Design of Quality Control System for Fighting Machine Operation Based on Beidou Navigation

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Abstract. In view of the serious waste and pollution of pesticide spraying, this study developed a sprayer flow control system based on the high-precision Beidou satellite navigation system software. The system uses a high-precision Beidou satellite navigation system R21 positioning receiver. Acquires the vehicle in real-time through the built-in GNSS board of the vehicle. The speed and position information are analyzed and processed by the vehicle intelligent control terminal, and sent to the flow control system corresponding control commands, so that the flow rate of the spray can be controlled according to the speed of the vehicle to realize the electrification control of the spray operation machine. Based on the field operation requirements of the fighting machine, an automatic navigation system path tracking control algorithm is designed to make the system complete the route of the line and curve. The real-time information collection of the work is carried out by using the APP carried by the industrial tablet, and the vehicle inherent parameter information is used to interface with the agricultural information platform through the Internet to realize the online monitoring of the spraying operation parameters. At the variable forward speed, tested in a farmland environment. The test results show that the designed automatic navigation path control system and spray flow control system have good working accuracy values and stable operation, which can meet the requirements of farmland environment spraying operation.

1. Introduction
Agricultural machinery is an important part of agricultural production. The development of advanced technology of agricultural machinery is one of the important measures to ensure high yield and good harvest of agriculture [1-2]. The traditional spraying machine has no corresponding flow control system, and the spraying precision is directly affected by the operator, and the spraying is uneven. Therefore, the research on the high-precision and high-uniformity of the spraying operation technology has become an urgent need for the modernization of the plant protection agriculture [3].

The vehicle intelligent control terminal is composed of a microcomputer system with a color display screen, and accesses the high-precision positioning information of the receiver upwards to obtain real-time dynamic positioning information. The vehicle speed is determined by combining the simplified two-degree of freedom vehicle steering model design. The linear path tracking control algorithm with position deviation and heading deviation as state variables is designed [4]. Based on the pure tracking model, the curve path tracking control algorithm is designed to issue instructions to...
the flow control system to control the flow of pesticide spraying. At the same time, by providing a graphical display interface, the working status information of the vehicle is displayed, and the setting function of the auxiliary navigation AB line is provided, thereby effectively avoiding the problems of missing tillage and re-cultivation. It is also possible to ensure that the sprayer operates at a constant spray rate by setting an initial flow threshold. Develop plant protection machinery operation quality information collection monitoring and operation quality evaluation system, support spray operation speed and flow, pressure and boom, medicine box status and other operational parameters online monitoring, where in the operation speed measurement error $\leq 0.2\text{m/s}$, flow measurement error $\leq 3\%$, pressure measurement error $\leq 5\%$; Establish a spray operation monitoring cloud platform to achieve the analysis of the operation quality parameters such as spray operation area, work repetition rate and leakage rate. At the same time, the system controls the flow according to the speed of the agricultural machinery operation, the flat panel visual operation, and the auxiliary technicians fight drugs.

2. Fighting machine operation system structure
The fighting machine equipment based on the Beidou navigation operation system is composed of a high-ground gap fighter main body, a machine-electric-liquid equipment and controller, through integrated receiver, flow valve block and a wireless monitoring display terminal, as shown in Figure 1. Among them, the high-gap fight drugs machine is in the form of four-wheel reverse steering, the wheels are of the same size, and the tires are solid tires. The spray bar consists of three sections: left, center and right, and each spray can be independently controlled.

![Figure 1. Fight drugs Beidou navigation operating system.](image)

Beidou satellite navigation system is the core of the navigation control system, including the navigation information acquisition and processing module, the automatic navigation controller and the control execution mechanism. Its structure and function are shown in Figure 2.

![Figure 2. Navigation controller function structure diagram.](image)
3. Advantages and innovations of project plans and technical routes

3.1. The Key technologies used in this project

3.1.1. Beidou/GNSS high-precision positioning system application. According to the high-precision GNSS positioning system, the position information and speed information of the device can be provided in real time, and based on the position information, the device operation information can be returned in real time, and relevant parameters are provided for informationization. Based on the speed information, data can be provided for the operation of the valve group. On the other hand, based on the high-precision positioning technology, the conversion of the software algorithm can provide the user with the function of assisting navigation, which is easy to ensure the efficiency of the operation and reduce the problems of repeated spraying.

3.1.2. Variable speed flow control algorithm. In addition to hardware, the main technology of the system lies in the software built in the terminal equipment. The mature software algorithm provides technical support for the use of the equipment. Based on the acquisition of speed information, the operation of the valve group is controlled to achieve accurate flow. At present, most of the market is based on physical buttons and digital tubes to visualize operations. The control accuracy and ease of operation are also far from the visual software operation used in this project. And based on continuous optimization of big data, subsequent version upgrades and algorithm upgrades will further improve the control accuracy of the system.

3.2. The Innovations in this project.

The implementation of the project's program has also made relevant innovations on the basis of the existing ones. Relevant innovations are mainly reflected in the following aspects.

3.2.1. Speed information collection. This project is based on a stable and reliable satellite positioning chip with high speed accuracy and accurate positioning information. In comparison, other products have two ways to obtain speed. One is to obtain the speed by means of sensors. In this way, the speed collection value has a large external influence, and has a great relationship with the installation. Degree affects the accuracy of its speed acquisition; the other is the installation of inexpensive positioning modules, such modules are not accurate enough, the data has jumps, directly affecting the control accuracy of the fight.

3.2.2. Operation terminal. The system can be equipped with different size flat plates and equipped with corresponding control operation software. Most of the products on the market are mechanical control switch integrated controllers, which display simple parameters through simple digital tube and Interaction, its function expansion, user interaction, information acquisition and our products have a greater disadvantage.

3.2.3. Software operation. The system is equipped with special operation software, which has natural advantages in the realization of the fight-doping function, the entry of parameters, and the acquisition of information and the display of data. And the software comes with an auxiliary navigation function, which can guide the user to perform higher precision work while realizing automatic drug control. At the same time, in the future function expansion, other functions related to assisted navigation, such as induction point function, linear navigation, and curve navigation, can be transplanted. The advanced operation mode that can be extended can also mark the plots, such as the plots with serious diseases, and increase the flow rate of drugs after entering these plots. Therefore, the combination of APP gives the system unlimited expansion possibilities. It is also a major innovation point of this project.
3.2.4. Supporting informational return. In the future, the trend of the country must be related to the supervision of the workload, location and quality of the drugs, and it is possible to carry out relevant subsidies. Our comprehensive information management platform supports the access of drug-fighting data. The mobile APP, background management system and equipment terminal constitute the informationization of the drug-making equipment.

4. Design of the Fighter control system

4.1. The Path tracking algorithm control

4.1.1. Straight path tracking control. Vehicle kinematics and steering control are important aspects of navigation control systems based on vehicle handling characteristics and vehicle motion. Because of the high center of gravity and narrow tires, the high-ground gap spraying machine in the field operation process, especially in the paddy field environment, the lateral deviation caused by the terrain fluctuation is easy to cause the body to produce side slip and affect the navigation control accuracy, which is represented by the yaw angle, disturbance with positional deviation. In the system, because the dual satellite antenna navigation and positioning system is equipped to achieve high-precision direct observation of yaw angle and positional deviation, the yaw angle of the vehicle body is not used as the motion state parameter in this study. At the same time, the medicine machine is in the form of four-wheel reverse steering and the tire specifications are the same. During the small angle steering, it can be assumed that the dynamics of the tires are basically symmetrical, and the wheel angles are approximately equal, and the two wheels on the axle can be replaced by one wheel. Based on the above characteristics, the four-wheel reverse steering vehicle model is simplified to the two-wheeler model in this study, as shown in Figure 3.

![Figure 3](image_url)

**Figure 3.** Simplified kinematics model of four-wheel steering sprayer.

The vehicle body coordinate system is established in the center of the vehicle body, and the kinematic differential equation description of the fight drugs is obtained in the navigation coordinate system, as shown in equations (1) to (2).

\[
\frac{d\psi}{dt} = \frac{V}{R} = 2V \frac{\tan \theta}{L}
\]

\[
\frac{dY_e}{dt} = V \sin \psi
\]

Where \(\theta\) is the wheel angle, rad; \(\psi\) is the yaw angle, rad; \(Y_e\) is the position deviation, m; \(L\) is the wheelbase, m; \(R\) is the turning radius, m; \(V\) is the body speed, ms\(^{-1}\); \(t\) is time, s.

\[
\theta = -k_1 \psi - k_2 Y_e
\]
Where $k_1$ is the yaw angle feedback coefficient and $k_2$ is the position deviation feedback coefficient. It is verified by experiments that the path tracking performance is stable when the pole of the closed-loop system is set to 0.5. The state feedback controller for linear path tracking is obtained by analyzing the characteristic polynomial of the system.

$$\theta = \frac{L\theta}{2V} - \frac{L\theta_e}{8V^2}$$

Because the platform cannot directly measure the center point position of the vehicle, and the body sway will cause the measurement "bar arm effect", based on the kinematics model of the sprayer, the main antenna position is projected to the ground projection of the vehicle center when the position information is acquired. Point. In the electro-hydraulic steering mechanism, the wheel angle following control has significant hysteresis characteristics [5]. For this purpose, the wheel angle control algorithm was designed based on the characteristic parameters of the electromechanical-liquid steering system, and the performance of the algorithm was verified by tracking the sine wave signal under the action of the spraying machine. As shown in Fig. 4, the wheel tracking signal has an amplitude of 1.5° and a period of 1.5s. The following angle curve shows a stable phase lag with respect to the command angle curve. The inflection point has no oscillation and the overshoot is small. The statistical following delay average is 0.2s, which determines the wheel angle control delay characteristics under the control system.

In the navigation control system, the delay of the wheel angle control causes the correction of the vehicle state to lag, resulting in a decrease in system stability, which is manifested by an increase in navigation heading deviation and positional deviation. Under the linear path tracking, the four-wheel reverse steering mechanism of the spraying machine makes the trajectories of the front and rear wheels have good homogeneity, and the motion trajectory can be approximated as the phase lead of the front wheel relative to the rear wheel with the magnitude $\tau = \frac{L}{V}$. Based on this, this study puts the antenna projection position forward and the distance is $d = V\tau$ to compensate the lag of the wheel angle control. The coordinate conversion formula is as shown in equation (5). This method has achieved results in practical applications, improving control accuracy and stability.

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix}_{\text{REF}} = \begin{bmatrix} N \\ E \\ D \end{bmatrix}_{\text{REF}} - E^{-1} \begin{bmatrix} \psi \\ \theta_p \\ \theta_r \end{bmatrix} \begin{bmatrix} r_x \\ r_y \\ \tau \end{bmatrix}$$

Where N-E-D is the main antenna coordinate, $x$-y-z is the vehicle coordinate, $\theta_p$ is the vehicle pitch angle, rad; $\theta_r$ is the roll angle, rad; $r_x$-$r_y$-$r_z$ is the coordinate of the main antenna in the vehicle body coordinate system.

Figure 4. Wheel angle tracking control.
4.2. Straight path tracking control

4.2.1. Ground steering control. The ground steering control algorithm is designed based on the pure tracking model, as shown in Figure 5: 1) Set the forward looking distance to \( D_h \), the current positioning coordinate to \( P_c(x_c, y_c) \), the current heading angle of the vehicle to \( \Phi_C \), and the closest point of the curve path discrete point distance \( P_c \) to \( P_n \); 2) Search point \( P_{n+k}(x_{n+k}, y_{n+k}) \) in the direction of the curve path from \( P_n \) to \( P_{n+k} \); 3) Target heading angle \( \Phi_{aim} \) of the spraying machine, as in equation (6).

\[
\phi_{aim} = \frac{180}{\pi} \arctan \left( \frac{y_{n+k} - y_n}{x_{n+k} - x_n} \right)
\]

\[\delta = k_f (\Phi_{aim} - \Phi_c) \]  

Where \( k_f \) is the decision wheel angle factor.

4.3. Spray quality control method

The flow control system adopts Beidou/GNSS satellite positioning technology to obtain accurate speed information in real time, obtain speed information in real time, and automatically adjust the spraying rate in real time according to the vehicle speed, spray width and target spray volume, and increase the spray speed when the speed is fast. When the amount is slow, the spray volume is reduced to ensure uniform application of the unit area, which can effectively prevent the pesticide from over-influencing the growth of the crop or the insufficient dose to achieve the control effect. The system can ensure that during the operation, the vehicle starts spraying, and the parking stops automatically, and the spraying amount is automatically adjusted according to the change of the vehicle speed, so that the spraying amount per unit area is kept uniform, no heavy spraying, no leakage, and the section Increase efficiency.

The flow control system adopts a high-performance flow control valve group, as shown in Figure 6. The product characteristics of the valve group are as follows: the control valve group pressure regulating proportional valve adopts PWM technology, and the control is more precise; the high-precision flow meter adopts fast response and accurate flow monitoring, and at the same time According to actual needs, the flowmeters with different ranges can be replaced to meet different operation requirements.
The filter can effectively filter impurities and reduce the probability of nozzle clogging; the segmented valve is calibrated and refluxed, the pressure stability is good, and the spray quality is high. The automatic operation query list of the spraying machine is designed, as shown in Table 1.

**Table 1.** Integrated autonomous operation quality control strategy.

| Working condition   | Valve group control | Throttle control | Spray pump control | Left lever control | Middle rod control | Right lever control | speed control | Operation management | Operational statistics |
|---------------------|---------------------|------------------|-------------------|-------------------|--------------------|--------------------|--------------|----------------------|------------------------|
| Straight line navigation | +                   | H                | +                 | /                 | /                  | /                  | +            | /                    | /                      |
| Left stick spray    | /                   | /                | +                 | +                 | -                  | -                  | +            | +                    | +                      |
| Rod spray           | /                   | /                | +                 | -                 | +                  | -                  | /            | +                    | +                      |
| Right shot          | /                   | /                | +                 | -                 | +                  | -                  | +            | +                    | +                      |
| Stop navigation     | -                   | L2               | -                 | /                 | /                  | /                  | -            | -                    | -                      |
| RTK exception       | -                   | L2               | -                 | /                 | /                  | /                  | -            | /                    | -                      |
| Job completion      | -                   | L2               | -                 | /                 | /                  | /                  | +            | +                    | +                      |

4.4. *Operation terminal and monitoring platform design*

The project does not use the physical buttons that are commonly seen on the market for flow control. With built-in software applications, flow control and traffic information are displayed in the same plane, easy to view and operate, and support subsequent iterative updates of Software functions. Use the WeChat app service applet to upload the basic information of the online drug fight device to the server, and interact with the online detection device and the server; interact with the APP through the network communication module in the vehicle terminal tablet, and the industrial tablet is equipped with the APP for real-time location, speed, and The information collection of flow, pressure, boom status and medicine box status is combined with the vehicle's inherent parameter information through the Internet to connect with the agricultural information platform to realize the online monitoring of the pesticide operation parameters, and provide data for the effective management of plant protection operations. The operation interface as shown in the figure 7, the WeChat platform as shown in Figure 8.
5. Test experiment

5.1. Test procedure
The navigation control system guides the spraying machine to automatically complete tracking of the linear walking and the ground turning, the high and low speed switching, the spray bar spray control, etc., when the vehicle starts, spraying, stopping or automatically completing the operation Stop and turn on the automatic alarm mode when the pressure is abnormal. 2) After the spraying operation is completed, the navigation process parameters are uploaded to the cloud platform, including pose information, tracking deviation, working area, leak rate, re-spray rate, And other status flags.

5.2. Test data
In the test field, four 100m long sections were selected, and the vehicle spraying mechanical system was used variable speed spraying. One of the four lanes was selected as the control group using the traditional method, while the other three used the system. Each section was randomly selected from 10 points as samples, and the error of the number of acres in the statistical system spraying operation was the number of flow errors, and the route offset distance, then evaluate the navigation path tracking control effect, where in the route offset distance is the distance between the center of the front wheel of the sprayer and the planned route.
Table 2. Statistics on the results of operation test on four runways.

| Experimental group number | Mut error | Mut flow error | And route offset distance | expected result |
|---------------------------|-----------|---------------|--------------------------|-----------------|
| Control group             | 4.01%     | 4.2%          | 5cm                      | qualified       |
| Experimental group 1      | 3.36%     | 2.1%          | 2.50%                    | perfect         |
| Experimental group 2      | 3.59%     | 1.72%         | 3.60%                    | perfect         |
| Experimental group 3      | 3.28%     | 2.51%         | 3.32%                    | perfect         |

The experimental results as shown in Table 2. The error of the number of acres in the spraying operation is less than 4%, the error of the flow rate per mu is about 3%, and the deviation distance of the route is 2.50–3.60cm, which can meet the operation requirements.

6. Conclusion
Based on the Beidou navigation positioning sensor paper, this paper designs the automatic spraying control system of the fight drugs. Experiments show that the system can automatically complete the spray path planning. The designed path tracking controller can guide the straight-line driving and ground steering of the sprayer. The controller can control the sprayer machine to automatically complete the spray control, which can ensure the amount of spray and the total spray volume at different speeds. The information platform integrates flow control related data, and can realize functions such as job location monitoring, job information statistics, and historical job track viewing.

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