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A New Adaptive PID and CMAC Controller Based on Multi-parameter Optimization

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Abstract: PID and CMAC compound controller was developed about thirty years ago but yet it lacks effective multi-parameter self-tuning method, including parameters of CMAC learning rate and inertia weight. Without proper control parameters, the control system based on PID and CMAC controller will converge very slowly, even becoming unstable after the simulation for a period of time. A new kind of multi-parameter self-adaptive optimization scheme based on adaptive genetic algorithm (AGA) was proposed for PID and CMAC controller. The central idea of self-adaptive multi-parameter optimization based on AGA is that PID parameters K_p, K_i, K_d and CMAC parameters η, α are regarded as a group of gene in GA. The PID and CMAC parameters are adjusted adaptively by AGA according to a certain objective function. Finally, the simulations show that the proposed control method can improve the performance effectively. It is a simple convenient and effective control scheme for the nonlinear and uncertain control system.

Key words: Excitation control, adaptive genetic algorithm, Multi-parameter Optimization, CMAC controller, PID controller

INTRODUCTION

A Cerebellar Model Articulation Controller (CMAC) was put forward by Albus (1975). It has many advantages, including dealing with nonlinear, self-learning, local generalization ability (Albus, 1975; Miller, 1990). The CMAC neural network has been widely used in industrial control recently, which is as fed-forward control with fixed gain PID feedback controller. But, this control system needs to set too many parameters. Since these parameters interact with each other, so it is difficult to tune. On the other hand, if improper selection of parameter will not only obtain bad control effect but also cause the system unstable. The literature (Li, 2002) demonstrated that fixed gain PD controller only can achieve locally finite stability when the system exists CMAC estimation bias or random disturbance. The literature (Zhou *et al*., 1997; Li, 2005) uses the genetic algorithm for PID controller optimal design. The literature (Lin and Mei, 2005) has put forward CMAC learning rate, optimization about adaptive genetic algorithm. The literature (Yeh and Tsai, 2010) has put forward self-organizing CMAC network. These papers obtained fruitful results. Meanwhile they did not involve control parameters interaction between PID and CMAC, as well as multi-parameter optimization problems. Under the inspiration of these literatures, this study further proposed a new kind of muti-parameter optimization about PID and CMAC controller based on genetic algorithm. Optimization parameters include CMAC learning rate, η inertia weight α, PID parameters K_p, K_i, K_d and so on. In order to verify the proposed algorithm control effect, a time-varying controlled object example is given to simulate and compare study. At last, the application of the proposed scheme is proved by the numerical simulation of excitation control.

PRELIMINARIES

CMAC neural network: The Cerebellar Model Articulation Controller (CMAC) neural network is an associative neural network, which has local generalization ability. Any one of the input is only associated with the smaller portion of the neuron and similar input will have similar output, while the different input produces different output. The principle of CMAC structure diagram is presented in Fig. 1. It can be viewed as two mapping composition, namely X corresponding to A and A corresponding to Y. The first mapping is obtained by rolling combination, whose purpose is the more similar input space vector, the more relative output space vector, namely X is implemented associative characteristics in A, where A, X and Y, respectively represents virtual space of imagination, the input and the output space of physical storage.

The working principle of the CMAC is any point x_i in input space will activate C cells in imagination space of A

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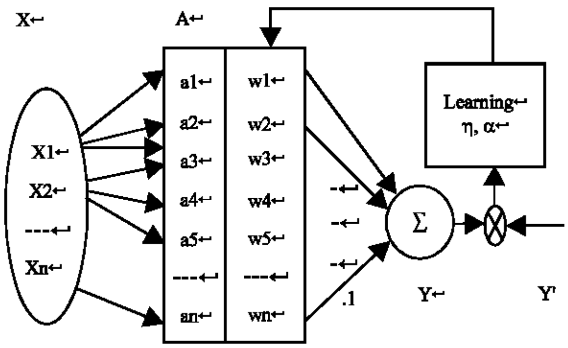

Fig. 1: Principle diagram of CMAC

(where, a_i = 1 means activation, C = 3). The output y of CMAC neural network is the sum of corresponding weight value of C cells, which are activated in A, such as Eq. 1. Weight value adjustments usually adopt the LMS algorithm which is defined as Eq. 2:

$$y = f(x_i) = a^T \bullet \omega = \sum_{j=1}^{C} \omega_j a_j(x) \quad (1)$$

$$\omega\ (k+1) = \omega\ (k)+\eta\ \hat{I}Et/C+a\ [\omega\ (k)-\omega\ (k-1)] \quad (2)$$

where, y is the actual output, y' is the desired output, C is the generalization coefficient, is the learning rate, α is the inertia weight, η and α are two important parameters, improper selection may cause the system to not convergence or rate of convergence slowly.

Adaptive genetic algorithm: Genetic Algorithm (GA) is a parallel random search optimization method which was proposed in 1962 by American professor Hollad Michigan (Li *et al*., 2002). Although, the genetic algorithm has its own advantages and characteristics but there are many problems and shortcomings, mainly lies in (1) The conventional genetic algorithm has premature phenomenon (2) The convergence speed becomes very slowly in the late stage of evolution, even becomes swing.

Aiming at the shortcomings and insufficiency of general genetic algorithm, some scholars proposed adaptive genetic algorithm (Deep *et al*., 2009). The basic idea is to self adjust Pc and Pm during evolution. Pc and Pm are taken a small value if the fitness of individuals is higher, otherwise taking a big value. This method can provide a solution to the relatively better Pc and Pm, which can keep the population diversity, at the same time to ensure the convergence of GA. The algorithm is adaptive for Pc and Pm which are defined as:

$$P_c = \begin{cases} P_{c1} - \dfrac{P_{c1} - P_{c2}(f' - f_{avg})}{f_{max} - f_{avg}} & f' \geq f_{avg} \\ P_{c1} & f' < f_{avg} \end{cases} \quad (3)$$

$$P_m = \begin{cases} P_{m1} - \dfrac{P_{m1} - P_{m2}(f_{max} - f\ )}{f_{max} - f_{avg}} & f \geq f_{avg} \\ P_{m1} & f < f_{avg} \end{cases} \quad (4)$$

where, f_{max} is the largest group fitness value; f_{min} is the average fitness value; f' is larger fitness value of two cross individual; f to adapt to the variability of individual; P_{c1}, P_{c2}, P_{m1}, P_{m2}, ∈0, 1.

DESIGN OF THE CONTROLLER

Design of PID and CMAC controller based on multi-parameter Optimization: CMAC neural network is the inverse dynamic model of the partial in the CMAC feed forward controller. In order to improve the system stability and anti-jamming, the learning process of CMAC network includes the entire dynamic inverse process of control system, which is control object and CMAC itself. A new CMAC composite controller based on improved genetic algorithm multi-parameter optimization is proposed in this study and its structure as shown in Fig. 2.

In the control structure, the improved composite controller being put forward in this study is different from the one proposed by the and Miller (1990) (1) The improved CMAC and PID composite controller uses the system error E (k) = Rin (k)-Yout (k) as weights training signal. The inverse dynamic model of the control system is to be realized for CMAC which including the conventional PID controller and CMAC controller. The improved structure effectively overcomes the study conflict of the conventional PID and CMAC controller, which lead to system instability. The improved structure also effectively overcomes the influence of cumulative error in the original control scheme and thus eliminates the system over learning phenomenon (He *et al*., 2001) (2) The improved GA is used to optimizing multi-parameter for CMAC composite controller learning rate η, inertia weight η and PID controller K_p, K_i, K_d. The control system can adjust the learning rate and the PID controller parameters in the learning process, which enhances the dynamic stability, self adaptive and operation. The improved system can adapt well to the change control system conditions and uncertain factors, so as to improve the control quality of the system.

The working process of improved PID and CMAC composite controller is divided into two stages for control and study. In control stage, the desired output Rin (k) and

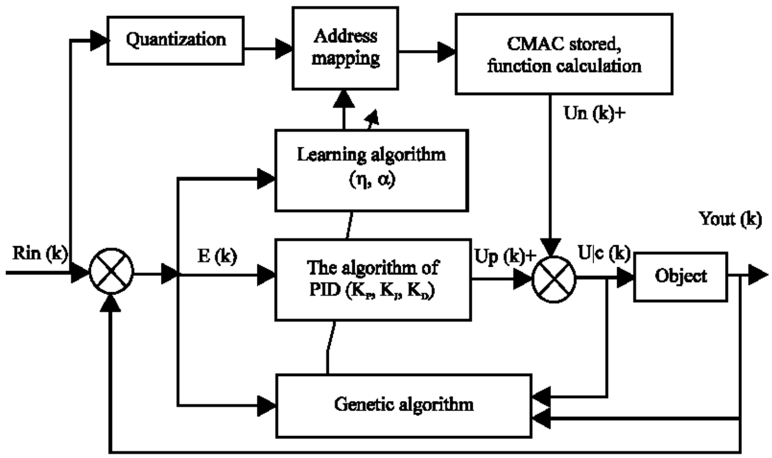

Fig. 2: PID and CMAC adaptive controller based on GA

the system tracking error E (k) = Rin (k)-Yout (k) are quantified as two-dimensional input address, which find the corresponding C unit in the CMAC memory. The output of the PID and CMAC composite controller is sum of the C unit weights. Un (k) is defined as follow equation:

$$U_n(k) = \sum_{j=1}^{c} \omega_j(k) a_j(k) \quad (5)$$

The total amount of output control system is summed of the output Un (k) of the CMAC and the output Un (k) of PID controller in parallel which is optimized by IGA:

$$U_c(k) = U_n(k)+U_p(k) \quad (6)$$

At the end of each control cycle, the control system enters the learning stage, in which weights are corrected by the error of the desired output and the control system actual output:

$$w(k) = w(k-1) + \eta \frac{e(k)}{c} \quad (7)$$

where, η is the learning rate, e (k) is tracking error for the system, the purpose of learning minimizes the system error e (k).

Algorithm implementation steps: Based on the traditional PID parameter tuning method and general experience, the ranges [min, max] of five optimized parameters is to be determined. The decimal code for each of actual parameter is defined as Eq. 8:

$$K = \min+(\max-\min)\ \text{Hrand} \quad (8)$$

where, rand∈(0, 1) is a random number, the individual chromosome is (K_P, K_I, K_D, η, α) other parameters such as iteration times, population size are to be set in the same time:

- It randomly generates n individuals' chromosomes to form the initial population P (0)
- Each individual's chromosome is decoded into the corresponding control parameters. Under the control of each parameters, the plant (10) gets the system error e (t) and control value u (t)
- According to the Eq. 9, the value J of the objective function is calculated for each of individual's chromosome, the adaptation value is defined as 1/J. If e (t)≤0, the objective function is defined as the Eq. 10:

$$J = \int_0^{\infty} \left(w_1 |e(t)| + w_2 u^2(t) \right) dt + w_3 t_u \quad (9)$$

if (e (t)<0)

$$J = \int_0^{\infty} (w_1 |e(t)| + w_2 u^2(t) + w_4 e(t)) dt + w_3 t_u$$

where, e (t) is the system error; u (t) is the total control amount of the controller output; t_u is the rising time; w_1, w_2, w_3, w_4 are the weights value and $w_4 >> w_1$, e (t) = y (t)-y (t-1), y (t) is the system output; the Eq. 10 is a penalty function which is used avoiding an overshoot:

- According to the fitness of each individual chromosome, the copy probability corresponding to each string is calculated in next generation

- The replication individuals is selected into matching pool in Pc probabilistic and cross location is determined randomly, adaptive Pc is defined as Eq. 3
- A adaptive mutation probability P_m is defined as Eq. 4 to conduct the operation
- The highest adaptation value in the Chronicles instead the worst individuals of the present, thus gets a new population p (t+1)
- Judging whether the iterations times reaches the preset value N or not. If so, end of program, else return to step 2
- The best individual chromosome after many generations of evolution is decoded as optimal control parameters

MATLAB SIMULATION ANALYSIS

In order to prove that the proposed PID and CMAC compound controller has the better control effect, simulation experiments based on MATLAB are done as follows. The controlled object is a second order transfer function, such as Eq. 11. In order to comparing the proposed controller performance, it gives the traditional PID and CMAC parallel control results under the same conditions by Miller (1990):

$$G(s)=\frac{1770}{s^2+60s+1770} \tag{11}$$

In simulation, the parameter of fixed PID and CMAC controller is, respectively, Kp = 25, Kd = 0.28, Ki = 0, η = 0.1. The domain of adaptive optimization parameter Kp, Ki, Kd, η, α is, respectively, [0, 30], [0, 0], [0, 1], [0, 1], [0, 1], parameters C = 5, N = 100, P_c = 0.1, P_m = 0.05, parameters of the objective function $\omega 1$ = 0.999, $\omega 2$ = 0.001, $\omega 3$ = 2.0, $\omega 4$ = 100, the sampling time T = 1 m sec.

Square signal tracking performance: The initial value and sampling time are constant as above. The input square signal (the black dotted curve) is r (k) = 0.5 sign (sin (4πkT)). The simulation results are shown in Fig. 3 and 4. In Fig. 3, the red curve is the tracking curve of PID and CMAC compound controller based on multi-parameter and the green one is the tracking curve of traditional PID and CMAC compound controller. In Fig. 4, the red curve is the error curve of PID and CMAC compound controller based on multi-parameter optimization and the green one is the error curve of traditional PID and CMAC compound controller.

From above tracking curve and error curve, the error value of PID and CMAC compound controller based on multi-parameter optimization reduces rapidly, so it has

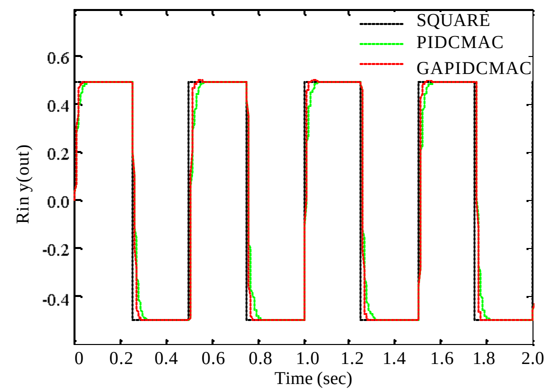

Fig. 3: Square signal tracking curve

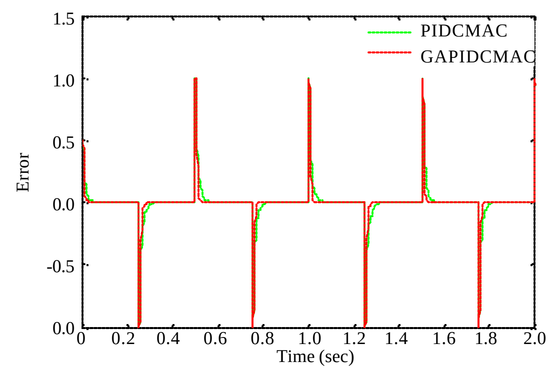

Fig. 4: Output control signal of compound controller

more rapid learning and weight-updating speed. The less the system error is, the better the effect of system input-output curve tracking is. Compared with the traditional compound controller, PID and CMAC controller based on multi-parameter optimization not only meets accurate tracking requirement but also has an adaptive control. Meanwhile, the system response and the convergence speed are both improved and the system stability has better guarantees.

Robustness simulation: In order to investigate the robustness of the proposed new PID and CMAC compound controller, the controlled object (Liu, 2003) suddenly becomes as Eq. 12 when the system is running in between 0.3 and 0.5 sec, while the system is still tracking the sine signal r (k) = 0.5sin (8πt), the corresponding simulation results are shown in Fig. 5 and 6:

$$G(s)=\frac{1770}{s^2+600s+17700} \tag{12}$$

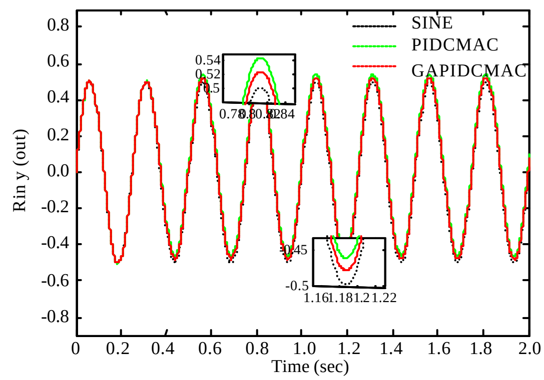

Fig. 5: Sine signal tracking curve

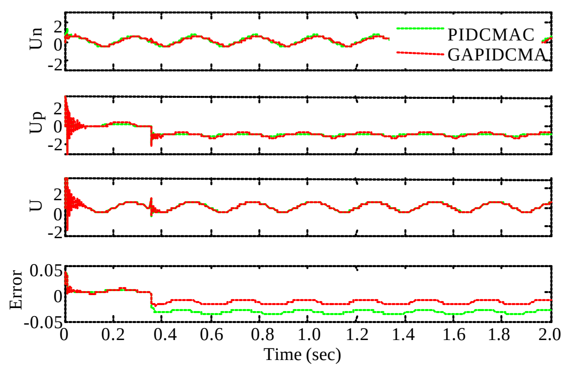

Fig. 6: Output control signal of compound controller

From above simulation plot, it shows that the traditional PID and CMAC compound controller is sensitive to the control object parameter change. It can not properly track the given signal. On the contrary, when the controlled object model parameter changes, the proposed controller not only has more rapid the response speed but also has higher control precision through on-line parameters adjustment by adaptive genetic algorithm. In Figure 6, the output error of the proposed scheme is always maintained in a small range, compared to the conventional PID and CMAC compound control, the new PID and CMAC controller has better robustness, faster learning speed and other advantages.

APPLICATION OF THE CONTROLLER

In this study, the step response simulation analysis of the PID and CMAC controller based on Multi-parameter Optimization for excitation control of synchronous generator is conducted. Synchronous generator has the characteristics of nonlinear, time-varying and complex system. Without considering magnetic saturation condition, the generator can be described as $K_G/(1+T_Gs)$. Where K_G is generator amplification coefficient, T_G is generator time constant. The voltage measure element is described as $K_M/(1+T_Ms)$, Where K_M is voltage ratio coefficient, T_M is measuring loop time constant. The actuator element is described as $K_E/(1+T_Es)$, Where K_E is amplification coefficient, T_E is amplification element time constant. The experiment parameters are set: sampling time T = 0.001 sec, KG = 1, $T_G = 11.2$, $K_M = 1$, $T_M = 0.035$, $K_E = 1$, $T_E = 0.7$. Then the excitation simulation control model based on PID and CMAC in MATLAB is as Fig. 7.

where, simulation parameters are Kp = 153, Kd = 10, Ki = 13, $\eta = 0.1$. The adaptive parameters are respectively $Kp\in[100, 200]$, $Ki\in[5, 20]$, $Kd\in[5, 15]$, $\eta\in[0.02, 0.1]$, $\alpha\in[0.02, 0.1]$. The object function is as above. The simulation time is 5 sec. The amplitude of 3 pulse disturbance signal is added between 3.5-3.6 sec.

The input-output simulation plots are obtained in Fig. 8 (the green curve represents the generator output of the proposed scheme, the red one is the generator output of the conventional PID and CMAC controller and the

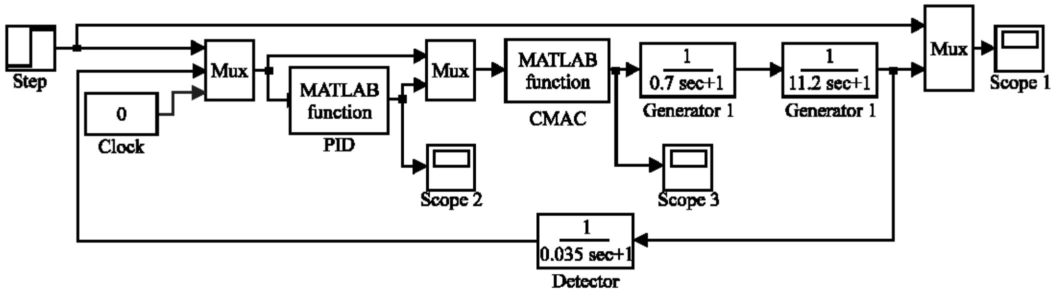

Fig. 7: Excitation simulation control model

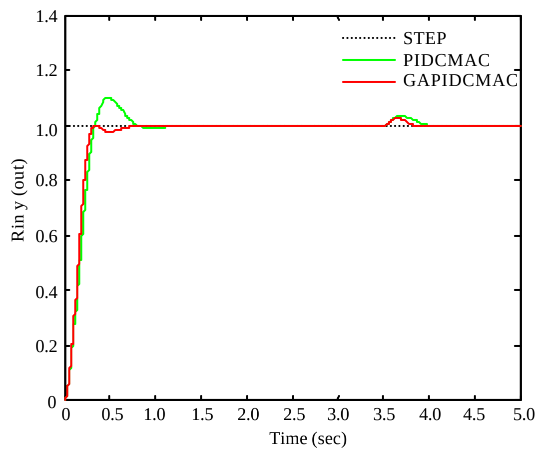

Fig. 8: Excitation simulation step response

black one is the input signal). It can be seen the error exists only at the beginning of a short time. The proposed scheme has the faster learning speed and higher accuracy under the same experimental conditions than the conventional PID and CMAC controller. Meanwhile the new system processes better robustness and anti-disturbance performance.

CONCLUSION

This study presents an effective multi-parameter optimization method to construct a new PID and CMAC controller based on adaptive genetic algorithm. It is composed of the adaptive genetic algorithm, CMAC network and PID controller. From the experimental results, the new compound controller has smaller error, faster learning speed and convergence speed, higher approximation accuracy and much better local generalization capability than the conventional compound controller. Under the changeable, complicated and disturbed conditions, on-line real-time control of the PID and CMAC compound control system can be realized. Meanwhile, the proposed method overcomes the problem that the control parameters are difficult to tune because of mutual coupling in conventional compound controller. It makes it possible that the PID and CMAC controller based on IGA can be easily implemented finally.

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