Research on Radar Servo Control System Based on Neuron Adaptive PID Control

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Abstract. Due to the fixed control parameters, traditional proportional integral differential (PID) control tend to have problems such as large overshoot, poor stability and low control accuracy, which is difficult to meet the high control quality requirement of modern radar servo system. In this paper, based on the neural network adaptive control theory, a radar servo control system is designed and its effect is improved through the self-learning of neurons, the adjustment of the weighting coefficient and the optimization of the PID controller parameters. The simulation results show that the radar servo control system using neuron adaptive PID control performs faster response speed and higher control accuracy, which is obviously better than the system with traditional PID control.

1. Introduction
The radar servo control system is widely used to control the radar antenna and other loads to achieve angle preset, target search, target tracking and other functions. Recently, in the field of new weapon equipment technology, radar servo control technology with high response and precision has become a hotspot. With the development of radar technology, servo system becomes more complex and variable, which is difficult to describe accurately by mathematical model. Traditional PID controller is suitable for accurate control system dynamic mode. However, with the continuous rise of artificial intelligence, neural network has been widely used in the fields of automatic control, pattern recognition, intelligent robot, prediction and estimation due to its strong capability of partial linear simulation and adaptability, and has achieved good results. Therefore, the application of neural network in radar servo control system is of great significance in engineering practice.

Neural network control methods have been widely studied in servo systems in the recent years. Cao [1] designed a composite neural network adaptive controller, which was used to simulate the servo control system and achieve a good control effect. Gong [2] proposed a supervisory control algorithm, in which the feedback controller continuously trained the neural network controller with its feedback error at the initial stage, and was finally replaced by the latter controller. Huang [3] designed a neural network controller based on sliding variable structure, which improved the stability of the system and made the servo system well applied in the missile field. Lu [4] designed an adaptive neural network controller to realize accurate control of hydraulic servo system with time-varying state constraints, the simulation results indicated its good control quality. He [5] proposed a parallel self-learning tracking controller of neural network, which achieved good control quality in the large-scale electro-hydraulic
servo testing machine and met the requirements of real-time performance of the system. In this paper, a neuron adaptive PID controller is designed for radar servo system position-tracking loop, which accelerates the response speed and improves the control accuracy of the system as well as verifies the advantages of the neuron adaptive PID control algorithm.

2. Neuron adaptive PID control
In neural network theory, the neuron model simulates three basic functions of biological neurons. Firstly, all input signals are weighted to different degrees according to different weights. Then these input signals are summed to obtain the combined effect. Finally, the neuron state function and output function are used to convert the information. By combining with the traditional PID control, we can get the neuron adaptive PID controller, which has strong self-learning and adaptive ability as well as the characteristics of simple structure, high reliability and easy parameter setting [6]. The control structure diagram is shown in Fig. 1.

![Neuron adaptive PID controller diagram](image)

Based on the control structure diagram, the mathematical expression of the control signal can be obtained:

$$u(k) = u(k-1) + K \sum_{i=3}^{3} w_i(k)x_i(k)$$  \hspace{1cm} (1)

$$\begin{align*}
x_1(k) &= r(k) - y(k) = e(k) \\
x_2(k) &= e(k) - e(k-1) = \Delta e(k) \\
x_3(k) &= e(k) - 2e(k-1) + e(k-2) = \Delta^2 e(k)
\end{align*}$$  \hspace{1cm} (2)

where $K$ is the gain coefficient, $K>0$; $x_i(k)$ is the state of neuron input; $w_i(k)$ is the weight coefficient corresponding to $x_i(k)$; $r(k)$ is the set value; $y(k)$ is the output value. From Eq. (1) and (2), we can get:

$$\Delta u(k) = K[w_1(k)e(k) + w_2(k)\Delta e(k) + w_3(k)\Delta^2 e(k)]$$  \hspace{1cm} (3)

Eq. (3) is similar to the traditional PID control algorithm, however, the parameters of the traditional PID are fixed after design, while Eq. (3) introduces the deviation signal $e(k)$, which is a performance indicator that can select different neural network learning rules according to the needs of different occasions, so as to constantly adjust $w_i(k)$ to achieve self-learning and adaptive effect and improve the robustness of the control system. In this paper, a supervised Hebb learning rule is adopted to adjust $w_i(k)$, the expression is[7]:

$$w_i(k+1) = (1-c)w_i(k) + \eta v_i(k)$$  \hspace{1cm} (4)

$$v_i(k) = e(k)u(k)x_i(k)$$  \hspace{1cm} (5)

where $v_i(k)$ is the attenuating progressive signal; $\eta$ is the learning rate, $\eta > 0$; $c$ is the constant, $1<c<0$. 

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Combined Eq. (5) with Eq. (4), we can get:
\[
\Delta w_i(k) = w_i(k + 1) - w_i(k) = -c[w_i(k) - \frac{n}{c}e(k)u(k)x_i(k)]
\]  

(6)

If there is a function \( f_i(w_i(k), e(k), u(k), x_i(k)) \), then the partial derivative with respect to \( w_i(k) \) is:
\[
\frac{\partial f_i}{\partial w_i} = w_i(k) - \frac{n}{c}g_i(e(k), u(k), x_i(k))
\]  

(7)

then Eq. (7) can be written as:
\[
\Delta w_i(k) = -c \frac{\partial f_i(\bullet)}{\partial w_i(k)}
\]  

(8)

According to Eq. (8) and the stochastic approximation theory, the function \( f_i(\bullet) \) can be searched along the negative gradient of \( w_i(k) \). If \( c \) is small enough, \( w_i(k) \) will approach the stable quantity and the deviation from the expectation is relatively small, which meets the requirement. Through normalizing the above learning algorithm, the control quantity expression can be expressed as:
\[
u(k) = u(k - 1) + K \sum_{i=1}^{3} w_i^*(k) x_i(k)
\]  

(9)

\[
w_i^*(k) = \frac{w_i(k)}{\sum_{i=1}^{3}[w_i(k)]}
\]  

(10)

\[
\begin{cases}
w_i(k) = w_i(k - 1) + \eta_p e(k)u(k)x_i(k) \\
w_2(k) = w_2(k - 1) + \eta_i e(k)u(k)x_2(k) \\
w_3(k) = w_3(k - 1) + \eta_d e(k)u(k)x_3(k)
\end{cases}
\]  

(11)

where \( K \) represents proportionality coefficient and \( \eta_p, \eta_i, \eta_d \) represent proportion, integral and differential learning rate, respectively.

3. Simulation of radar servo control system

This paper takes an azimuth radar servo system as an example. It requires turntable control system to complete multiple tasks such as angle preset, target tracking and scanning, which need the accurate control of the angle. Ignoring the inductance of the motor armature, and considering that the current loop and the velocity loop are open loops, the dynamics equation of the servo system can be written as [8]:
\[
\ddot{\theta} = -\frac{K_m C_v}{J R} \dot{\theta} + K_m \frac{K_m}{J R} u(t) - \frac{T_f}{J}
\]  

(12)

where \( K_m \) is the PWM power amplification coefficient; \( R \) is the armature resistance; \( K_m \) is the motor moment coefficient; \( C_v \) is the voltage feedback parameter; \( J \) is its moment of inertia; \( T_f \) is the disturbance torques. Combined with neuron adaptive PID controller, the structure description is shown in Fig 2.
Figure 2. Structure diagram of neural adaptive PID radar servo control system
Considering the external disturbance $T_f/J=0.3$ at 0.2s, then, the unit step response curves of traditional PID control and neuron adaptive PID control are obtained and are shown in Fig. 3. The weight coefficient curves of neuron adaptive PID are shown in Fig. 4.

Figure 3. Step response curves

Figure 4. Weight coefficient curves

a) $w_1$ coefficient curve
b) $w_2$ coefficient curve
It can be seen from Fig.3, the unit step response rise time of neuron adaptive PID and traditional PID is less than 0.15s, while the former has better rapidity and improves the dynamic characteristics of the system effectively. When there is external disturbance, the neuron adaptive PID can eliminate the disturbance faster and ensure the stable accuracy of radar servo system. As shown in Fig. 4, neuron adaptive PID updates the weight coefficient \( w(k) \) in real time according to the error information at different moments, so that the equivalent PID parameters change, thus the neuron adaptive PID can ensure the tracking accuracy of the system.

4. Conclusion
In this paper, a neuron adaptive PID controller is designed for the position-tracking loop of radar servo system. The structure of the neuron adaptive control algorithm is established, and the supervised Hebb learning method is utilized to adjust the weight and optimize the parameters of the PID controller. Then the neuron adaptive radar servo control system is established and its position-tracking loop is simulated. The simulation results show that the radar servo system using neuron adaptive control is obviously better than the system with traditional PID control, which can improve the response speed and control accuracy of the system.

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