Application of Combined Controller Based on CMAC and Nonlinear PID in Dual Redundant Telescope Tracking System[1]

LiHeng[1,3],RenChangzhi[1], SongLibin[4],Wujun

1. National Astronomical Observatories / Nanjing Institute of Astronomical Optics & Technology, Chinese Academy of Sciences, Nanjing 210042, China

2. Key Laboratory of Astronomical Optics & Technology, Nanjing Institute of Astronomical Optics & Technology, Chinese Academy of Sciences, Nanjing 210042, China

3. Graduate University of Chinese Academy of Sciences, Beijing 100049, China

4.Dept. of Mechanical Engineering Tsinghua University, Beijing 100084,China

ABSTRACT

The direct drive tracking system of Telescope is one multivariable, nonlinear and strong coupling complex mechanical control system which is disturbed by some nonlinear disturbance such torque ripple, wind disturbance during the tracking process. the traditional PID control cannot fundamentally solved the contradiction between static and dynamic performance, tracking data and disturbance .This paper explores a kind of CMAC with nonlinear PID parallel composite control method for dual redundant telescope tracing servo system. The simulation result proves that combined algorithm based on CMAC and PID realizes the servo system without overshoot and accelerates the response of the system. What's more, CMAC feed-forward control improves anti-disturbance ability and the control precision of the servo system.

Keywords - direct drive; Nonlinear – PID; CMAC;Dual Redundant Telescope Tracking System; Dual-redundant six phase direct drive motors

1.INTRODUCTION

Double/three closed loop PID control algorithm is simple and widely applied in various industrial control field, so as the most astronomical telescope tracking system at home and abroad, for example, VLT[1], Keck[2] telescopes. With the demand of larger diameter, higher tracking precision, there is a very huge challenge for the future telescope, while direct drive technology provides an effective solution to the more and more complex tracking system. However, the direct drive tracking system of telescope is a multivariable nonlinear, strong coupling, complex mechanical and electrical controlled object, which is disturbed by some nonlinear disturbance such torque ripple, wind disturbance during the tracking process. Traditional PID

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control cannot fundamentally solve the contradiction between static and dynamic performance, tracking data and disturbance, which is more apparent in telescope with such a huge inertia.

The nonlinear PID can overcome contradiction in response speed and overshoot that is existed in conventional linear PID. In high precision servo control system, the tracking performance can be improved by feed-forward control [3]. The cerebellum model controller (CMAC) is a kind of imaginative neural network, which the learning algorithm, with local network generalization ability, is a kind of simple linear optimization and the convergence speed is much faster than ratio error back propagation (BP) algorithm, What's more, the algorithm doesn't exist the local minimum values problems and is suitable for real-time control. This paper explores a kind of CMAC with nonlinear PID parallel composite control method for dual redundant telescope tracing servo system, while CMAC neural controller achieves optimal feed-forward control, nonlinear PID controller realizes feedback control.

2. DUAL-REDUNDANT TELESCOPE'S TRACKING SYSTEM

Dual-redundant telescope tracking system is consisted of controllers(UMAC), actuators (Dual-redundant six phase direct drive motors), amplifier, sensors etc., of which the position, velocity and acceleration has to be controlled. Industrial PC receives telescope observation system (OCS) or remote control system's instructions through the Ethernet and instructs UMAC communicate with the amplifier to control tracking servo motors to implement dual-axial pointing or tracking motion after certain data processing. one PCI GPS card is plugged in the IPC to receive and get accurate UTC time and geographical coordinates. the tracking target 's azimuth Angle and height is calculated by astronomical formula according to the information and the target ascension and declination coordinates, which is feed back to the telescope tracking controlling system to implement target tracking and pointing.

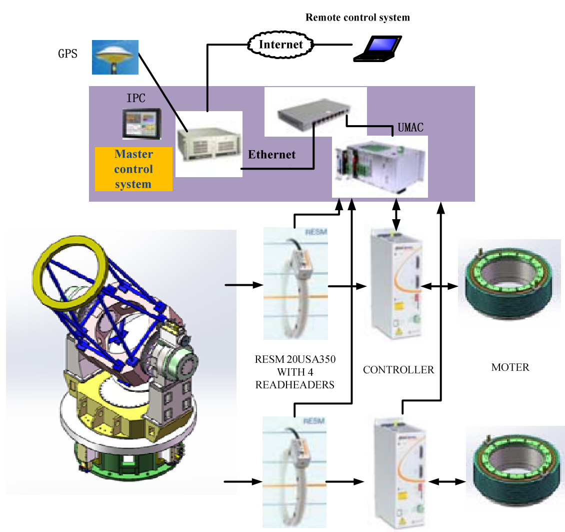


Figure 1 the construction of hardware of Dual-redundant telescope tracking system

Dual-redundant six phase direct drive motors is designed to drive the Azimuth and Altitude axis, which has more advantage such as low voltage, large output power, more smaller torque ripple, higher reliability, Compared with the traditional three-phase motor. Position feedback information is measured by the RENISHAW company's no built-in bearing angle encoder RESM20USA350, 55040 lines, including grating drum and four reading heads. Encoder signals are subdivided into 4096 by ACC-51E of UMAC as position feedback signals.

In order to improve the efficiency and reliability of the system, double redundancy, one hot backup control mode is used in dual redundant six phase torque motor, that is, The two redundant six phase torque motor work at the same time under normal circumstances, when one of them fail to work, the control system remove failure parts and enabling the other normal one immediately . however, cold backup work style is adopted in its control system.

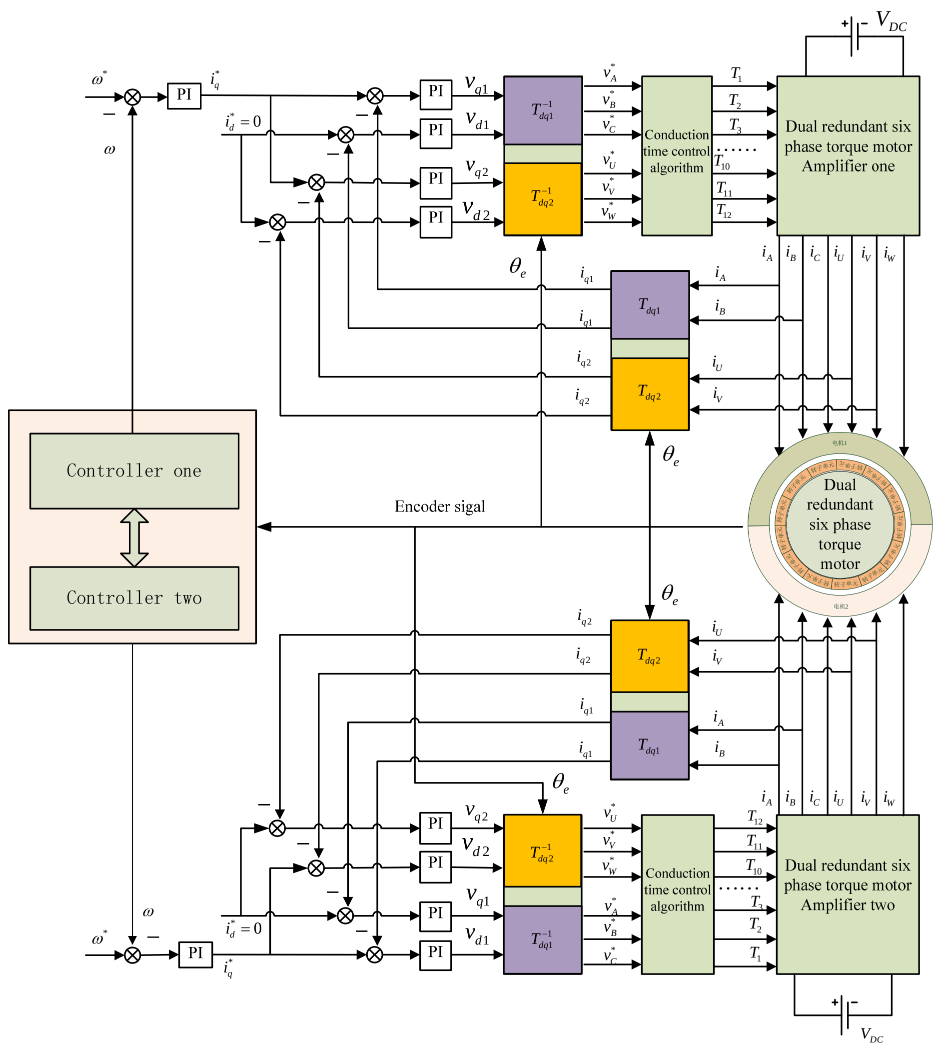


Figure2. Dual redundant six phase torque motor speed control principle diagram

3.PARALLEL CONTROL ALGORITHM BASED ON THE NONLINEAR PID AND CMAC

The nonlinear PID can overcome contradiction between speed response and overshoot that is existed in conventional linear PID. The nonlinear PID controller gain parameters is nonlinear function of the error variations and is determined by the error trend. If the nonlinear function is selected appropriate, the control system can achieve fast response without overshoot and enhance anti-disturbance ability. According to various gain parameters on the performance of the system and the influence of both the rapidity and stability, proportion, differential and integral gain parameters can choose according to the following equations:

$$k_p(e(t)) = a_p + b_p(1 - \sec h(c_p e(t))) \quad (1)$$

$$k_d(e(t)) = a_d + b_d / (1 + c_d \exp(d_d \cdot e(t))) \quad (2)$$

$$k_i(e(t)) = a_i \sec h(c_i e(t)) \quad (3)$$

Where the parameters $a_p, b_p, c_p, a_d, b_d, c_d, d_d, a_i, c_i$ are real count. k_p, k_d, k_i is the nonlinear PID parameters. The output of nonlinear PID controller can be expressed:

$$u(t) = k_p(e(t))e(t) + k_i(e(t))\int_0^t e(t)dt + k_d(e(t))\frac{de(t)}{dt} \quad (4)$$

CMAC is a cerebella biological model based on a proposed adaptive control to imitate the brain connected model by J. Albus in1975[4], which is suitable for a nonlinear mapping. CMAC models has the ability of generalization from the beginning of input, what's more, it may have some effect on its neighboring samples by learning of some input samples, Therefore, neighboring samples in the input space will results in more similar results in the output space by the CMAC algorithm. In addition, CMAC convergence rate is much faster than BP algorithm and other network models. It particularly can map a multi dimensional value into input space to a smaller limited area of the output space. So, by learning some samples in the multi dimensional state space of the input, it can learn to track and control solutions. Thus, CMAC algorithm is especially suit for non-linear function system. The advantages CMAC over other neural network are reflected in the following aspects:

- The CMAC is a local learning neural network, which the information is stored in the local structure and only very little network parameters are modified. It not only ensures the performance of functions under the premise of nonlinear approximation but also enhances learning speed, which makes the CMAC network suitable for real time control.
- A certain generalization that similar inputs produce similar output, different output is given by different input.
- It is capable of the continuous (analog) input and output ability
- Program by addressing, which is benefit for the serial computer to make simulation, makes the system respond far faster.
- As one nonlinear approximation realization, it is not sensitive to the order of learning data.

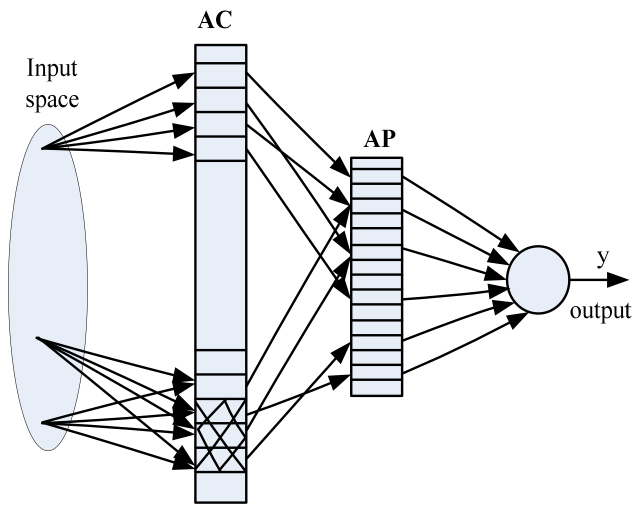


Figure3. CMAC model structure paragraph

With the superior performance of CMAC, it has better ability of general nonlinear approximation than other neural network model and is more suitable for complex nonlinear dynamic real-time control environment. Therefore, in the precise tracking platform system, a parallel control algorithm by the CMAC with nonlinear PID control is designed, while the CMAC neural controller achieves optimal feed-forward control, nonlinear PID controller realizes feedback control.

An instructor supervised way is adopted in the CMAC fore feed controller, the output $u_n(k)$ of CMAC is computed and compared with the total input of the system $u(k)$ after every circle, then modify the power of the parameter of the CMAC until the error of the total input and the output of CMAC become smallest. By the study of CMAC, the total output is ultimately controlled by the CMAC.

$$\begin{aligned} u_n(k) &= \sum_{i=1}^{c} w_i a_i \\ u(k) &= u_n(k) + u_p(k) \end{aligned} \tag{5}$$

There, a_i is binary selection value， c is CMAC network generalized function， $u_n(k)$ is the output of CMAC， $u_p(k)$ is the output of non-PID。

Firstly, the concept map of CMAC is divided the input space S $\left[S_{\min}, S_{\max}\right]$ into *N+2C* quantitative interval.

$$\begin{aligned} &v_1 \quad \cdots \quad v_c = S_{\min} \\ &v_j = v_{j-1} + \Delta v_j \qquad (j = c+1, \cdots, c+N) \\ &v_{c+N+1} \quad \cdots \quad v_{c+2N} = S_{\max} \end{aligned} \tag{6}$$

Then, the real map of CMAC can be expressed in the following.

$$a_j=\begin{cases}1 & \text{if } S_j\in\left[v_j,v_{j+c}\right], j=c+1,\cdots,c+N\\ 0 & others\end{cases} \tag{7}$$

$$\begin{aligned} E(k)&=\frac{1}{2}(u_n(k)-u(k))^2\frac{1}{c}\\ \Delta w(k)&=-\eta\frac{\partial E(k)}{\partial w}=\eta\frac{u(k)-u_n(k)}{c}a_i=\eta\frac{u_p(k)}{c}a_i\\ w(k)&=w(k-1)+\Delta w(k)+\alpha(w(k)-w(k-1))\end{aligned} \tag{8}$$

Where, η is the study efficiency of the CMAC network, $\eta\in(0,1)$ α is the inertial coefficient, $\alpha\in(0,1)$.

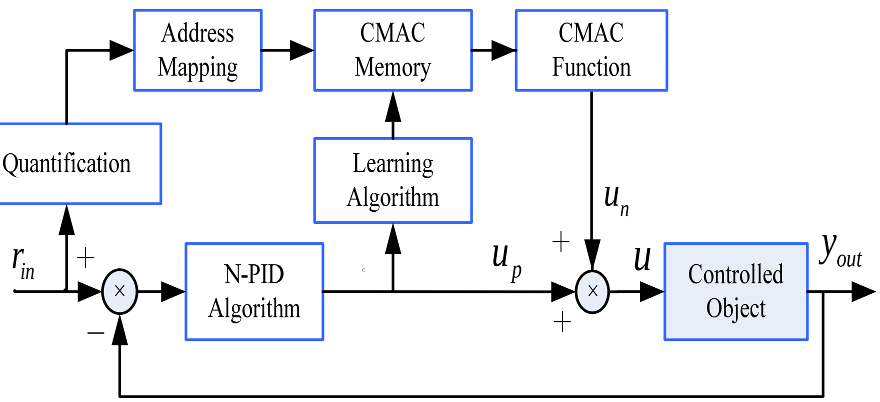


Figure 4. Controlled paragraph of non-PID with CMAC foreword feed controller

4.SIMULATION AND RESULTS

AZ axis rotary moment of inertia of the dual redundant telescope tracking bed is: $1451\,\mathrm{kg\cdot m^2}$, damping coefficient B is 0.025, the direct drive precision bed of confounding factors has not been more precise estimated and the simulation process does not take into account the actual non-linear disturbances, but only with random noise to simulate. The function of the direct drive precision bed can be expressed：

$$G_{plant}(s)=\frac{1}{1451s+0.025} \tag{9}$$

While the current circle is simplified by one Proportion regulator $k_i=20$； Speed filter is determined as:

$$G_{Filter}(s) = \frac{1}{0.026s + 1} \tag{10}$$

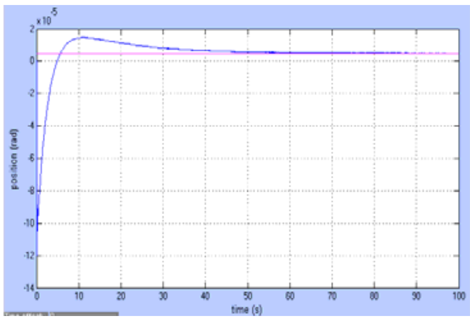
While the system is only controlled by nonlinear PID where a position p control method is adopted：

$$a_p = 2.25, b_p = 10.75, c_p = 0.8 \tag{11}$$

the k_p can be expressed as:

$$k_p(e(t)) = 2.25 + 10.75(1 - \sec h(0.8 * e(t))) \tag{12}$$

The simulation results of the dual redundant telescope tracking bed are shown in Figure 5 .



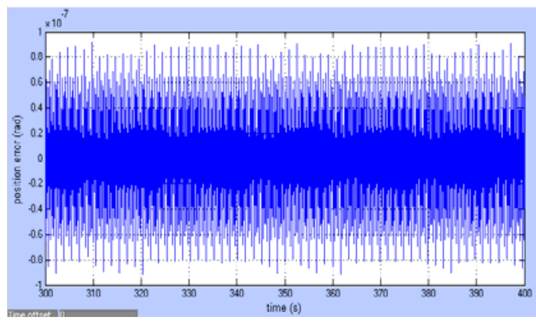
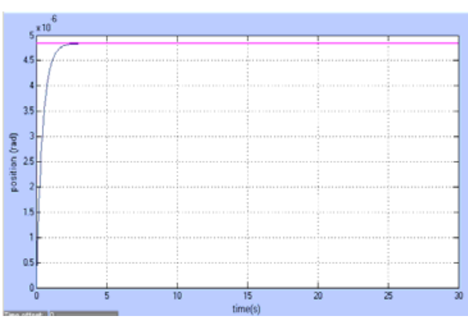


Figure 5. step response and the position error response with traditional PID

While the system is controlled by parallel control algorithm based on the nonlinear PID and CMAC where a position p control of nonlinear PID method is adopted： $a_p = 2.25, b_p = 10.75, c_p = 0.8$, $k_p(e(t)) = 2.25 + 10.75(1 - \sec h(0.8 * e(t)))$

The simulation results are shown in the following, for the nonlinear PID controller combined with forward-feed CMAC controller the results are shown in figure 6.



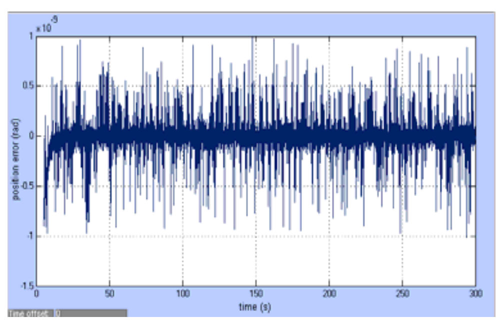


Figure. 6 step response and position error response nonlinear PID controller combined with forward-feed CMAC

5. CONCLUSION

Simulation results show that the simple PID control method will lead to large overshoot and the adjustment time is too long, which is especially apparent in the telescope direct drive tracking system with such a huge inertia. The nonlinear PID regulator can be achieved a better response without overshoot, but not do too much help for the system accuracy, the parallel control algorithm combined with the CMAC and nonlinear PID not only speeds up system response of the tracking system without overshoot but also greatly improved the accuracy, which also prove such an algorithm is effective and could be used in the real telescope drive.

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