Research on PID Control Algorithm of BP Network based on Two Axis

Digital Control Turntable

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Abstract

Under the research context of two axis digital control turntable, this paper has set up a mathematical model of control system of turntables. Proceeding from such model, it has made an analysis on the deficiencies of classical PID control during turntable control. Against the feature of PID parameters difficult to be tuned, the neural network is thus introduced in the optimizing process of turncontrol PID parameters, during which PID controller is designed based on BP network. In addition, the PID algorithm control based on BP network is simulated with results indicating PID controller designed so featuring high tracking accuracy, stable performance and strong robustness, which provides a solution to the problem of inadequate precision required by classic PID control as regards to the control precision.

Key Words

BP network; neural network; PID control; Axis Digital Control Turntable

1. Introduction

In recent years, intelligent control of electric drive systems has become a hot spot with its objective to improve the robustness of control system. Among numerous control strategies, the conventional PID control is one of the earliest control strategies. As for setting up control system of mathematic models, it has such advantages as simple algorithm, high accuracy and great reliability. On the other hand, the generality of control algorithm also reflects the limitation of PID controller with respect to control quality. Its limitations may be analyzed specifically as following: a. the simplicity of algorithm structure defines that PID control is relatively suitable for minimum phase system, requiring combination of multiple PID controller or with other controllers to handle uncontrollable objects with long time lag and unstable open loop as to achieve better control effects; b. the simplicity of algorithm structure also defines that PID control can determine only a few of main zero-poles in the closed loop system: fundamentally, the closed loop property is approximately assumed only based on low order with dynamic properties; c. due to the same reason, it is determined that the single PID controller can not meet the different performance requirements from assumed setting value control and servo/tracking control. In this connection, in the control system, by virtue of self-learning ability of neural network, it is able to fully approximate any complicated nonlinear relationship properties and design a new algorithm, combining the advantages of PID control with the properties of neural network as to gain balance, which not only has flexible control and strong adaptability, but also has the high accuracy owned by PID control, enabling to obviously improve the static and dynamic performances of the system with better control effects.

2. Control system and working principles of digital control turntables

The digital control turntable is a typical electrical servo system, which can control certain state of controlled object to make it recur with the change rule.
of input signals in an automatic, continuous and accurate way, generally appeared as closed loop control system. During the information transfer in the system, it has to pass some parts like detection device, amplifying device, executive component, signaling conversion circuit and compensation unit, making each part effectively coordinated with each other by certain control rules as to have the system entailed with excellent operation qualities as well as to realize the detection on input and output signals of the system. Besides, above each part can not function without corresponding energy equipment, protection devices, control equipment and other auxiliary equipment.

2.1. Overall structure of digital control turntable control system

![Fig.1 Structural representation of control system](image)

The system indicated in Fig.1 has its working principles outlined below:
- Test task dispatching and working state setting is finished on the control computer.
- The control computer respectively carries out parameter handling under working state via control card. After that, the system will be ready for start.
- Synchronous start and run signals are sent out by control computer via control card.
- The calculation of closed loop control signals is made on the turntable control computer and turntable control signals will output to signal conditioner via D/A port.
- After isolation amplified in the signal conditioner, the control signals are output to torque motor controller and the torque motor is driven to finish the command movement.
- The angle and angular rate signal output by the turntable will give out feedback signals after rotary transformer measuring and go for processing by signal conditioner via conducting ring, changed into 16-digit quantity read by micro-computer, thus forming closed loop control of turntable therein. Doing output to signal conditioner for processing via conducting ring, the product output signal will output to data acquisition computer.

2.2. Working principles of digital control turntable control system

The turntable control system has two control circuits, namely in horizontal direction and pitching direction. The making of two circuits is basically same. The control circuit is mainly composed of turntable control computer, D/A, A/D, control card multi-function plug-in, signal amplifying circuit, signal conditioner, motor controller, torque motor, rotary transformer and tacho generator with details as following:

1. Control computer: a digital controller of turntable control system to realize position closed loop control. It may carry out real-time calculation, processing, logical decision and storage according to system control laws, obtain commands and parameters required by normal system operation, then output to other equipment. As indicated in Fig.2, it is for the general schematic of digital servo control system in running. \( \theta_i \) before switch I is for input angle of digital servo system from upper-class computer.

The control computer terminal is for its D/A port outputting continuous analog signals through PWM amplifier control motor. Once a sampling cycle starts, the control computer will sample a given angle value \( \theta_{in} \) from upper-class through one input interface, which corresponds to closing the sampling
switch I. Then the control computer will sample $\theta_a$ from shaft encoder through another input interface, which corresponds to closing sampling switch II (the sequence of switch I and II may be changed if required). With $\theta_a(n)$ and $\theta_a(n-1)$ taken in this sampling cycle, $\theta_a(n-1)$ and $\theta_a(n-2)$ taken in last cycle as well as $\theta_a(n-2)$ and $\theta_a(n-3)$ taken in last last cycle, etc., the control computer combines these data as original ones of control variable in the calculation of sampling cycles to execute the solidified control algorithm. Finally, the control variable obtained at this moment is output via D/A, which corresponds to closing switch III. From the perspective of control computer, D/A conversion interface is an output one; while from the perspective of signal conversion, it includes a zero-order holder and a D/A converter. Its continuous analog signals are output to the input terminal of PWM amplifier ready for next sampling cycle.

Fig.2 Digital servo system principle schematic

(2) Signal interface: finishing data transmission and information communication between control computer and turntable controller, comprising A/D conversion module, D/A conversion module and digital quantity module.

(3) Turntable servo controller: the analog controller of turntable control system realizes analog control of position and speed closed loop, realizes monitoring and protection of turntable in service, conditions the feedback signals, sends into power amplifier for amplification after correcting and filtering the control signals.

(4) Power amplifier: the turntable torque motor DC control and amplifying circuit, achieving power amplification of control signals, adequate power output to drive and execute the motor, satisfying voltage and current ratings required by it.

(5) Measuring elements: angular motion sensitive elements in flight control system are generally called sensor, used to detect the position and speed signals of turntables and converted into corresponding impulse signal and voltage signal.

3. Electromechanical control model of digital control turntable system

The drive of digital control turntable is servo system, controlling the rotation speed of motor by changing the armature voltage and realizing rotation through speed gear. A balance equation is set up for servo motor torque: suppose that the gear speedup ratio as $n$, stiffness of threaded spindle as $KL$, moment of inertia as $JL$, damping coefficient $BL$, load torque as $Md(t)$ and the angle of rotation of output threaded spindle as $\theta_L(t)$.

Voltage balance equation of servo motor:

$$u_a(t) = R \cdot i_a(t) + K_i \cdot \frac{d \theta_a(t)}{dt}$$  (1)

Torque balance equation of servo motor:

$$K_i \cdot i_a(t) = J_a \cdot \frac{d^2 \theta_a(t)}{dt^2} + K_1 \cdot \left[ \frac{\theta_a(t)}{n} - \theta_L(t) \right]$$  (2)

Torque balance equation of driven assembly:

$$K_i \left[ \frac{\theta_a(t)}{n} - \theta_L(t) \right] = J_a \cdot \frac{d^2 \theta_L(t)}{dt^2} + B_L \cdot \frac{d \theta_L(t)}{dt} + M_d(t)$$  (3)

After Laplace transformation of last formula, it can obtain

$$K_i \cdot s \cdot \theta_a(s) = J_a \cdot s^2 \cdot \theta_a(s) + \frac{K_i}{n} \left[ \frac{\theta_a(s)}{n} - \theta_L(s) \right]$$  (4)

Generally, the sliding frictional resistance is ignored in low-speed system and the mechanical damping is usually small, therefore, the motor transfer function (4) is simplified as to get the function as following:
\[ G(s) = \frac{\theta z(s)}{u(s)} = \frac{K_n}{T_e s - T_n s^2 + T_m s + 1} \]  

(5)

Where, \( k_n = \frac{1}{k_b} \) is for motor transfer function,

\[ T_n = \frac{J_m R_a}{k_n c_m} \]

for motor electromechanical time constant and

\[ T_e = \frac{J_m R_a}{R_a} \]

for electrical time constant.

For horizontal axis, there is:

\[ \frac{\theta z(s)}{u(s)} = \frac{K_n}{T_e s - T_n s^2 + T_m s + 1} \]  

(6)

For pitch axis, there is:

\[ \frac{\theta z(s)}{u(s)} = \frac{K_n}{s(T_n s^2 + T_m s + 1)} \]  

(7)

(6) and (7) are electromechanical control models of two axis digital control turntable system, with the transfer function (7) of pitch axis generally regarded as the electromechanical control model of turntable system.

4. **PID controller model design based on BP network**

In order to get a better control effect, PID control should have the control actions of scale, integral and differential calculus well adjusted, forming a relationship mutually coordinated and interacted. Such relationship is not always a simple “linear combination”, with the best one to be found in the non-linear combination with endless changes. The random nonlinear expression ability of neural network enables PID control a best combination by virtue of learning system performance. A self-learning PID controller with parameters as kp, ki, kd may be established using BP network.

As indicated in the figure for PID control system mechanism based on BP network, the controller is composed of two parts as below:

1. Classical PID controller is directly closed-loop controlled by controlled object and three parameters as kp, ki, kd are online adjustment means.

2. The neural network is to adjust the parameters of PID controller according to the system running condition as to achieve optimization of certain performance index, making the output state of output layer neuron correspond to the three adjustable parameters as kp, ki, kd. Through self-learning of neural network and adjustment of weighting coefficient, the neural network outputs are caused to correspond to PID controller parameters under certain optimal control law.

Fig.3 Network structure

The control algorithm of classical incremental digital PID is as:

\[ u(k) = u(k-1) + \Delta u(k) \]

\[ \Delta u(k) = k_p(error(k) - error(k - 1)) + k_i error(k) + k_d(error(k) - 2error(k - 1) + error(k - 2)) \]  

(8)

Where, kp, ki, kd respectively stands for scale, integral and differential coefficient.

The adoption of three-layer BP network has its structure indicated in Fig.3.

The input of network input layer is as:

\[ o_j^{(1)} = x(j) \quad (j=1,2,\ldots,M) \]  

(9)

Where, the number M of input variance is governed by the complexity degree of controlled system.

The network hidden layer has its input and output as:

\[ a_i^{(2)}(k) = f(net_i^{(2)}(k)) \quad (i=1,2,\ldots,Q) \]  

(10)

Where, \( w_{ij}^{(2)} \) is for hidden layer weighting coefficient with superscripts (1), (2), (3) respectively standing for input layer, hidden layer and output layer. The activation function of hidden layer neuron is determined subject to the Sigmoid function with positive and negative symmetry:

\[ f(x) = \tanh (x) = \frac{e^x - e^{-x}}{e^x + e^{-x}} \]  

(11)

The input and output of network output layer is as:
The output nodes of output layer respectively correspond to three adjustable parameters as $k_p$, $k_d$, $k_j$, negative undesired, therefore, the activation function of output layer neuron is dependent upon non-negative Sigmoid function as:

$$g(x) = \frac{1}{2} (1 + \tanh(x)) = \frac{e^x}{e^x + e^{-x}}$$

Performance index function is adopted as:

$$E(k) = \frac{1}{2} (\text{rin}(k) - \text{yout}(k))^2$$

The network weighting coefficient corrected using gradient descent is searched and adjusted as per the negative gradient direction of $E(k)$ against the weighting coefficient and an add-on minimal inertia item to make the search quickly converge the situation as a whole:

$$\Delta w_{_{oi}^{(3)}}(k) = -\eta \frac{\partial E(k)}{\partial w_{_{oi}^{(3)}}(k)} + \alpha w_{_{oi}^{(3)}}(k-1)$$

Where, $\alpha$ is for inertia coefficient and $\eta$ for learning rate.

$$\frac{\partial E(k)}{\partial w_{_{oi}^{(3)}}(k)} = \frac{\partial E(k)}{\partial \text{rin}(k)} \frac{\partial \text{rin}(k)}{\partial \text{y}(k)} \frac{\partial \text{y}(k)}{\partial \Delta u(k)} \frac{\partial \Delta u(k)}{\partial o_{_{oi}^{(3)}}(k)}$$

$$= \frac{\partial \text{rin}(k)}{\partial \text{y}(k)} \frac{\partial \text{y}(k)}{\partial \Delta u(k)} \frac{\partial \Delta u(k)}{\partial o_{_{oi}^{(3)}}(k)}$$

$$= \frac{\partial o_{_{oi}^{(3)}}(k)}{\partial \text{net}_{_{oi}^{(3)}}(k)} \frac{\partial \text{net}_{_{oi}^{(3)}}(k)}{\partial w_{_{oi}^{(3)}}(k)}$$

Due to unknown $\frac{\partial \text{y}(k)}{\partial \Delta u(k)}$, the symbolic function $\text{sgn} (\frac{\partial \text{y}(k)}{\partial \Delta u(k)})$ is approximately employed instead and the influence of inaccurate calculation caused thereby may be compensated by adjusting learning rate.

From formula (9), we can obtain:

$$\frac{\partial \Delta u(k)}{\partial o_{_{oi}^{(3)}}(k)} = \alpha(k)$$

$$\frac{\partial \Delta u(k)}{\partial o_{_{oi}^{(3)}}(k)} = \text{error}(k) - \text{error}(k-1)$$

$$\frac{\partial \Delta u(k)}{\partial o_{_{oi}^{(3)}}(k)} = \text{error}(k)$$

$$\frac{\partial \Delta u(k)}{\partial o_{_{oi}^{(3)}}(k)} = \text{error}(k) - 2 \text{error}(k-1) + \text{error}(k-2)$$

From above analysis, we can obtain the learning algorithm of network output layer weighting coefficient as:

$$\Delta w_{_{oi}^{(3)}}(k) = \alpha \Delta w_{_{oi}^{(3)}}(k-1) + \eta \delta_{_{oi}^{(3)}}(k)$$

$$\delta_{_{oi}^{(3)}}(k) = \text{error}(k) \text{sgn} (\frac{\partial \text{y}(k)}{\partial \Delta u(k)}) \frac{\partial \Delta u(k)}{\partial o_{_{oi}^{(3)}}(k)} g(\text{net}_{_{oi}^{(3)}}(k))$$

$$(l=1,2,3)$$

In a similar way, we can obtain the learning algorithm of hidden layer weighting coefficient as:

$$\Delta w_{_{ij}^{(2)}}(k) = \alpha \Delta w_{_{ij}^{(2)}}(k-1) + \eta \delta_{_{ij}^{(2)}}(k)$$

$$\delta_{_{ij}^{(2)}}(k) = f(\text{net}_{_{ij}^{(2)}}(k)) \sum_{l=1}^{Q} \delta_{_{ij}^{(3)}}(k) w_{_{ij}^{(3)}}(k)$$

$$(l=1,2,\ldots,Q)$$

The structure of PD controller based on BP network is shown as in Fig.4 with the control algorithm induced below:

Fig.4 PID controller design based on BP network

The structure of BP network is determined by input layer node count M and hidden layer node count Q, given initial values of each layer weighting coefficient as $w_{_{ij}^{(1)}}(0)$ and $w_{_{ij}^{(2)}}(0)$ and selected learning rate $\eta$ and inertia coefficient $\alpha$, here $k=1$;

1. From sampling, it is obtained with rin(k) and yout(k) to calculate the error at this moment as error(k)=rin(k)-yout(k);

2. Calculate the inputs and outputs of each layer neuron of neural network NN, the outputs of NN
output layer are just the three adjustable parameters kp, kd, kj of PID controller;

(3) Calculate the output u(k) of PID controller;

(4) Carry out neural network learning and online adjust the weight coefficients as $w_{ij}^{(1)}(k)$ and $w_{ij}^{(2)}(k)$ to realize adaptive adjustment of PID control parameters;

(5) Place $k=k+1$ and return to step (1).

5. Simulation and analysis of PID controller based on BP network

According to the specific structural parameters of turntable, the electromechanical control model of turntable system is as:

$$G(s) = \frac{0.02419}{8.901 \times 10^{-6} s^3 + 0.004437 s^2 + 0.00718 s}$$

(18)

It is simulated with: learning rate $\eta = 0.28$ and inertia coefficient $\alpha = 0.04$, weighting coefficient adopted with the random number among the interval $[-0.5, 0.5]$. Input command signals fall into two types:

(1) Step response: $rin(k)=1.0$;

(2) $rin(k)=\sin(2 \pi t)$. It is step tracking when $s=1$ and sine tracking when $s=2$. The initial weight is adopted with random value. The stable running value replaces the random value.

The following has made illustrations on the two input command signal tracking results and relevant curves as to present the performance of algorithm based on analysis of tracking curve.

When step response: $rin(k)=1.0$, the step response curve of turntable is indicated as in Fig.5 below:

Fig.5 Step response curve

From the step response results we can observe that the transitional response time of the system is relatively long but without overshoot, realizing error-free tracking as well.

The tracking error curve of turntable step response is indicated as in Fig.6 below:

Fig.6 Response error in the process of step response

It can be observed that at initial moments, the response errors are big, but with the termination of transitional process, the tracking error of system step signals reduces to zero.

6. Conclusion:

verified by experiment, PID control algorithm based on BP network is feasible and has stable tracking, reliable tracking accuracy reached and the system all along maintains strong robustness throughout the experiment.

References


