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Agricultural machinery photoelectric automatic navigation control system based on back propagation neural network

Yerong Sun, Kechuan Yi

School of Mechanical Engineering, Anhui Science and Technology University, Fengyang, Anhui, China

Abstract

To study the influence of speed factors on the stability of a tractor automatic navigation system, combined with the neural network control theory, the authors proposed a dual-objective joint sliding mode control method based on lateral position deviation and heading angle deviation, using a back propagation neural network to establish a two-wheel tractor-path dynamics model and a straight-line path tracking deviation model. The overall system simulation was carried out using Matlab/Simulink, and the reliability of the control method was verified. The experimental results showed that when the tractor was tracked with the automatic control of a linear path under the condition of variable speed, the maximum deviation of the lateral position deviation was 12.7 cm, and the average absolute deviation was kept within 4.88 cm; the maximum deviation of the heading angle deviation was 5°, and the average absolute deviation was kept within 2°; the maximum value of the actual rotation angle was 3.13°, and the standard deviation of the fluctuation was within 0.84°. Under the conditions of constant speed and variable speed, using the joint sliding mode control method designed by the authors, the dual-objective joint control of lateral position deviation and heading angle deviation could be realized, the controlled overshoot was small, the controlled deviation was small after reaching a stable state, and the adaptability to speed factors was strong, which basically could meet the accuracy requirements of farmland operations.

Correspondence: Yerong Sun, School of Mechanical Engineering, Anhui Science and Technology University, Fengyang, Anhui 233100, China. E-mail: sunyr@ahstu.edu.cn

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Introduction

Agriculture is the foundation of the national economy and one of the key issues to be solved. As a major agricultural country in the world, with the continuous development of society, the area of arable land is still shrinking, the resources of arable land cannot be used effectively, the environment is gradually deteriorating, and the incidence of pests and diseases is high, which seriously restricts the food security of our population (Xu *et al*., 2021). In addition, Gan and Zhong (2021) analyze that our country is experiencing a process of gradually accelerating aging, and the most direct change brought about by it is the reduction of labor supply, especially in rural areas. This is another major blow to the output of grain. Therefore, improving the utilization rate of agricultural resources, reducing production costs, and increasing crop yields have become the development trends of modern agriculture. To ensure the food security of the Chinese population, it is necessary to make full use of intelligent high-tech to vigorously develop modern agriculture. Fundamentally, it can solve many problems such as the high cost, low efficiency, low yield, and environmental pollution of traditional agriculture. The key is to promote the progress of agricultural science and technology, improve production efficiency, and maximize the use of decreasing land to produce more food (Li *et al*., 2020).

In this environment, “precision agriculture” has received a rapid and strong response in China. Precision agriculture, precision farming, or computer-aided farming, these concepts and assumptions were first proposed by the United States in the early 1980s. The original intention of precision agriculture is to minimize the amount of production, reduce agricultural production costs, and avoid environmental pollution caused by excessive application of chemical fertilizers and pesticides (Sikarev *et al*., 2020). On a technical level, precision agriculture integrates modern information technology with agricultural technology and engineering technology to obtain high-yield, high-quality, and efficient farmland production. The rapid development of differential global positioning system (DGPS), geographic information system (GIS), and decision support system provides the necessary technical means for precision agriculture. Tan *et al*. (2020) introduced the current research status of environmental perception technologies and navigation control strategies at home and abroad and analyzed the advantages and disadvantages of common environmental perception technologies and navigation control strategies. Figure 1 shows the control principle diagram of the agricultural machinery automatic navigation system (Zhuo *et al*., 2021). Precision agriculture is the crystallization of high technology and agricultural production, an important breakthrough in agricultural production in the 21st century, and an important way to achieve sustainable agricultural development. In order to realize the generalization and productization of the tractor automatic navigation control system, aiming at the problems in the existing agricultural machinery automatic navigation system, in-depth theoretical research is carried out, and the corresponding hardware system is reformed. It is very important to improve the intelligence level of Chinese tractors, shorten the gap with foreign tractors, and enhance the ability for independent innovation (Yan *et al*., 2020).

Literature review

Aiming at this research problem, Song *et al.* (2020) studied the automatic control function of a tractor based on a map. Based on the real-time kinematic-global position system (RTK-GPS), geomagnetism direction sensor (GDS), machine vision and others have developed an automatic navigation control system based on multi-source information fusion. The system introduced an extended Kalman filtering algorithm and a two-dimensional probability density function method for positioning and combined these three methods into different combined navigation and positioning systems. On this basis, the experiment with four kinds of navigation path planning control strategies was designed. The test results showed that the combined navigation method based on the GDS sensor and RTK-GPS technology has achieved satisfactory results, and the obtained navigation accuracy was 7.4 cm (Song *et al*., 2020). Tanino *et al*. (2020) used a John Deere tractor as a research platform and installed four GPS-receiving antennas. By measuring the angle of each GPS antenna relative to the satellite and the phase difference of the GPS signal, the position and attitude information of the tractor could be calculated. Zhang *et al*. (2020) developed an automatic weeding control system based on RTK-GPS and Kalman filtering. Some people used the laser range finder on the agricultural robot to realize the monitoring and navigation of the peatland. Pei and Petrenko (2020) used a laser scanner to generate 3D GIS maps. Antonov *et al.* (2020) developed an automatic obstacle avoidance navigation system for agricultural robots based on a laser range finder and GPS positioning. It could be seen that this vehicle robot laboratory, under the leadership of Professor Noboru, has carried out a lot of research on positioning technology, navigation methods, and control theory and has made great contributions to the field of agricultural robots.

Chen *et al*. (2021) took the Tie Niu 654 tractor and the Lovol TG1254 tractor as research platforms and carried out the electro-hydraulic transformation of the automatic steering system using GPS, electronic compass, gyroscope, monocular camera, and other positioning sensors. The positioning algorithm and navigation control algorithm were studied, and the basic automatic navigation of the tractor was realized. Ghthwan *et al.* (2020) designed a set of agricultural vehicle automatic navigation control systems composed of a GPS receiving module, display control terminal module, front wheel angle sensor, heading sensor, and automatic steering controller. The Dongfanghong X-804 tractor developed an automatic navigation control system based on the real-time kinematic-DGPS positioning system for the research platform, including an electronically controlled hydraulic steering device, a steering controller, a navigation controller, *etc*. Based on the fusion of the tractor kinematics model and the steering control model, the state equation of the straight-line tracking navigation control system was derived, and a cross-line headland steering control method was proposed (Rubanov *et al*., 2020).

Komaha and Yelenych (2020) took the Foton Oubao 4040 tractor as a research platform, carried out the electronic control transformation, and applied the scheme of driving the servo motor to control the automatic steering. The Leica TCA1105 automatic tracking locator was used to measure the position information, and the heading angle information was obtained through the fiber optic gyroscope (FOG) sensor. Sikarev *et al.* (2020) established an automatic control system for orchard tractors based on laser navigation. Laser scanners were used to collect fruit tree location information in real time, and the orchard tractor navigation path was planned using the least squares method. Li *et al.* (2019) developed a path-following control algorithm for a tracked robot based on a sliding mode variable structure algorithm and the control system, carried out a Matlab/Simulink and a joint simulation test, and the simulation results showed that the sliding mode variable structure algorithm could achieve better control.

Lian and Zhai (2021) presented a sliding mode controller for trajectory tracking of robotic manipulators with actuator faults, which was applied to control a two-link robotic manipulator in

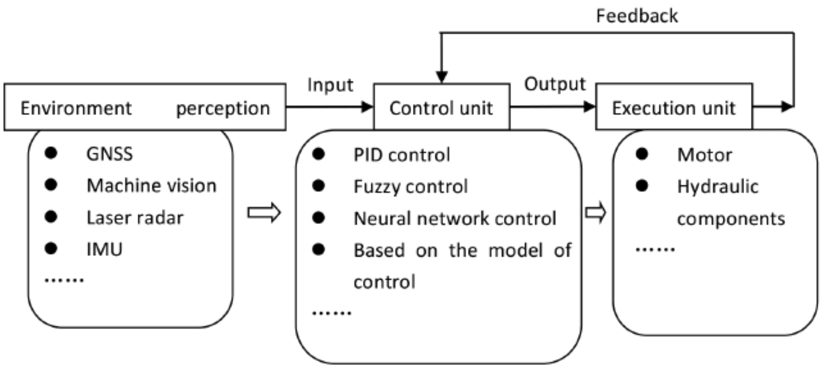

Figure 1. The control principle diagram of agricultural machinery automatic navigation. GNSS, global navigation satellite system; IMU, inertial measurement unit; PID, proportional-integral-derivative.

simulation, and the results validated the effectiveness of the control scheme. Zhu and Shen (2017) introduced the optimization algorithm combined with a back propagation (BP) neural network and the computed torque method of an automatic controller in the trajectory optimization of a precision agriculture robot, taking automatic control as the goal, and the result showed that it could effectively optimize the robot motion path and improve the overall operation efficiency of the robot; the system was stable and reliable; and the external environment interference factors had a strong adaptive ability to learn. Li *et al.* (2023) proposed a fractional order sliding mode fault tolerant (FSMFT) control based on a nonlinear fault observer, which was verified by Matlab/Simulink. Simulation results show that the FSMFT could effectively ensure the safety and reliability of the system, improve the velocity tracking control capability of the crawler plant protection robot driving system, and have a fast dynamic response with a smaller steady-state error. Based on the current research, considering the characteristics of the agricultural machinery common operation, neural network control can overcome the uncertainty and stagnation effects of the controlled objects to achieve precise control. This paper proposes a photoelectric automatic navigation control system for agricultural machinery based on a BP neural network and a dual-objective joint sliding mode control method based on lateral position deviation and heading angle deviation. It can realize the dual-objective joint control of lateral position deviation and heading angle deviation; the control overshoot is small, and the control deviation is small after reaching a stable state. It has strong adaptability to speed factors and basically meets the precision requirements of farmland operations.

Materials and Methods

Back propagation neural network

The BP neural network is a multi-layer feedforward neural network with one-way propagation. Its main features are the forward propagation of the signal and the reverse propagation of the error. The essence of the algorithm is the error between the output of the network and the expected output. Through BP “apportioned” to the weights and thresholds of each neuron, the predicted output of the BP neural network is continuously approached to the expected output through multiple iterations (Zinchenko *et al*., 2020). The structure of the BP neural network is relatively simple; its composition is shown in Figure 2. Each layer contains several neurons; different layers of neurons are fully interconnected through weights, and there is no connection between neurons in the same layer. In theory, it has been proven that the hidden layer is a one-layer neural network structure that can simulate any complex nonlinear mapping relationship (Bitar *et al*., 2020).

Neural network control can be based on nonlinear object modeling and overcome dynamic effects such as the uncertainty of the controlled object, lag, and so on. It does not need a precise mathematical model, has a strong ability for nonlinear fitting, and is easy to implement on a computer. Therefore, it can be applied to the automatic navigation control system of agricultural machinery to realize precise control. The navigational neural network structure of agricultural machinery constructed in this paper is shown in Figure 3. The neural network model is a 4-4-3 structure. There are four input units, which are the current lateral position y(k), the current heading angle φ(k), the current steering angle α(k), and the variation of Δα(k). There are three output units, which are the lateral position y(k+1), the heading angle φ(k+1), and the steering angle α(k+1) at the next sampling point.

Levenberg-Marquardt back propagation neural network

The BP network algorithm is a kind of traditional standard algorithm that uses the steepest descent algorithm. So the convergence rate of the BP neural network is generally slow. Directing against the deficiency of the above problem, this dissertation adopts a derived algorithm, the Levenberg-Marquardt back propagation algorithm, which is the combination of the gradient descending method and Gauss-Newton. There are both the global gradient descent method and the local convergence of the Gauss-Newton method to speed up the convergence rate of the optimization process.

The construction performance index is expressed in Eq. 1:

$$F(x)=\sum_{q=1}^{Q} e_q^T(x)e_q(x)=\sum_{h=1}^{N} \upsilon_h^2(x) \tag{1}$$

Among them, $h=(q-1)s^2+k$ constructs the vector $\upsilon,\upsilon^T=\left[e_{1,1}e_{1,2}\ldots e_{s^2,1}\ldots e_{j,q}\ldots e_{s^2,1}\right]$ so that $F(x)=\upsilon^T(x)u(x)$ here. The dimension of υ is $\langle N\times 1\rangle$ is. Among them, $N=s^2\times Q$.

Calculate the recursion sensitivity $\bar{S}^2$ as in Eq. 2:

$$\bar{S}_{j,h}^2=-\frac{\partial a_{k,q}^2}{\partial n_{j,q}^2} \tag{2}$$

Calculate the initialization sensitivity $\bar{S}^1$ as in Eq. 3:

$$\overline{S_{i,h}^1}=\overline{S_{i,h}^2}\times\omega_{j,i}^2\times\dot{F}^1(n_{i,q}^1) \tag{3}$$

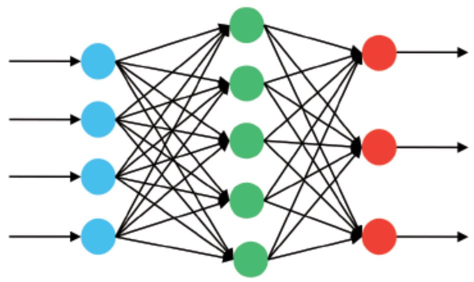

Figure 2. Three-layer neural network.

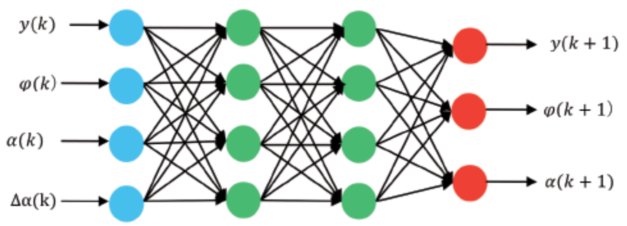

Figure 3. Structure of neural network.

By the chain rule, combined with matrix multiplication, we get Eq. 4:

$$\bar{S}^1=\bar{S}^2\times\frac{\partial n^2}{\partial n^1} \tag{4}$$

Compute the Jacobian matrix. The dimension of the Jacobian matrix is $\langle N\times n\rangle$. Among, $N=s^2\times Q$,$n=s^2(s^1+1)+s^1(s^0+1)$.

Calculate the variation of each weight and threshold as in Eq. 5:

$$x_{k+1}=x_k-[J^T(x_k)J(x_k)+\mu_k I]^{-1}J^T(x_k)\upsilon(x_k) \tag{5}$$

Repeat the above process. If the newly calculated performance index $F(x)$ is smaller than before, then (Eq. 6):

$$\mu_{k+1}=\mu_k/\theta \tag{6}$$

Go to Eq. 2, *i.e.* recompute the Jacobian. If the newly calculated performance index $F(x)$ is not less than the previous one, then (Eq. 7):

$$\mu_{k+1}=\mu_k\times\theta \tag{7}$$

Go to Eq. 5, where the initial value of μ_k is set to a small positive number, and θ is a constant greater than 1.

Automatic navigation path tracking control algorithm

Overall plan

In the established straight-line path tracking deviation model, the straight-line path tracking control is a dual-target joint control with lateral position deviation and heading angle deviation as the control targets (Nosov *et al*., 2021); its schematic diagram is shown in Figure 4. With the expectation that under the premise of realizing speed adaptation, taking into account the lateral position deviation state and the heading angle deviation state during the tractor-driving process. Therefore, a dual-objective joint sliding mode control algorithm based on lateral position sliding mode control and heading angle sliding mode control is designed (Liu, 2017). The algorithm for hybrid sliding mode control is shown in Figure 5.

Design of sliding mode controller

For the lateral position deviation control system, the output error is defined as in Eq. 8:

$$e_w=y_p-y_d \tag{8}$$

where y_d is the target lateral position deviation, m; for the linear target path, its value is 0, and w is the logo of the lateral position sliding mode controller. The control sliding surface of the design

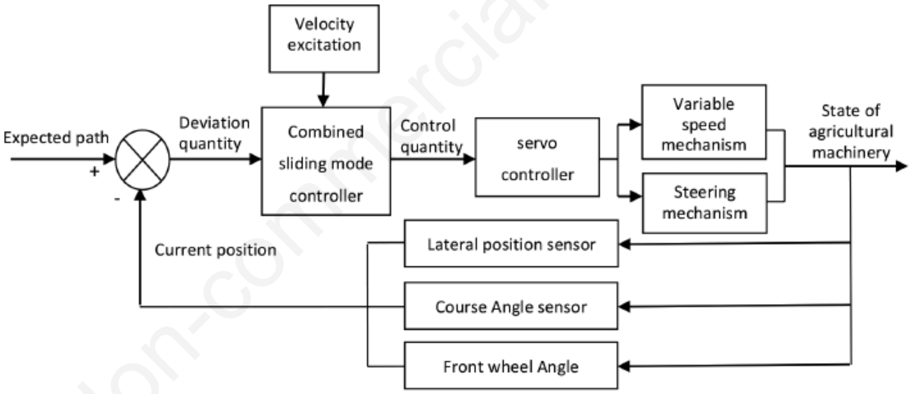

Figure 4. Schematic diagram of two-target combined control.

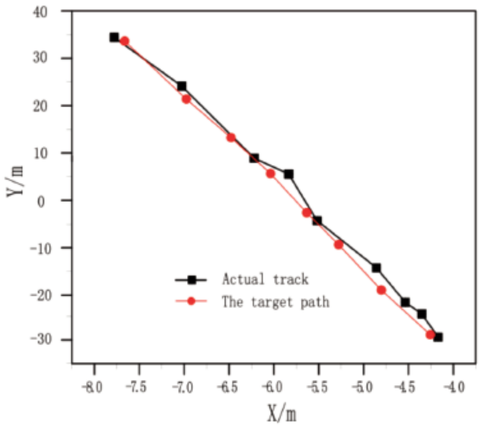

Figure 5. Path tracking trajectory.

lateral position deviation is (Eq. 9):

$$S_\omega=C_{l\omega}e_\omega+e^{\cdot}_{\omega} \tag{9}$$

where S_ω represents the sliding mode surface of the lateral position sliding mode controller, and $C_{l\omega}$ is the lateral position sliding mode coefficient, which is a positive value. Select the Lyapunov function $V(s_\omega)=s_\omega^2/2$ and take the derivation to get Eq. 10:

$$\dot{V}(s_w)=\frac{1}{2}\frac{d}{dt}s_w{}^2=s_w\dot{s}_w\leq-\eta_w|s_w| \tag{10}$$

where η_w is any small positive integer, $\eta_w>0$. According to Lyapunov stability theory, if the designed control system is stable, it must satisfy Eq. 10.

Taking the derivation of Eq. 9 and combining it with the straight-line path tracking deviation model, we can get Eq. 11:

$$\begin{aligned}\dot{s}_w&=C_{\lambda w}\dot{e}_w+e_w^{\cdot\cdot}=C_{\lambda w}(\dot{y}_p-\dot{y}_d)+(A_{11}+LA_{21})\dot{y}_p-V_C(A_{11}+LA_{21})\Delta\varphi_P\\&+(v_C-LA_{11}-L^2A_{21}+A_{12}+LA_{22})\Delta\dot{\varphi}_P+u_1-\ddot{y}_d\end{aligned} \tag{11}$$

Assuming that the system dynamic error is in the sliding mode plane, there is $s_w=\dot{s}_w=0$, and the equivalent control output after the system enters the lateral position sliding mode controller is (Eq. 12):

$$\begin{aligned}u_1&=\ddot{y}_d-C_{\lambda w}(\dot{y}_p-\dot{y}_d)-(A_{11}+LA_{21})\dot{y}_p+V_C(A_{11}+LA_{21})\Delta\varphi_P\\&-(v_C-LA_{11}-L^2A_{21}+A_{12}+LA_{22})\Delta\dot{\varphi}_P\end{aligned} \tag{12}$$

To reduce the influence of the controller jitter on the stability of the control system, and improve the robustness of the system to external disturbances, using the continuous saturation function $sat(s_W/\psi_W)$ to replace the sign function $\mathrm{sgn}(s_W)$ often used in the ideal sliding mode state, the equivalent output of the lateral position sliding mode controller can be obtained as in Eq. 13:

$$U_l=u_1-e_W sat(s_W/y_W) \tag{13}$$

Similarly, the equivalent control output of the heading angle sliding mode controller is (Eq. 14):

$$\begin{aligned}U_2&=\Delta\ddot{\varphi}_d-C_{\lambda h}(\Delta\dot{\varphi}_p-\Delta\dot{\varphi}_d)-A_{21}\dot{y}_p+V_CA_{21}\Delta\varphi_P\\&-(A_{22}-LA_{21})\Delta\dot{\varphi}_P-\varepsilon sat(s_h/\Psi_h)\end{aligned} \tag{14}$$

In the formula, the calculation method of $sat(s_W/\psi_W)$ is the same as that of the lateral position sliding mode controller, C_{lh} is the heading angle sliding mode coefficient, which is a positive value, and h is the identification of the heading angle sliding mode controller (Liu *et al*., 2020). In fact, it is difficult to achieve ideal control of lateral position deviation and heading angle deviation at the same time. Therefore, the mixing coefficient γ is introduced into the controller to adjust the mixing degree of the two control strategies, and the value of γ is [0, 1]. When $\gamma=0$, it is lateral position sliding mode control; when $\gamma=1$, it is heading angle sliding mode control; The value of γ between 0 and 1 needs to comprehensively consider the characteristics of lateral position sliding mode control and heading angle sliding mode control. The output of the joint sliding mode control strategy is (Eq. 15):

$$\delta=\delta\bullet d_2+(1-\gamma)\delta_1 \tag{15}$$

Results

Test platform

To analyze and verify the performance of the designed tractor's automatic navigation control system, the Futan Leiwo Oubao TG1254 tractor was used as the carrier. Based on the existing positioning system, steering system, and navigation control terminal, a field test platform for the tractor's automatic navigation control system was built.

Test scheme

The test site was in the north area of the Shangzhuang test station of an agricultural university. The test plot was a cotton planting field before sowing. The main contents included the tractor straight-line path tracking test under constant speed and variable speed conditions. In the tractor-path model, the predicted value of the dead position deviation at the control foresight distance L was 0 as the control target (Someswari *et al*., 2020). During the field test, the lateral position deviation and the heading angle deviation were calculated based on the tractor pose coordinates collected in real-time, and we monitored the lateral position deviation and heading angle deviation of the tractor center of mass at the current moment to evaluate the control effect of the tractor navigation automatic control system. The front sight distance L was set to 5 m, the sampling frequency of the system was 5 Hz, the control frequency was 5 Hz, and the sampling time was 80 s. Before the start of the experiment, a target straight-line path was first planned according to the actual field crop row. The position coordinates of the starting point of the path were collected statically through the combined navigation and positioning system, and the coordinates were converted to the navigation coordinate system. Two points were connected to get the target path. Then the tractor was moved close to the target path, the automatic navigation control mode was turned on, and the target path was tracked (Gu and Li, 2020). During this process, the position coordinates of the tractor were collected in real-time through the positioning system of combined navigation; that is, the trajectory of the tractor could be formed under the navigation coordinate system. At the same time, the real-time lateral position deviation and heading angle deviation of the tractor during the movement were calculated, and through the feedback signal from the front wheel steering angle sensor, the actual steering angle of the tractor was calculated. The collected data was calculated and analyzed through the controller and navigation control terminal (He *et al.*, 2021; Zayats and Malevich, 2021).

Straight-line path tracking test under the conditions of constant speed

The tractor traveled at a constant speed in A_2 gear (v=0.55 m/s), B_1 gear (v=0.80 m/s), and B_2 gear (v=1.05 m/s) respectively, for straight-line path tracking. Statistical analysis was performed on the test results, and the control effect of the test was evaluated by the maximum value and standard deviation of the steering angle, the mean absolute deviation and maximum deviation of the lateral position deviation, and the maximum deviation and mean absolute deviation of the heading angle deviation. The statistical analysis results are listed in Table 1.

It can be seen from Table 1 that, under the constant speed of different speed conditions, the maximum deviation of the lateral position deviation is 10.50 cm, and the average absolute value deviation can be kept within 3.40 cm. The maximum deviation of the heading angle deviation is 3.86°, and the average absolute value deviation is kept within 1.60°. The maximum value of the actual rotation angle is 7.62°, and the standard deviation of the fluctuation is within 2.87°. Further analysis of the front wheel steering angle of the tractor shows that after reaching a steady state, the swing range of the front wheel steering angle is within 3°, and the standard deviation of the swing is 0.80°.

Linear path tracking test under the conditions of variable speed

In the straight-line path tracking test under the conditions of variable speed, the tractor was in B_1 gear, and the opening of the throttle was controlled to change continuously. Simulating the variable speed conditions of the tractor, the target straight-line path was tracked. The test results are shown in Figures 5-8.

It can be seen from Figures 5-8 that under the conditions of variable speed, when the tractor is tracked with the automatic control of the linear path, the maximum deviation of the lateral position deviation is 12.7 cm, and the average absolute deviation is kept within 4.88 cm. The maximum heading angle deviation is 5°, and the average absolute deviation is kept within 2°. The maximum value of the actual rotation angle is 3.13°, and the standard deviation of the fluctuation is within 0.84°. In summary, under the conditions of constant speed and variable speed, the joint sliding mode control method designed by the authors can realize the dual-objective joint control of lateral position deviation and heading angle deviation; the controlled overshoot is small; the controlled deviation is small after reaching a steady state; and the adaptability to the speed factor is strong, which basically meets the accuracy requirements of farmland operations.

Discussion

Comparative analysis

Compared with the existing research, the maximum lateral deviation of straight-line path tracking is 15 cm (Pei *et al*., 2011); the maximum lateral deviation is 12 cm, and the maximum heading angle deviation is 1.1° (Keli *et al*., 2016). Analysis shows that, using the joint sliding mode control method designed by the authors, the maximum lateral deviation of the straight-line path tracking control is smaller than the experimental results of Pei *et al.* (2011) and Keli *et al.* (2016), and the heading angle deviation is larger than the experimental results of Keli *et al.* (2016). This is because, in the field test process, the value of the mixing coefficient focuses on the control of the lateral position deviation, which causes the heading angle deviation to become larger. In addition, the proportional-integral-derivative-based automatic navigation control method of the orchard tractor and the combined control method of the tractor speed and routes based on the optimal navigation, which was carried out under the approximating constant speed condition of the tractor, make the adaptive control of speed conditions difficult to realize during the operation of the tractor. However, the joint sliding mode control method proposed by the authors can basically realize self-adaptive control under the conditions of uniform and variable speed. In future research, the value of the mixing coefficient g will be further adjusted through simulation and field experiments, which will improve the linear path tracking control effect based on the speed-adaptive tractor automatic navigation control method.

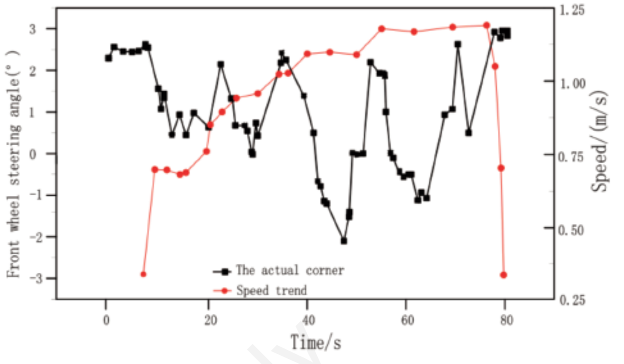

Figure 6. Front wheel steering angle.

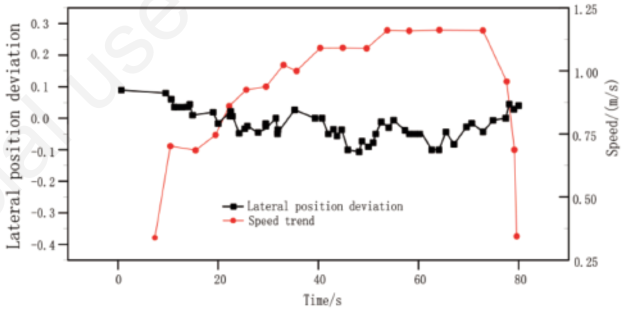

Figure 7. Lateral position deviation.

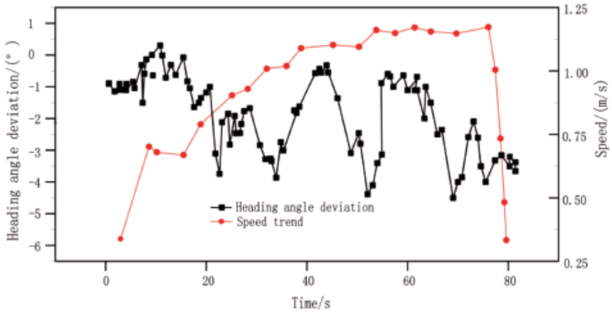

Figure 8. Heading angle deviation.

Table 1. Analysis of test results under the conditions of constant speed.

Speed (m/s)	Lateral position deviation (cm) Mean absolute deviation	Lateral position deviation (cm) Maximum value	Heading angle deviation (°) Mean absolute deviation	Heading angle deviation (°) Maximum value	Actual steering angle (°) Mean absolute deviation	Actual steering angle (°) Maximum value
0.55	3.4	10.5	1.01	3.86	6.83	1.84
0.8	1.7	3.8	0.86	2.23	4.96	1.77
1.05	2.7	4.7	1.60	2.75	7.62	2.87

Conclusions

On the one hand, neural network control has a strong self-learning function and strong nonlinear fitting ability, which can improve the environment adaptability and the field processing ability of the controller. On the other hand, the driving environment of agricultural machinery is more complex. So, this paper proposes a photoelectric automatic navigation control system for agricultural machinery based on a BP neural network. The structure of a neural network for controlling agricultural machinery automatic navigation was constructed.

Furthermore, the joint sliding mode control method was proposed, and a schematic diagram of two-target combined control was constructed. The field test was conducted to verify the reliability and control effect of the designed automatic navigation control system. The maximum deviation of the lateral position deviation was 12.7 cm; the average absolute deviation was kept within 4.88 cm; the maximum deviation of the heading angle deviation was 5°; the average absolute deviation was kept within 2°; the maximum value of the actual rotation angle was 3.13°; and the standard deviation of the fluctuation was within 0.84°. They could meet the requirements of automatic navigation operations. Under the conditions of constant speed and variable speed, it could basically realize the adaptive control of speed conditions. In future research, through simulation and field experiments, the value of the mixing coefficient will be further adjusted, which will improve the linear path tracking control effect based on the speed-adaptive tractor automatic navigation control method. At the same time, curve tracking control will be considered the research object in the next step. For the increasingly mature automatic navigation system, in the qualitative and quantitative aspects of navigation accuracy, there is still no systematic evaluation method or relatively unified evaluation standard. Therefore, it is also necessary to develop a set of automatic navigation evaluation systems and industry standards based on "precision agriculture" to improve the evaluation of the accuracy of the navigation system, which should also be the direction of our researchers in the field of automatic navigation positioning and control.

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