RESEARCH AND APPLICATION OF THE ADAPTIVE AGRICULTURAL MACHINERY PATH TRACING METHOD BASED ON BP NEURAL NETWORK

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Abstract. Advanced agricultural machinery and equipment is the basis for the realization of agricultural modernization. Aiming at the path tracking and the problem of control in the autonomous operation of intelligent agricultural machinery, this paper proposes an adaptive agricultural path tracking method based on BP neural network, which can realize the adaptive tracking of an agricultural machinery path. In this paper, the method is applied to the agricultural machinery with intelligent hydraulic brake control system to realize the path tracking experiment of the real vehicle; the straight path tracking and curve path tracking test are carried out for it. The test results show that the path tracking method designed in this paper can effectively improve the tracking accuracy. If compared to the classical PID control method, the precision of the straight path is improved by 12% to 3 cm. The accuracy of the curve path is improved by 20% to 6 cm. The algorithm designed in this paper has a high effectiveness and robustness, which is very important for improvement of the stability of agricultural machinery and the level of automatic navigation.

Keywords: BP neural network; agricultural machinery path tracking; adaptive method; navigation

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Problem statement. Agricultural automatic navigation is the key to the realization of precision in agriculture and the basis of future agricultural modernization. Automatic navigation technology can greatly improve the efficiency of agricultural machinery and the quality of operations [1], reduce the requirements for the agricultural machinery operator's skills to make the job more popular. It is of great significance to promote the application of agricultural machinery in modern agriculture.

Agricultural machinery path tracking is one of the key technologies to realize automatic navigation control of agricultural machinery, which is also an urgent task in the field of agricultural automatic navigation research. Automatic navigation and positioning of agricultural machinery [6] are achieved by means of GNSS (global navigation satellite system), such as GPS, Beidou, Groen, etc. At present, GPS has been widely used in modern agricultural machinery, performing automatic navigation and positioning in Europe, the United States, and other developed countries. However, due to the current progress of agricultural modernization, especially the proposed fine agriculture, the navigation requirements are getting more and more stringent, but it is difficult to achieve high precision with the traditional GPS [7]. Usually the difference between the errors in meters above, if the detection of those data directly applied to agricultural navigation can only play a supporting role and not achieve the needs of fine agriculture on the navigation and positioning, especially in China, due to the US military restrictions, received GPS Navigation positioning signal error is greater. Therefore, the future of agricultural automation that needs to be addressed [8] is to use the relevant technology to enhance the accuracy of agricultural positioning to achieve high-precision machinery tracking.

THE ARTICLE AIM is to propose an adaptive agricultural path tracking method based on BP neural network, which realizes the adaptive tracking of the machinery path and effectively improves the traditional tracking based on GPS and PID control technology. It demonstrates a high effectiveness and robustness and is quite significant for the promotion and implementation of precision and automation of agricultural development.

Basic material

1. Intelligent electronic control hydraulic steering system

In this paper, the adaptive farm path tracking method based on BP neural network is finally applied to the agricultural machinery which has the intelligent electronic control hydraulic steering system. Electromechanical hydraulic steering system is the core of intelligent trajectory and path control, which performs automatic control of the machinery turning equivalent to that in the tractor controller. Its working principle is shown in Fig 1.

The electronic control hydraulic steering system has three working conditions. Their control is the key to realize the machinery movement according to the predetermined path.

1.1. Left turn state of agricultural machinery

In the left turn state, the agricultural machine turns being controlled by the electronic control hydraulic steering mechanism. The working state of the electronic control hydraulic steering system is shown in Fig. 1. Two three-way electromagnetic valves and three four-way electromagnetic proportional b-bit valves electrify at the same time. At that, hydraulic oil of the hydraulic system passes through the two three-way solenoid valves on the right, then through the system's one-way valve into the right of three-way electromagnetic proportional valve, and finally it enters the hydraulic cylinder of the balance valve. The main valve stem in the hydraulic cylinder will be driven by the action of the pressure oil to push the steering wheel of the machine to drive the wheels to turn left.

1.2. Right turn state of agricultural machinery

The right turn state is the opposite of the left turn. According to the principle of the electro-hydraulic system operation shown in Fig. 1, in the right turn the agricultural machinery only needs to turn to the system of two three-way electromagnetic valves and three four-way electromagnetic proportional valves at the same time to achieve right turn control.

1.3. Agricultural machinery to unloading state

Steering system unloading state refers to the absence of the need for steering in the agricultural control. That is, when the front wheel steering angle of the agricultural machine and the expected steering angle are within the allowable range of the error, the cylinders in the hydraulic oil maintain a certain pressure due to the role of the balance valve. Therefore, the control of the left and right turn of the two three-way solenoid valves and three four-way solenoid valves do not need to supply power in the pressure relief state of the hydraulic steering system.

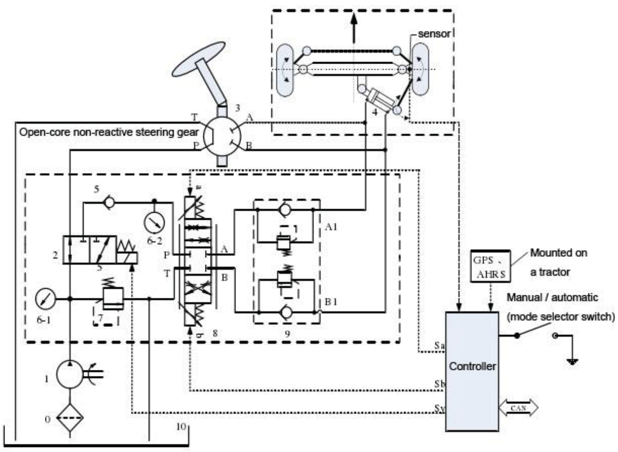

Fig. 1. Diagram of the hydraulic steering system with intelligent control of agricultural machinery

0 — filter; *1* — quantitative pump; *2* — position three-way solenoid valve; *3* — diverter (open core without reaction); 4 — tum cylinder *5* — way valve; *6* — pressure gauge; *7* — relief valve; *8* — three-way proportional electromagnetic valve (O-type); *9* — balance valve; *10* — hydraulic tank

PID control algorithm is usually used in order to further improve the steering system control accuracy. Its basic operating principle is shown in Fig 2.

In the PID control, three control parameters are usually applied to adjust the system control and ensure its precision.

2. The relative movement model of agricultural machinery based on a spatial parameter

The key of agricultural machinery tracking is to ensure that its movement error lies within a certain allowable error margin. Therefore, we need to establish a relative movement model which can describe the machinery movement in the process of tracking its path, which would account for variation of this error. Based on that, this paper defines a navigation coordinate system and a Freeman coordinate system on a path in the design process. Then, a relative movement model describing the agricultural machinery movement is constructed based on the two coordinate systems. The movement relation is shown in Fig. 3.

In the relationship between the agricultural machinery and the path described above, the R parameter indicates the center of the circle of the instantaneous rotation of the agricultural machinery. The *L* parameter indicates the wheelbase of the agricultural machinery, and *S* represents the arc length of the curve path. In this paper, the relative agricultural machinery movement model is taken as the spatial parameter, the *D* parameter indicates the error of the horizontal position of the agricultural machinery relative to the path, the *C* parameter represents the control point of the agricultural machinery, the *T* parameter indicates the distance from the agricultural control point on the path of the agricultural machinery movement, δ represents the deflection angle of the agricultural steering wheel, ψ_c indicates the expected heading value on the path from the nearest point.

In the construction of the mathematical model, this paper proposes the following assumptions:

$$H1: \ 1 - c(s)\,d \neq 0 . \quad (1)$$

$$H2: \theta_e \neq k\pi + \frac{\pi}{2} \quad (k=0, 1, 2, \ldots). \quad (2)$$

In the above equation, the θ_e parameter represents the heading error of the agricultural machine relative to the path, and $c(s)$ represents the curvature of the agricultural machinery path.

Based on the above assumptions, this paper has proved that the theory has been completed in [3]. The mathematical model of relative movement of agricultural machinery is as follows:

$$\begin{cases} \zeta_1' = (1 - \zeta_1 c(s)) tan\zeta_2 \\ \zeta_2' = -c(s) + (1 - \zeta_1 c(s)) usec\zeta_2 \end{cases} . \quad (3)$$

In the formula, $\zeta' = \frac{d\zeta}{ds}$, $\zeta = [d \ \ \theta_e]^T$. (4)

The model does not feature the agricultural speed parameter. The relative movement description of agricultural machinery based on the model has nothing to do with the speed of agricultural machinery. Therefore, the agricultural path tracking method based on the model is also independent of the speed of agricultural machinery, which can adapt to different speeds of path tracking.

3. Design of adaptive agricultural path tracking method based on BP neural network

3.1 Basic principles of BP neural network algorithm

BP neural network was developed on the basis of artificial neural network. In 1986, Rinehart, McClelland and others proposed multi-layer feedback network back propagation (BP-Back Propagation) learning algorithm [9]. It inherits the basic characteristics

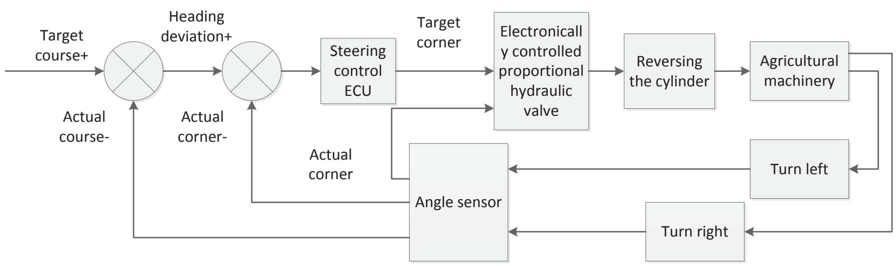

Fig. 2. Steering PID control principle

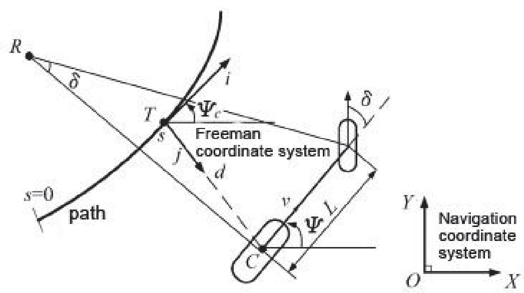

Fig. 3. Relative movement and position relationship between agricultural machinery and path

and advantages of neural networks through the use of nonlinear micro-function to train the network. The learning algorithm has a high plasticity and simple structure, so it is widely used in many fields [9].

BP learning algorithm can also be called BP network, which is divided into input layer, hidden layer and output layer. The network contains at least one hidden layer. The external signal is transmitted to the neural network through the input layer, and then goes through processing in at least one hidden layer, and finally is outputted through the output layer. The signal passes through the forward transfer layer by layer and iterates in the BP network and gets the result. If the output does not correspond to the expected value, one should calculate the output value and the expected value of the error, reverse propagation through error, and modify the parameters of the neurons in each layer until the desired output is obtained [10–11].

Based on the above analysis of the control principle of the hydraulic control system, the electronic control hydraulic steering system is managed mainly through the PID algorithm to achieve precision. However, the control parameters of the *P*, *I*, and *D* algorithms in the classical PID algorithm are deterministic and can not be adjusted automatically, which makes the accuracy of the PID control algorithm lower and affects the navigation accuracy. In order to further improve the steering system control precision, this paper combines the self-learning function of the neural network, based on the relative movement model of the agricultural machinery constructed above, and uses the relative error as input to realize the automatic control of the PID parameters of the hydraulic control system adjustment so as to further improve the tracking accuracy.

3.2. Adaptive agricultural machinery path tracking method based on BP neural network

In the design of neural network, this paper adopts a typical neural network system structure [15], which uses a three-layer model and has an input and three outputs. It is based on the previous analysis and design of the principle of hydraulic steering PID and the relative movement model of agricultural machinery. The parameters d and θe in the relative movement model are regarded as input of the neural network. The three control parameters of the PID algorithm are used as the output of the neural network. The whole network system is shown in Fig 4.

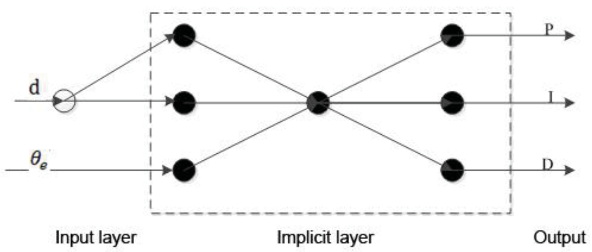

Fig. 4. Diagram of the PB neural network system structure

This paper considers pre-input some of the existing statistical parameters to achieve model self-learning. When each parameter is input to the model through the input layer, the connection weights and thresholds of the neurons are initialized at the hidden layer, and then the learning mode starts working. At this point, each neuron in each of the hidden layers computes the net input and output, and then the output of the hidden layer becomes the input of the output layer. When the output layer is input, the net input and output of each neuron are calculated. Both the hidden layer and the output layer are compared with the output, the threshold is set, and the generalized error is calculated. The hidden layer adjusts the connection weights between the hidden layer, the output layer and the thresholds of the respective cells of the output layer according to the generalized error. The output layer adjusts the connection weights between the input layer and the hidden layer and the thresholds of the respective cells in the hidden layer according to the generalized error. Then the learning model is updated, and it is determined whether the learning mode is completed, if not — the steps above are re-applied. If the learning mode is completed, the number of learning is updated, and then it is determined whether the number of learning or error is standard. If it does not meet the standard, the jump will re-apply the learning mode to the network step; reaching the standard marks the end. Specific algorithm flow of the implicit layer is shown in Fig. 5.

The actual forecast requires only the real-time calculation of the relative machinery movement as the input data for the network. The PID parameters of the PID controller can be obtained from the output layer. The PID parameters of the three PID controllers are used as the PID control parameters of the electronic control hydraulic steering system to control the steering system, and then to achieve the steering control of agricultural machinery to perform path tracking.

4. Experimental test simulation

The proposed BP neural network based on the adaptive agricultural path tracking method was integrated and experimented on the John Deere C230 combine harvester. The ARM platform of the test system completes the development, design and deployment of the algorithm. The algorithm is integrated into the improved control system of this type of harvester, the bit sensor uses the RTK GPS receiver as the positioning of the machine. The positioning accuracy is optimized within 30 cm. The MTi heading sensor is used after the completion of the entire algorithm deployment. It carries out experimental tests and transfers real-time data to the host computer software through the wireless module for the analysis. The resulting effect is shown in Fig. 6. Is linear path accuracy increased by 12%, reaching 3 cm; curve path accuracy increased by 20%, reaching 6 cm.

The error analysis of the tracking experiment is carried out and compared with the free PID tracking method. The results are shown in Table 1.

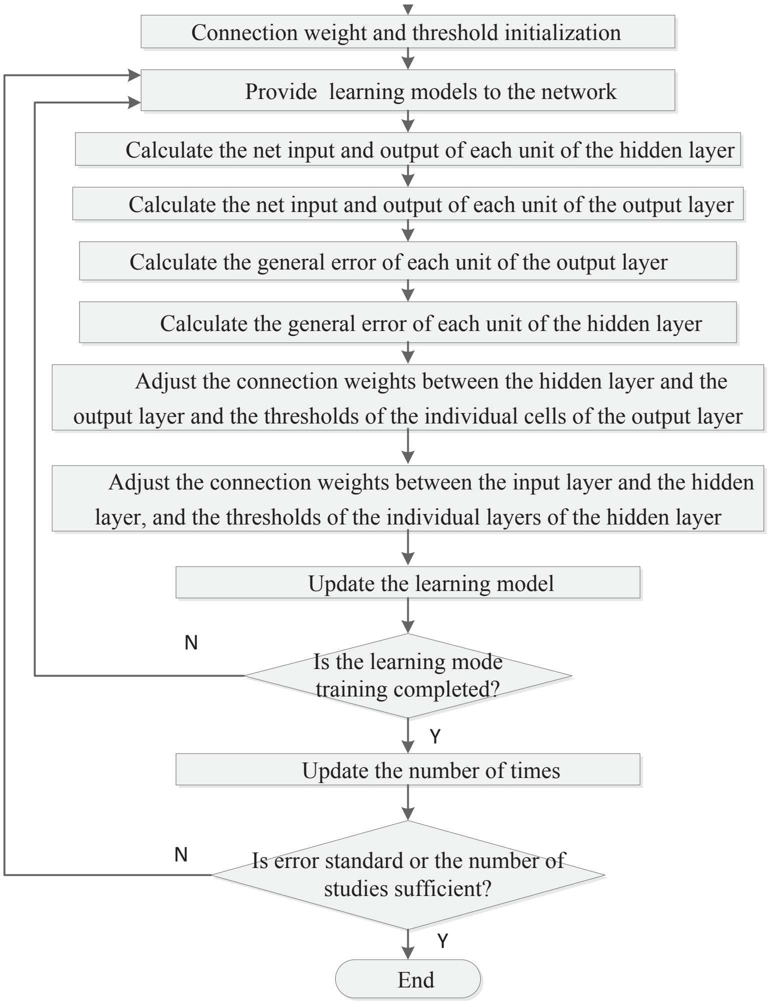

Fig. 5. BP neural network flow chart

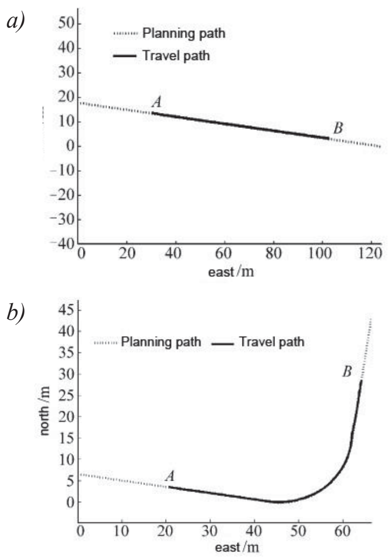

Fig. 6. Results of the tracking experiment: *a* — straight path tracking effect graph; *b* — curve tracking effect graph

Table 1. Error comparison analysis of this method and a single PID tracking method

Speed (m/s)	The maximum error of this method (m)	PID method maximum error (m)	The absolute error of this method (m)	PID method absolute error (m)
0.6	0.11	0.15	0.04	0.07
0.8	0.10	0.20	0.04	0.09
1.0	0.10	0.26	0.04	0.12

As shown in Table 1, it can be concluded that the performance of the adaptive agricultural path tracking method based on BP neural network is better than that of the single PID control algorithm. In this paper, the relative movement model is adopted to solve the problem of tracking the influence of agricultural speed, and the path tracking with a lower error can be achieved under different agricultural speed.

CONCLUSION. Agricultural machinery path tracking is the basis of precision in modern agriculture, which is also an urgent need to break through the technical bottlenecks in the field of agricultural navigation and positioning. Based on the above reasons, this paper proposes an adaptive agricultural path tracking method based on BP neural network. This method constructs the relative movement model of agricultural machinery and integrates the BP neural network and the traditional PID control method to realize the adaptive control of a hydraulic control system of agricultural machinery and electronic control, which effectively improves the accuracy of agricultural machinery path tracking and is quite significant for the future to achieve precision in the agricultural technology.

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