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Design of One Dimensional Adjustment Platform Servo Control System Based on Neural Network

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Abstract

This paper designed a one dimensional adjustment of high precision servo control system, in order to provide individual comprehensive combat system high precision gun visual Angle. In servo control system hardware design based on DSP digital signal processing (DSP) chip as the CPU control circuit, in regard to algorithm, using the three layers BP neural network algorithm for PID integral gain and differential gain and intelligently adjusting proportion gain. On this basis, also analyzes the advantages and disadvantages of the traditional BP neural network algorithm, carries on the improvement. Vector using adaptive control, numerical optimization and introducing the steepness factor method, solve the contradiction between the stability and learning time, greatly improving the convergence speed and stability of the system performance, the static stability of the turntable accuracy is less than 3″, indicators reached the design requirements.

Key words: Neural network PID; Ac servo motor; Adjust machine

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INTRODUCTION

As an instrument to provide accurate angle and position for the bearing body, the adjustment table is widely used in the measurement system and the precision inertial guidance system. As the servo control system has a direct impact on the accuracy of the adjustment platform, but there are many nonlinear factors in the system, which restricts the control precision of the servo system. Firstly, the most important factor is the change of load, because of the structure and assembly of the platform, the center of gravity is not geometric center, and it is random, because of the gravity; secondly, the platform at work but also by the effect of drag torque, due to wind age size and direction depending on the local wind speed and wind direction, which belongs to the unpredictable factors, in addition, to adjust the servo control system is also affected by the friction torque disturbance, shaft coupling, sensor noise, electromagnetic interference and other a series of thorny.

To design a one dimensional adjustment system which meets the requirements of the technical indicators, the general method is to use the PID algorithm for servo control. Using PID algorithm to control AC servo motor, the most difficult problem is how to set the proportion of PID parameters, integral parameters and differential parameters. In the whole control process, the parameters of PID algorithm are kept constant. In the practical application, the whole system is unable to predict in advance, and the state of the controlled object changes with the time, and the fixed PID parameters cannot make the system achieve the best control effect. Also in the Integrated Individual Soldier Combat fire test system test, depending on the carrier and the carrier in different states, the transfer function of the system are not the same. Therefore, it is necessary according to the system of the different state adjusting system parameters. The research content of this thesis includes the hardware circuit design of the control system, the control scheme design and the control algorithm.

At present, most of the servo control system on the market is the traditional PID control algorithm, although it can achieve a more considerable control accuracy, but unfortunately there are many defects in the anti - jamming and adaptive learning. Based on the traditional PID control algorithm, the control algorithm cannot meet the needs of scientific research. In order to get a can of complex external environment quickly adapt to, intelligent learning and strong anti disturbance ability to adjust, this paper presents the neural network with error back propagation algorithm is used to adjust the control algorithm can effectively improve the control system fault tolerant ability and strengthen the self adapt to external disturbance performance.

1. ONE DIMENSIONAL ADJUSTMENT PLATFORM SERVO SYSTEM DESIGN

One dimensional adjustment is mainly used for carrying the measured integrated individual soldier combat system, integrated individual soldier combat system provides a target pitch angle gun target angle information. Because it has good self stable performance and accurate angle control, the process of Integrated Individual Soldier Combat System divided into each module of the system, testing the performance parameters of the is used in weapons and Integrated Individual Soldier Combat System integration test and system. In order to achieve its precision angle control and performance index requirements, in the adjustment of the machine design and servo control circuit design aspects have been deliberately considered, the following is an one-dimensional adjustment of the servo control system design and hardware circuit design.

1.1 Servo Motor Control Scheme Design

The control circuit of the servo system is the digital signal processor as the core, which can complete the data processing of the sensor signals in the digital control of permanent magnet synchronous motor, and realizes the PID parameter auto tuning of the motor vector control algorithm based on neural network. Its structure is shown in Figure 1

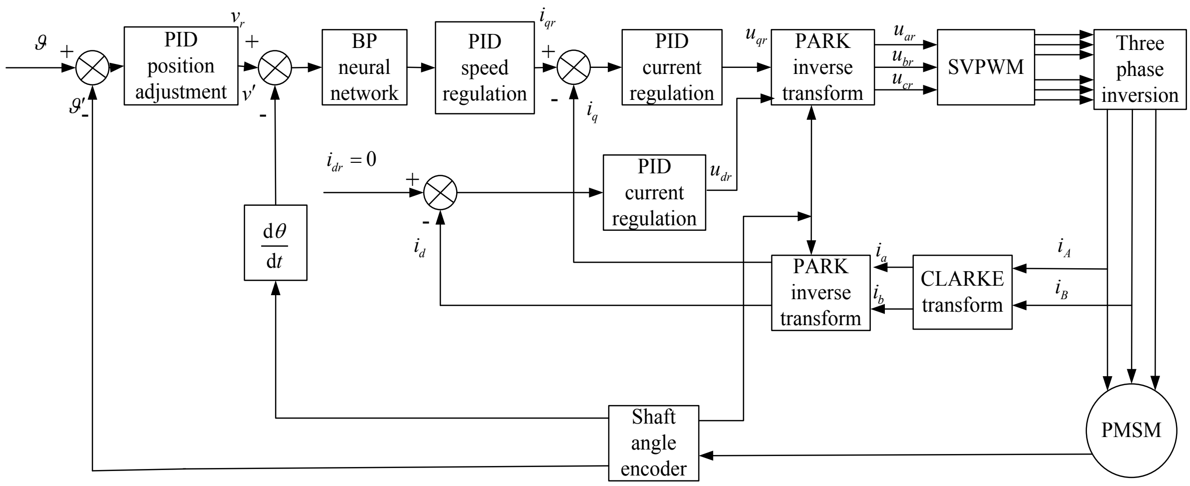

Figure 1
Schematic Diagram of PID Vector Control Based on Neural Network

The whole control scheme is composed of three parts, the top layer control module is BP neural network control module, in which the PID proportional integral differential control module, the most basic is the SVPWM voltage space vector PWM control module. The servo feedback loop can be divided into three parts, respectively, the position feedback loop, the speed feedback loop and the current feedback loop (Lin, Shyu, & Lin, 1999).

The role of position loop is to make the rotation angle of the turntable to reach the preset angle accurately. According to the angle of axis angle encoder feedback as a reference standard, the speed loop is to keep the speed of the rotary table. The fundamental purpose of vector control is to simplify the control method of AC motor. It uses the method of coordinate transformation and directional control to control the AC motor's control to the control of DC motor. Using id=0 vector control as the control strategy, through the use of id=0 control mode, the rotor current and the permanent magnetic flux decoupling, so the torque and the AC current IQ into a proportional relationship, the current loop can be controlled by IQ direct control of torque. Voltage space vector pulse width modulation control module output PWM control AC motor drive circuit power switch device, and realize the AC servo motor vector control. In order to realize the vector control and need to detect the three-phase current coordinate transformation, which Clark transform is from three-phase coordinate system ABC into two-phase stationary coordinate d-q coordinate system conversion, and park transformation is refers to the two stationary coordinate system is converted into a rotation of the coordinate transformation, which in front of the already mentioned (Saudon, 1992).

The electromagnetic torque of the permanent magnet synchronous motor is almost entirely determined by two aspects. One is the stator current component and the other is the rotor flux linkage. In permanent magnet synchronous motor, the rotor flux is constant, so the motor can be controlled by controlling the stator current component. The vector control strategy for the control of id=0 control, this control strategy called voltage space vector pulse width modulation, at the same time, also known as SVPWM (space vector pulse width modulation) control, the control method is by changing the power converter device is insulated gate bipolar transistor IGBT (Insulated Gate Bipolar Transistor). The turn-on and turn off voltage vector, get different, through the combination between different voltage vector, to obtain approximate circular magnetic field, IGBT is a voltage driven type power semiconductor device, it consists of two parts, one is the BJT (bipolar transistor), the other is the MOS (insulated gate type FET), it is also the same composite full control type semiconductor device, not only has the characteristics of high input impedance MOSFET, but also has the advantages of low conduction voltage drop GTR.

Vector control is a control part of the most close to the motor. The input of the SVPWM module is the current component of the d axis and the current component of the PWM axis in the p axis and the rotor position. The output of the PWM wave of AC servo motor drive circuit directly control, so as to control the operation of motor. The input of i_d and i_p SVPWM module is composed of a three-phase current through coordinate conversion by, And three-phase current is PID (proportional integral differential) module are given, namely PID module output loading to motor three phase current, Through coordinate transformation get quadrature axis in the d-axis current component i_d and axes in the P axis component of current i_p, namely PID module output quantity for the input of the PWM. While the PID input is K_i (integral coefficient), K_p (ratio) and K_d (Differential coefficient). While the three input parameters of PID are dynamic and depend on the algorithm of neural network.

1.2 Servo Motor Control Circuit Design

The permanent magnet synchronous servo motor control system of a rotary table is composed of servo motor, power management module, signal processing control module, motor driver module, human-computer interaction module, communication module and signal processing module.

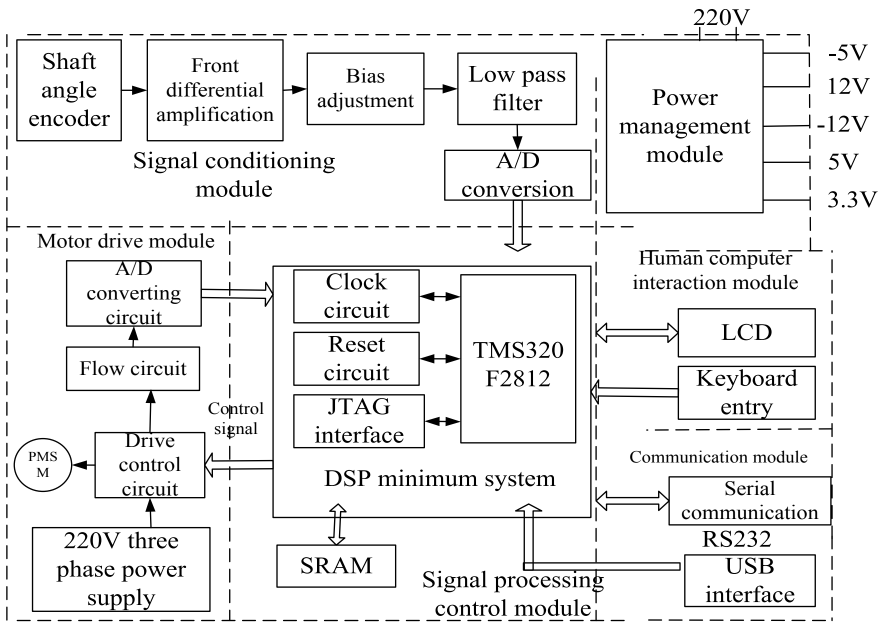

Figure 2
Hardware Block Diagram of Servo Motor Control System

The signal processing control module is composed of TMS320F2812 and clock circuit, reset circuit, JTAG port and so on. It is the core of the whole system's control and signal processing. DSP integrates a wealth of on-chip peripherals, in this system, it mainly uses EV, GPIO, SPI, SCI, PIE, RAM, Flash, etc. In addition, the system has expanded the SRAM 64K as data storage.

The man-machine interaction module is composed of two parts, the LCD module and the independent key module, which are composed of TFT touch LCD screen and capacitive buttons, Touch screen models for T32 flurries company production of 3.2 inch TFT LCD touch screen, can display control data and commands, and the touch screen capacitance touch button can be effective the setting parameters of user input to the system, as well as the PC to input commands to control turntable operation.

Communication module is mainly responsible for the communication between PC host computer and micro controller. The digital signal is TTL level, that is, the high level is 3.8V to 5V, and the low level is 0V to 0.8V. While the host computer sends the received data of the digital signal is the reverse RS232 level, that is, the high level of -12V to -15V for 12V to 15V. In order to unify the rules of digital signal level, using the MAX232 chip to carry the level conversion circuit, so that the level of the two sides to send the received level to achieve unity, as the role of the translator. In addition to the serial communication mode, there is a common USB interface communication (Sepe & Lang, 1991).

Power management module is mainly to the AC 220V voltage conversion to DC voltage, which includes the DC 3.3V voltage provided by the DSP microprocessor, to the TFT touch screen provided by the DC 5V voltage, to provide the serial circuit with DC 12V voltage. Signal conditioning acquisition module is mainly for the acquisition of data from the shaft angle encoder, the signal input to the DSP microprocessor as the signal input, in order to filter out the signal of the shaft angle encoder signal and get more accurate angle feedback signal, especially the use of sub circuit and pre filtering circuit.

Motor drive module uses the IGBT (insulated gate bipolar transistor) power control device, by changing the power conversion circuit power device insulated gate bipolar transistor (IGBT) on and off to control the motor operation. In order to protect the motor overload operation and accurate control of the motor torque, the use of current detection circuit to detect the current detection circuit of the motor three-phase current for real-time detection, which also includes the motor current measurement, after AD conversion input to the main control chip for feedback control.

2. CONTROL ALGORITHM BASED ON NEURAL NETWORK

2.1 Establish BP Neural Network Model

The tuning method of PID parameters is back propagation neural network, which is BP neural network back-propagation algorithm, it is a front to the feedback network, the network each neuron hierarchical arrangement. A total of three layers, respectively, for the input layer, hidden layer and output layer; the relationship between them is a layer of layer to pass, that is, the input layer of signal transduction to the hidden layer, the output signal of the hidden layer and then transmitted to the output layer. The relationship between them is strong and weak, and there is a strong inhibition, the function is to rely on weight values to achieve, the strength of the relationship is to rely on the size of the value of the size of the excitation and suppression is to rely on the weight value of the positive and negative values to achieve. The final signal received by each layer is the sum of all output signals corresponding to the output signal of the first layer, and then calculates the value of the output signal and compares with the fixed threshold, and finally determines whether the input signal is valid.

The working process of the BP network mainly has two parts, which are the study period and the working period. The learning period is divided into two parts, one is the signal forward transmission input information, and the other is the error feedback information of the signal back propagation. When the positive signal propagation, by the input will be a positive signal passed to the hidden layer, and then the hidden layer transmits the signal to the output layer, layer by layer in order to pass, a layer of the received signal only by a layer of the transmitted signal, the leapfrog is not affected. Because the input signal and the received signal always have a certain deviation, we call this kind of error, and the error signal is transmitted back to the back of the error signal, which is the error feedback information of the back propagation. If the deviation is large, then the weight of the back propagation signal is large, and vice versa. By adjusting the weight value to reduce the error, to achieve the consistency of the input and output signals. After this way back and forth, the input and output of basic stability, the weight will remain in a fixed range of fluctuations, even for a fixed value, then this state we call the end of the study period, after a difficult period of study, the system can smoothly enter the work period. The system does not have a back propagation signal in the working period, because the error has been corrected in the study period, and the system will transmit the signal according to the forward transmission mode (Lin & Chiu, 1998).

Neural BP network can have multiple layers, a complete neural network system for at least three layers, as shown in Figure 2.

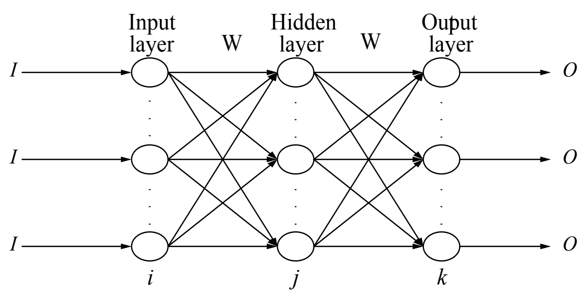

Figure 2
Schematic Diagram of BP Neural Network

2.2 Analysis of BP Algorithm of Neural Network

A function can be used to describe the error of the neural BP network algorithm, the error expression is:

$$E = F(X^p, W, V, d^p). \quad (1)$$

It is worth noting that the type (1) in the error function to adjust the degree of freedom for is n_w. This value is equal to the number of weights in each layer, and then the sum of the number of the layers: $n_w = m \times (n+1) + l \times (m+1)$. In this way, the error function E is a function of the weight and the threshold value of the two variables, so the error function is represented by graphical representation, It is a n_w+1 dimensional space on the surface. The uneven surface height represents the size of the weights, the higher the altitude, the greater weight, and vice versa. And the vertical coordinate is the size of the weight n_w, as the name suggests, this surface is called the error space curved surface, which reflects the distribution of error in the right space. Figure 3 shows an error surface figure in a two dimension spaces:

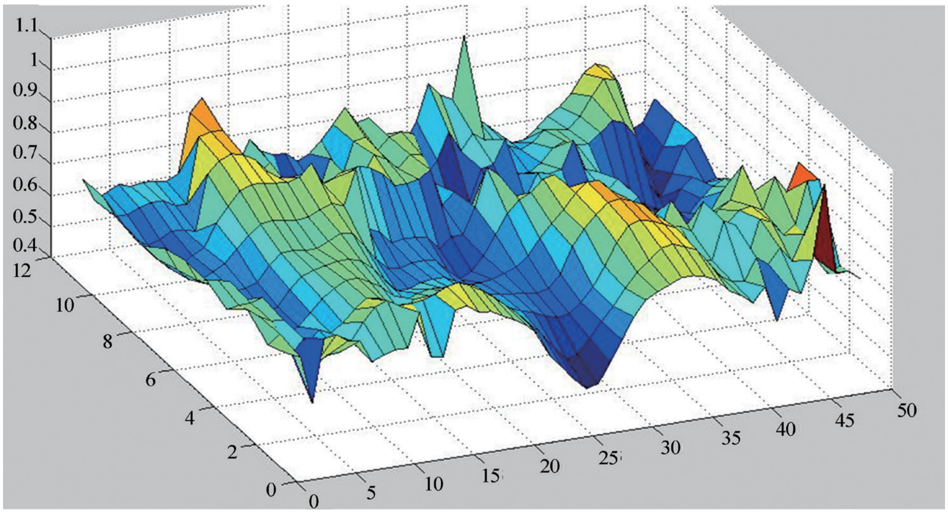

Figure 3
Error Surfaces of the Space of Two Adults

In space dimension of above only two dimensions, through the graphical expression can be seen very complex surface in the second space rights, high-low, rugged smooth place. Its main features are as follows:

It is not difficult to see, although the complex two-dimensional surface is uneven, but will also see some flat, In this case, the main reason is that the gradient is small, the input is too large, even if changing the weight, it is difficult to play a role, the differential relationship between the weight value of the error function is as follows:

$$\frac{\partial E}{\partial w_{ik}} = -\delta_k^o y_j \ . \tag{2}$$

If the error δ_k^o is small to a certain extent, infinite close to zero. So δ_k^o expression is available:

$$\delta_k^o = (d_k - o_k)o_k(1 - o_k) \ . \tag{3}$$

As you can see, there are 3 possible δ_k^o close to zero: The first is that o_k constantly close to d_k, on the graphics tables now a depression; the second is o_k always close to 0; the third is o_k always close to 1.In the second and third cases, the error value cannot be judged in the curved surface or the convex source, but it can be judged that the coordinates must be flat, because the gradient is small and the function change rate is small. Because the Sigmoid function is saturated with this feature, so o_k will be infinitely close to 0 or close to 1 unlimited, as shown in the Figure 4.

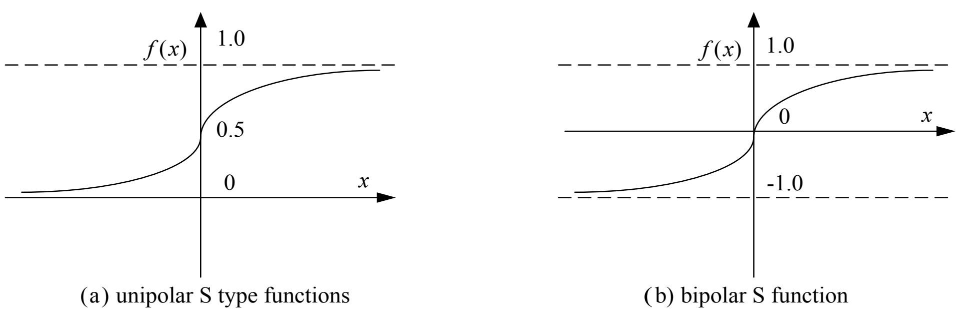

Figure 4
S Transfer Function

2.3 Improvement of BP Algorithm for Neural Network

According to the BP neural network algorithm of the error surface of a detailed theoretical analysis, although it can be seen that the BP neural network algorithm has many good features, For example, it can be applied to all kinds of nonlinear control fields, and it is also able to approximate a nonlinear function with more flexible characteristics. So it is accepted by more and more fields. It has also exposed many shortcomings, there is no man is perfect. Its major disadvantage is listed as follows:

(a) Although the calculation of the minimum, but only limited to the local, cannot take into account the overall situation;
(b) In the flat area cannot be fast learning, the need to train for a long time, increase the time cost;
(c) There is no more appropriate theory to guide the selection of the hidden function nodes;
(d) In the learning process, easy to master the old knowledge is not solid, the grass is always greener.

To solve the above four problems, this paper proposes three improved algorithms, respectively, as follows.

2.3.1 Adaptive Learning Rate

BP neural network algorithm of learning rate and stepper motor step has different approaches but equally satisfactory results; they are the smallest unit of that amount. In mechanics known as a unit pulse equivalent. When a learning cycle is completed, a weight value is modified by the error back pass signal, the size of a modified weight is a learning rate η, also known as BP neural network learning step size. If the step size is too large, the step size is too small, if the step size is too small, it will affect the running speed of the stepping motor. If the learning rate η is too high, will make the system unstable, cannot adjust to the minimum point; if the learning rate η is too small, will affect the convergence rate, increase the learning time. In order to solve the problem of the contradiction between the learning speed and the system stability, a dynamic learning rate is given in this paper η, when the system is in the 3D error surface of flat land, increase the learning rate, and quickly find the minimum error. When the system is in the depression of the 3D error surface, the learning rate is reduced, and the global minimum value is not missed. In order to get a reasonable dynamic learning rate η, the scientists described as painstaking research, a lot of methods to change the learning rate η, changes in the use of learning rate method are through the judgment of a learning cycle, the error amount of change to adjust the size of learning rate η.

2.3.2 The Introduction of Gradient Factor

When the system enters the flat area of the three dimensional error surfaces, the slope is relatively small because the whole surface is flat. By the S type curve function can also be known, in this case the system is extremely easy to enter the saturated zone, once the system into the saturated zone, the change of the error is no longer sensitive to the changes in weight. So to error adjustment to the specified range is bound to increase the time to adjust, so to on a flat area to increase learning efficiency, the introduction of steepness factor λ:

$$o_k = \frac{1}{1+e^{-\frac{\mathrm{net}_k}{\lambda}}} . \quad (4)$$

How to judge the flat area of the system to enter the 3D error surface, a judge is ΔE approaching to zero, but d_k - o_k is not very small, it is judged as flat area. In this order λ>1; when the system across the flat region, then set λ = 1, as shown in the Figure 5:

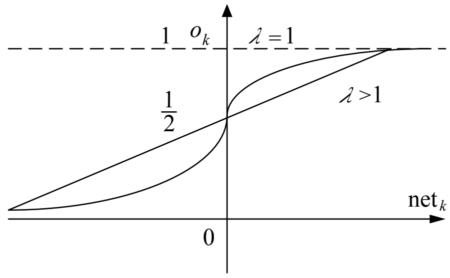

Figure 5
Transfer Function Curves Before and After Net Compression

From Figure 5 can be learned, when λ>1, the cross coordinate's net_k narrow λ times. Error on the weights of the sensitive region increased significantly, Therefore, the $\mathrm{net}_k$of the error of the control strength, can quickly adjust the error value. When λ = 1, curve function restored to original condition, because when the system goes into the 3D error surface uneven regional, weight of error control returned to the original strong control ability, error of weight again sensitive, if you also want to reduce the transfer function of the abscissa may miss error minima cause system oscillation.

2.3.3 Numerical Optimization

The contradiction between the stability and the convergence speed of the BP neural network is a new method using the numerical optimization method. It is different from the two different methods, Numerical optimization algorithm not only uses the difference between the theoretical output and the actual output information, but also the use of this difference in the rate of information, so that the difference can be predicted by the changes in the situation, Therefore, it is more advantageous to adjust the weights. The change rate of the extraction error and the weights can be divided into three methods. They are: quasi Newton method, conjugate gradient method and levenburg-marquardt method. The three methods have different points, which can be expressed as a formula:

$$\begin{cases} f(X^{k+1}) = \min f(X^k + a^k S(X^k)) \\ X^{k+1} = X^k + a^k S(X^k) \end{cases} . \quad (5)$$

Among them: X^k—weight vector and threshold vector;

$S(X^k)$—A method for searching the optimal solution in the space of weight and threshold vector;

a^k—When the direction is $S(X^k)$, $f(X^{k+1})$ is minimum value represents the step value.

This can be, to get the optimal weight of the method steps essential step is two steps: The first step is to determine the direction, because the search direction once blurred, it is easy to take a detour, but the efficiency is low. The second step, once determined the direction should be in the direction of the search, so to determine a suitable step size to be able to search for high efficiency, in this can borrow in front of two methods to achieve dynamic search step size.

According to different search directions, we can create different numerical optimization algorithms, because the problems encountered in the ever-changing, it is impossible to use a suitable algorithm to solve all the problems, so we can choose different algorithms to solve the problem. When the network parameters are small, the Levenburg-Marqaardt algorithm can be used to compensate the shortcomings of the gradient descent method, and try to avoid the errors in the error of the step size is too large, and avoid the error of the time is too small to be sensitive. When the network parameters are moderate, it can choose the quasi Newton algorithm, which is the most important one advantage, is that the calculation speed is very fast, so that the system can quickly achieve convergence effect. For the two order derivative of the error vector function, get a new two order derivative matrix H^k, is Hessian matrix, This matrix can effectively reflect the gradient information in all directions, which is advantageous to find the best search direction; When the network parameters are many, the conjugate gradient method is used, This method is mainly based on the selection of the direction of the search, he first in the direction of the gradient as a reference, the positive and negative two direction back and forth, Do the benefits of being able to carpet search, spare no pains to find optimal weights and bypassing the could not exist in the direction of the optimal weights, reduce the search work, which greatly enhances the efficiency of search.

Through the above introduction, we can know that the more accurate algorithm need to calculate the amount of the hardware speed requirements of the micro controller is also higher, in order to take into account the hardware and software of the mutual cooperation, to save the memory consumption of micro controller, reasonable selection algorithm is very necessary. When the current loop is calculated, the network parameters are more and the conjugate gradient method is used, when calculating speed loop, the network parameters are moderate, and the numerical optimization is carried out by using Levenburg-Marquardt, The network parameters are few and the numerical optimization of the quasi Newton method is carried out.

Need to explain is that every system varies widely and need to choose different methods according to the different situation to solve the problem, effectively reduce the convergence time, increase the system stability, cannot be generalized.

3. SYSTEM POSITION TEST EXPERIMENT

3.1 System Test

In order to verify the stability accuracy of one dimensional adjustment platform, using the model of DT302L with the accuracy of 0.1″ the angle of the rotation of the turntable plane, then the rotation angle and the setting angle are compared, and the angle of every 0.2s is measured, when the adjustment table tends to be stable, the discrete time and the corresponding angle values are recorded respectively, and the measurement data are as follows Table 1.

Table 1
Angle Measurement Data Table

Experiment serial number	Starting angle	Target angle	Running time	Termination angle	error	Stabilization time
			5.2s	36625″	-3″	
			5.4s	36627″	-1″	
1	0″	36628″	5.6s	36629″	1″	1.4s
			5.8s	36628″	0″	
			6.0s	36629″	1″	
			3.2s	25987″	3″	
			3.4s	25981”	-3″	
2	0″	25984″	3.6s	25986″	2″	1.6s
			3.8s	25985″	1″	
			4.0s	25986″	2″	
			1.2s	15430″	-2″	
			1.4s	15435″	3”	
3	0″	15432″	1.6s	15430”	-2″	1.6s
			1.8s	15431″	-1″	
			2.0s	15433″	1″	
			3.2s	-15921″	3″	
			3.4s	-15923″	-2”	
4	0″	-15924″	3.6s	-15924″	1″	1.4s
			3.8s	-15924″	0″	
			4.0s	-15925″	-1″	
			5.2s	-36565″	3″	
			5.4s	-36565″	3″	
5	0″	-36568″	5.6s	-36569″	-1″	1.4s
			5.8s	-36568″	0″	
			6.0s	-36567″	1″	

This position measurement experiment is divided into 5 groups, each group of 5 times the accuracy of repeated measurement. The five groups corresponding to the point of uniform distribution within the angle adjustment range of the index requirements, and every 5 inferior precision measurement are in position curve tends to be stable after, each 0.2s record corresponding to discrete time and position data.

3.2 Experimental Result Analysis

As shown in Table 1, one dimensional adjustment units are from 0″ to 36628″, 25984″, 15432″, -15924″ and -36568″, these five positions corresponding to the angle of the unit converted into angular units are: 10.17°, 7.22°, 4.29°, -4.42°, -10.16°. When the position curve tends to be flat, there are five position data and the corresponding time. According to the Bessel formula, the repeatability of the single measurement of the various positions can be obtained by the residual error *σ*:

When the target angle is 10.170°:

$$\sigma_1 = \sqrt{\frac{\sum_{i=1}^{5}(x_i - \overline{x})^2}{5-1}} = \sqrt{\frac{11}{4}} = 1.67 \tag{7}$$

When the target angle is 7.22° :

$$\sigma_1 = \sqrt{\frac{\sum_{i=1}^{5}(x_i - \overline{x})^2}{5-1}} = 1.89 \tag{8}$$

When the target angle is 4.29° :

$$\sigma_1 = \sqrt{\frac{\sum_{i=1}^{5}(x_i - \overline{x})^2}{5-1}} = 0.98 \tag{9}$$

When the target angle is -4.42° :

$$\sigma_1 = \sqrt{\frac{\sum_{i=1}^{5}(x_i - \overline{x})^2}{5-1}} = 1.35 \tag{10}$$

When the target angle is -10.16° :

$$\sigma_1 = \sqrt{\frac{\sum_{i=1}^{5}(x_i - \overline{x})^2}{5-1}} = 1.25 \tag{11}$$

Can be seen from Table 1, the limit error of the single measurement value and the target value is no more than 3, the repeatability of the five position experiment is less than 2″, overall single measurement repeatability is:

$$\overline{\sigma} = \frac{\sigma_1 + \sigma_2 + \sigma_3 + \sigma_4 + \sigma_5}{5} = \frac{7.14}{5} = 1.43 \tag{12}$$

In the five position experiments, the maximum angle and the minimum angle are more than ±10° meet the requirements, and the maximum stabile time is not more than 10s.

SUMMARY

This paper designed a one dimensional adjustment of high precision servo control system, in order to provide individual comprehensive combat system high precision gun visual angle. The whole servo system control circuit with digital signal processor as the core, it can complete digital control of permanent magnet synchronous motor of sensor signal acquisition and data processing, implementation of PID parameters self-tuning based on neural network motor vector control algorithm, produce the ac servo motor control PWM signal.

In servo control system hardware design based on DSP digital signal processing (DSP) chip as the CPU control circuit, not only including photoelectric sensor and servo ac motor phase current signal acquisition circuit, data transmission interface circuit, DSP minimum system circuit, voltage regulator circuit and under-voltage protection circuit, etc. In regard to algorithm, using the three layers BP neural network algorithm for PID integral gain and differential gain and intelligently adjusting proportion gain. On this basis, also analyzes the advantages and disadvantages of the traditional BP neural network algorithm, carries on the improvement. Vector using adaptive control, numerical optimization and introducing the steepness factor method, solve the contradiction between the stability and the learning time, greatly improving the convergence speed and stability of the system performance, the static stability of the turntable accuracy is less than 3″, indicators reached the design requirements.

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