure 1 shows the block diagram of PID controller. As it can be seen, the output of plant is reached to wanted target by PID control.

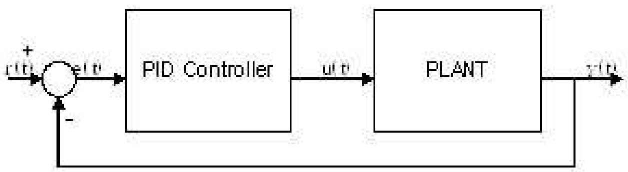

Fig. 1. PID controller

Equation (8) presents PID controller in the time domain.

$$u(t) = K_P e(t) + K_I \int_0^T e(t)dt + K_D \frac{de(t)}{dt} \quad (8)$$

In this paper, we try to search for PID optimization gain by using SVMGA methods.

3.2. PID gain optimization using SVMGA

Likewise to Simple Genetic Algorithm, PID controller using SVMGA methods must establish object function which is evaluated about performance. The following three equations can be applied to evaluate the system's performance.

$$ISE = \int_0^T [r(t) - y(t)]^2 dt \quad (9)$$

$$IAE = \int_0^T |r(t) - y(t)| dt \quad (10)$$

$$ITAE = \int_0^T t|r(t) - y(t)| dt \quad (11)$$

where r(t) is reference input, y(t) is measured output.

That is, PID controller gains are optimized using SVMGA in order to minimize the results of the above three equations. According to each specific problem, performance index can be defined the function of overshoot, rising time, etc.

Using SVMGA, optimized parameters, consisted of proportional gain(K_P), integrate gain(K_I), derivative gain(K_D), are represented in 8 bits of binary strings and each parameters complete a chromosome structure in the forms of substring.

4. Experiment

We applied using SVMGA to optimal tuning of PID controller to erect inverted pendulum. Inverted pendulum is a unstable system that can't erect by itself in natural state but fall down. It is made up of two parts. The lower part consists of motor and encoder, and the upper part is long rod on axis which is connected potential meter. The cart can move to horizontally, and it can balance through moving when rod starts to fall down.

We defined that x is the displacement of cart and θ is the angle of rod. The following equations are the equations of motion of inverted pendulum.

$$(M + m)\ddot{x} + C\dot{x} - mL\ddot{\theta} = F \quad (12)$$

$$mL\ddot{x} = (J + mL^2)\ddot{\theta} - mgL\theta \quad (13)$$

where M is a mass of cart, m is a mass of rod, C is a coefficient with rail, and L is a length of rod.

We selected the object function, Integration of Square Error (ISE), which can be quantitatively evaluated the performance of PID controller. To present the performance, we compare the SVMGA with *Ziegler* and *Nichols* method in table 1.

tuning method	K_P	K_I	K_D	P_{OS}	t_r
ZN	44.21	5.53	0.98	0.088	0.015
SVMGA	42.50	5.62	1.00	0.039	0.002

Table 1. Compare gain and performance with two methods

Also, figure 2 shows unit-step response about two methods. As we see table 1 and figure 2, we got the better results using SVMGA than *Ziegler* and *Nichols* method. Figure 3 shows the best object value versus generation in PID control. Through this figure, we also see that SVMGA method is faster than conventional genetic algorithm.

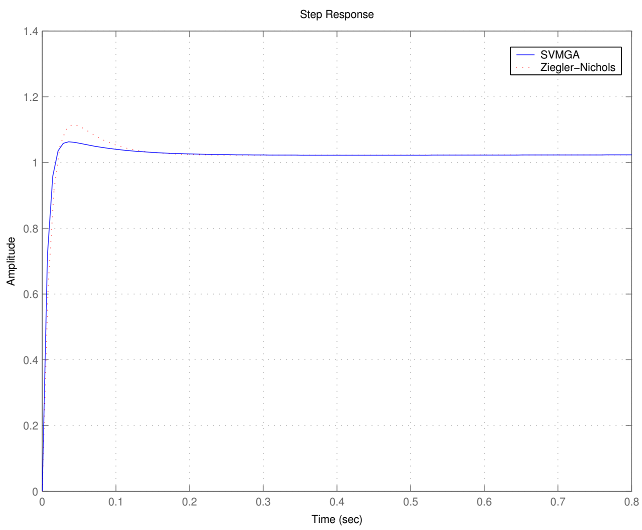

Fig. 2. Compare unit-step response with two methods

5. Conclusion

In this paper, we practiced controlling the optimal tuning of each parameter's gains of PID controller with the modified Genetic Algorithm using Support Vector Machine (SVMGA). And *Ziegler* and *Nichols* method has been used as a comparison in evaluating performance.

As a result, one was able to determine the modified genetic algorithm using SVM, yielded significant outcomes such as

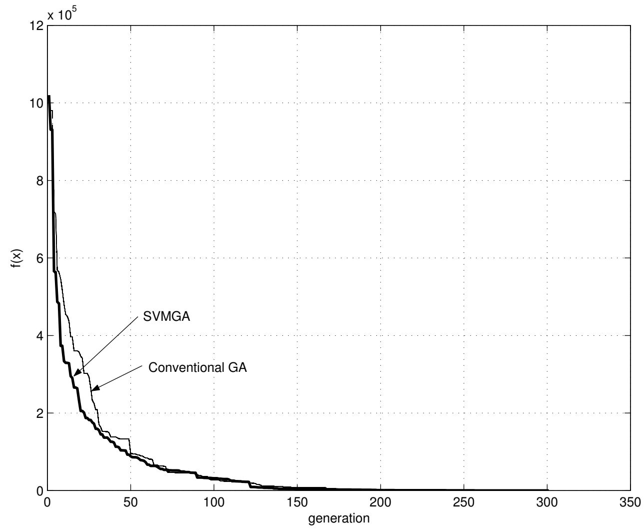

Fig. 3. Best of object value vs. generation

reducing loads to the systems, improving performance and elevating evolutionary speed. Moreover, it was evident that the method suggested above surpassed other tuning methods in terms of adapting optimum settings. Though this paper established boundaries by focusing mainly on optimized application of PID controllers, I hope to conduct further research the modified Genetic Algorithm using SVM to other systems that are in need of optimum systems.

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