Abstract--Based on the self-learning property of neural network, a controller of neural network is put forward for the velocity loop of stabilized platform in the paper. The experimental results are given in both the controller of neural network and the traditional controller designed with traditional frequency domain methodology. The experimental results demonstrate that the controller of neural network is very effective for improving the low speed property of stabilized platform in applications. Therefore, it’s valuable for the application of a neural network controller in practical engineering.

Index Terms--Neural network, Self adaptation, Stabilized platform, Velocity loop.

I. INTRODUCTION

In the photoelectrical equipment for scouting and measuring carried in vehicles, ships or airplanes, the optic axes of photoelectrical sensors, such as, visible light cameras, infrared cameras and laser telemeters, fixed in the above-mentioned equipment, are usually required to aim at target precisely in order to accomplish capturing, tracking and measuring for the target. The stabilized platform is an important part to ensure the optic axes of photoelectrical sensors to stabilize. The structure of stabilized platform is electromechanical multi-frames. Generally, the numbers of the required stabilized axes in platform are two or three. The control system in stabilized platform is one of key factors in ensuring the platform stabilizing performance. The double closed-loop of control structure for a stabilized axis is shown in Fig. 1.

Velocity closed-loop is composed of speed gyro, velocity loop compensation, power amplifier, motor and load. Position closed-loop is composed of encoder, tracker, position loop compensation and velocity closed-loop.

According to the design methodology of the traditional frequency domain on condition of meeting the requirements of both amplitude margin and phase margin, the velocity loop compensation part of stabilized platform is designed. Because the mathematical model of the controlled object isn’t measured precisely and the properties of the controlled object will vary along with the environment, especially, the changes of the carrier pose will result in the changes of center of gravity of stabilized platform and the changes of friction moment among shafting, the controller doesn’t ensure the control system to possess the most superior performance first midst and last. Therefore, we expect, on the basis of the control parameters obtained with the design methodology of the traditional frequency domain, that the control parameters can regulate self-adaptively along with the changes of the controlled object properties to ensure the control system to possess the most superior control performance from the beginning to the end.

Aimed at the afore-mentioned existing problem and based on the self-learning property of neural network, we design a new controller fulfilling the control parameters to regulate self-adaptively in the paper. The factual results demonstrate that the new controller is very effective for improving the low speed property of stabilized platform and for overcoming the influence of the various disturbance moments, such as, friction and wire screwing. The new controller decreases the requirement for the mathematical model precision of the controlled object. It is valuable in practical engineering.

II. GENERAL DESIGN METHODOF DIGITAL CONTROLLER

In the digital control system, the general design method of digital controller used widely in engineering is that the continuous controller is discretized using some discretization methods. When the system sample frequency is very high (In general, the sample frequency is 5 to 10 times compared with the system open end frequency.), the digital controller is regarded as the continuous controller approximately. Use the design method.

Fig. 1. Block diagram for a stabilized platform control system.
of traditional frequency domain to design transfer function of continuous compensation part, then discretize this transfer function using certain discretization method, such as, impulse invariance, zero-pole matching or double linear converter, to bring impulse transfer function. Thereby, we can obtain digital control algorithm from the impulse transfer function. Double linear converter is a kind of discretization method adopted widely in engineering.

Supposedly, transfer function $D(s)$ of continuous compensation part is given by

$$D(s) = \frac{U(s)}{E(s)} = \frac{B_0 + B_1 s + B_2 s^2 + \cdots + B_m s^m}{A_0 + A_1 s + A_2 s^2 + \cdots + A_n s^n}\quad(1)$$

Using double linear converter to discretize (1), we can obtain impulse transfer function $D(z)$ as shown by

$$D(z) = D(s)\left|_{s = \frac{z - 1}{T}}\right. = \frac{u(z)}{e(z)} = \frac{b_0 + b_1 z^{-1} + b_2 z^{-2} + \cdots + b_m z^{-m}}{1 + a_1 z^{-1} + a_2 z^{-2} + \cdots + a_n z^{-n}}\quad(2)$$

Where $s$ is Laplace operator. $T$ is sample period. It is obvious that there is a certain fixed relationship between coefficients $B_0, B_1, \cdots, B_m, A_0, A_1, \cdots, A_n$ and coefficients $b_0, b_1, \cdots, b_m, a_1, a_2, \cdots, a_n$ at a certain fixed sample frequency. Therefore, after we have designed the transfer function $D(s)$, we can obtain the impulse transfer function $D(z)$ at a certain fixed sample frequency. Moreover, $D(z)$ is the same rank as $D(s)$.

Take inverse transform of (2) to yield recursion formulation fulfilling digital control as shown by

$$u(k) = \sum_{i=0}^{m} b_i e(k-i) - \sum_{j=1}^{n} a_j u(k-j)\quad(k = 0, 1, 2, \cdots)\quad(3)$$

Where $k$ is the current sample moment. Both $(k-i)$ and $(k-j)$ are the past sample moments and they apart or j sample period with the current sample moment. Because every coefficient (control parameters) in (3) is constant, such design controller doesn’t ensure the control system to hold the most superior performance first midst and last on condition that the properties of the controlled object are changing or that the controlled object is suffered various disturbances. That is, the controller doesn’t possess self-adapting ability. If every coefficient in (3) can regulate automatically along with the changes of the properties of the controlled object or various disturbances for the controlled object, such design controller can improve the control performance greatly. Because neural network possesses ability of regulating weight matrix in real-time and approaching any nonlinear function, neural network is every effective method to regulate the control parameters automatically. A kind of linear neural network is applied to regulate the control parameters automatically to meet the needs of the real-time control system.

III. USING NEURAL NETWORK TO REGULATE CONTROL PARAMETERS AUTOMATICALLY

In accordance with the theory of adaptive linear neural network, an adaptive linear neural network can be constructed with (3) as shown by Fig. 2.

Where both $e(k), e(k-1), \cdots, e(k-m)$ and $u(k-1), u(k-2), \cdots, u(k-n)$ are input variables of neural network. These input variables can be obtained with calculating and measuring in the control system. Both $b_0, b_1, \cdots, b_m$ and $a_1, a_2, \cdots, a_n$ are weights. Neural network regulates weights automatically to meet a certain control performance according to least mean-square (LMS) algorithm when the system is running.

$$u(k-1) = a_1, u(k-2) = a_2, \cdots, u(k-n) = a_n$$

Fig. 2. Structure of adaptive linear neural network.

Using the neural network in Fig. 2, we may construct the control structure of velocity loop for a gyro stabilized platform as shown by Fig. 3.

Fig. 3. Structure diagram of velocity loop for a gyro stabilized platform.

Where $r(k)$ is input variable of velocity loop, $y(k)$ is output variable of velocity loop, $r(k) - y(k)$ is error signal $e(k)$. In order to overcome the shortcoming that neural network converges slowly when the error signal $e(k)$ is bigger, the paper designs two controllers for the velocity loop of stabilized platform. One is the controller of adaptive linear neural network, and the other is the traditional controller. Two controllers switch each other according to magnitude of the error signal $e(k)$. That is, when the error signal $e(k)$ is bigger, the traditional controller is applied. On the contrary, when the error signal $e(k)$ is smaller, the controller of adaptive linear neural network is applied. In short, the system control performance is satisfactory in spite of the condition that the error signal $e(k)$ is big or small.
Adaptive linear neural network trains network with least mean-square algorithm. The performance function of the control system is given by
\[ E_r(k) = \frac{1}{2}(r(k) - y(k))^2 \]  
(4)

Differentiating \( E_r \) with respect to the weight vector \( W \) yields
\[ \frac{\partial E_r}{\partial W} = -(r - y) \frac{\partial y}{\partial u} X^T \]  
(5)

We may write increment of the weight vector as follows
\[ \Delta W = -\eta \frac{\partial E_r}{\partial W} - \eta (r - y) \frac{\partial y}{\partial u} X^T \]  
(6)

Finally, we may formulate the LMS algorithm as follows
\[ W(k) = W(k-1) + \Delta W(k-1) \]  
(7)

Where \( X \) is input variable vector of neural network \([x_1, x_2, ..., x_{m+1}]^T\). \( W \) is weight vector \([w_1, w_2, ..., w_{m+1}]^T\). Relationship between control value \( u \) and output variable \( y \) of velocity loop is linear approximately, then we may measure \( \partial y / \partial u \) by experiment. \( \eta \) is learning-rate. It is usually positive and affects heavily the converging speed and the validity of LMS algorithm. \( \eta \) is regulated with adaptive manner as shown by Fig. 4.

![Fig. 4. Adaptive learning-rate.](image)

The essential principle of regulating \( \eta \) is that increasing \( \eta \) on condition of ensuring algorithm convergence in order to shorten learning time, and that decreasing \( \eta \) on condition of algorithm divergence until algorithm is convergent. In Fig. 4, the value of increasing coefficient \( \alpha \) is greater than 1 and the value of decreasing coefficient \( \beta \) is less than 1 but greater than 0.

The initializing values of neural network weight vector (control parameters) influence on the control system performance heavily. If they are taken inadequately, the convergence speed of neural network will slow down. Consequently, the control system performance is destroyed. In engineering, we can construct an imprecise mathematical model of the controlled object by experiment. Based on the imprecise mathematical model of the controlled object, we can design the transfer function of compensation part using the design methods of traditional frequency domain for the control system. The transfer function is specified like (1). Discretizing (1) with double linear converter at a certain fixed sample frequency yields the impulse transfer function as shown by (2). Therefore, the control parameters \( b_0, b_1, ..., b_n, a_1, ..., a_n \) can be solved. The control parameters \( b_0, b_1, ..., b_n, a_1, ..., a_n \) are regarded as the initializing values of neural network weight vector to ensure the system to run smoothly when two controllers switch each other.

IV. EXPERIMENTS

In a gyro stabilized platform, the above-mentioned control strategy is applied to the velocity loop. Measuring the electromechanical time constant \( T_n \) is 0.038s by experiment. Electromagnetical time constant \( T_e \) is very small and may be ignored. Basing on experimenting and comparing time after time, we design the compensation part with the design method of the traditional frequency domain. When the structure and parameters of the compensation part are taken as shown by (8), the system control performance is better.
\[ D(s) = \frac{u(s)}{e(s)} = \frac{0.00286 s^2 + 0.111 s + 1}{3.03 s^2 + 5.212 s + 1} \]  
(8)

Discretizing (8) with double linear converter at 1kHz sample frequency yields the recurrence formulation as shown by
\[ u(k+1) = 0.99785 u(k) - 0.99785 u(k-2) + 0.000967 e(k) - 0.001887 e(k-1) + 0.000921 e(k-2) \]  
(9)

Hence, we may construct an adaptive linear neural network with 5 input variables. The initializing weight value of each input variable is selected \( a_1 = -1.99785 \), \( a_2 = 0.99785 \), \( b_0 = 0.000967 \), \( b_1 = -0.001887 \), \( b_2 = 0.000921 \) respectively. \( \partial y / \partial u \) is 0.327 by experiment. The initializing value of learning-rate \( \eta \) is selected 0.001. The increasing coefficient \( \alpha \) of learning-rate is selected 1.05 and the decreasing coefficient \( \beta \) of that is selected 0.75. The switch point of two controllers is that switching to the traditional controller when the error signal \( e(k) \) is greater than \( 2^2 / s \), otherwise, switching to the controller of neural network.

![Fig. 5. Step response of velocity loop.](image)

The step response for the control system is shown by Fig. 5. It is obvious that the switches between two controllers are very smooth.

When the system is running at low speed (Less than \( 2^2 / s \)), Fig. 6(a) shows the system response with the traditional
controller and Fig. 6(b) shows the system response with the controller of adaptive linear neural network. It is obvious that the controller of adaptive linear neural network can improve the system smoothness at low speed heavily.

![Response curve comparison between the traditional controller and the controller of neural network at slow speed.](image)

**V. CONCLUSIONS**

The velocity loop property for stabilized platform has importantly effective on the control performance of the whole platform. The controller of adaptive linear neural network can improve the low speed performance of the velocity loop greatly on condition of unknowing the precise mathematical model of the controlled object or suffered various disturbances. Firstly, the obtained control parameters adopting the design method of the traditional frequency domain are regarded as the initialized values of neural network weight vector. Selecting initialized values of weight vector in such way may make the system respond rapidly. This is an effective method in selecting the initialized values of weight vector and it’s valuable in practical engineering. Secondly, the learning-rate is regulated adopting the self-adapting fashion. The self-adapting fashion of the learning-rate can effectively shorten learning time on condition of ensuring algorithm convergence.

**REFERENCES**