Design of Control Platform for Pineapple Pesticide Application Machine

Wang Runtao*, Chen Zhigui, Liu Jintang, Mo Chengjie, Peng Jiajun, Ye Tingwei, Zhang Yuanshan, Huang Jiner, Ma Zhaodong

School of Electronic and Electrical Engineering, Lingnan Normal University, Zhanjiang, Guangdong, China

**Corresponding author*

Abstract: In response to the waste and pollution issues during pineapple pesticide application, this article designs a pineapple pesticide application machine control platform based on STM32F103ZET6 microcontroller. The device utilizes Hall sensors and GPS modules to obtain speed data, and uses Kalman filtering fusion algorithm to fuse the data, reducing the maximum standard deviation of speed data from 0.433km/h to 0.173km/h. By constructing a PID algorithm and adjusting the output flow rate of the water pump, the error is controlled within 4%, ensuring that the spraying amount meets the standard and achieving precise spraying, reducing waste and pollution problems during pineapple spraying.

Keywords: Spray; Pineapple; Mechanical Platform; Kalman Filtering; PID Control

1. Introduction

With the development of technology and the transformation of agricultural production methods, agricultural automation has gradually become an inevitable trend in the development of modern agriculture. Automated spraying technology is one of the important components of agricultural automation. The traditional spraying method often requires a large amount of manpower and material resources, which is not only costly, but also due to the varying technical levels of operators, there are often problems such as uneven spraying and pesticide waste, seriously affecting the spraying effect and crop quality. According to statistics, the annual use of pesticides in China is about 150 tons. The extensive use of pesticides has caused problems such as environmental pollution and high dependence of crops on pesticides. According to incomplete statistics, the average effective utilization rate of pesticides in China is 20% to 25%, and most pesticides are lost to farmland. Agricultural automation spraying technology can effectively solve these problems, improve spraying efficiency and pesticide utilization.

The traditional pineapple production process mainly relies on manual spraying for pineapple plant protection, which is inefficient and dangerous, and can no longer meet the requirements of modern plant protection operations. This project focuses on the wide ridge characteristics of pineapple fields and designs a pineapple spraying machine control platform. This device matches the vehicle speed and spraying flow rate to achieve precise spraying, which can improve spraying efficiency and reduce costs. It has broad application prospects.

2. System Framework

The control system of pineapple pesticide applicator is based on TM32F103ZET6 as the core component, mainly composed of TOFSense-M laser radar dot matrix module, BD-280GPS positioning module, BLDC driver, HC-05 Bluetooth module, DC brushless motor, 57HB6C stepper motor, SL-DP16 high-pressure water pump, LCD1602 LCD screen, etc. Sensors are mainly used for signal acquisition of detection indicators, DC brushless motors are used for the operation of pineapple pesticide dispensers, SL-DP16 high-pressure water pumps are mainly used to control water pressure, and data exchange is carried out on mobile phones through HC-05 Bluetooth modules. The 3D modeling diagram of the pineapple pesticide application platform is shown in Figure 1.

The detection system consists of GPS module, Hall sensor, and laser radar dot matrix module. The GPS module obtains the speed of the sprayer, and the TOF LiDAR dot matrix obtains crop height information. The environmental information obtained by the detection system will be analyzed and fused by the main control system. The main control system is composed of STM32 microcontroller, which communicates with the mobile phone through Bluetooth and can send data to the mobile phone for data analysis. The main control microcontroller will perform algorithm analysis on the received environmental information, accurately restore the driving speed of the sprayer, and thus finely control the execution system. The execution system consists of a brushless DC motor, a high-pressure water pump, and a stepper motor. The brushless DC motor controls the driving speed of the sprayer, the high-pressure water pump controls the flow rate of the nozzle, and the stepper motor controls the spraying height. The pineapple spraying machine adopts the Kalman filtering algorithm to fuse the GPS module to obtain the speed of the spraying machine and the wheel speed captured by the pulse, achieving accurate analysis of the walking speed of the pineapple spraying machine. The DC brushless motor controlled by PID can achieve precise speed control, allowing the sprayer to travel at a constant speed. The overall framework of the system is shown in Figure 2.

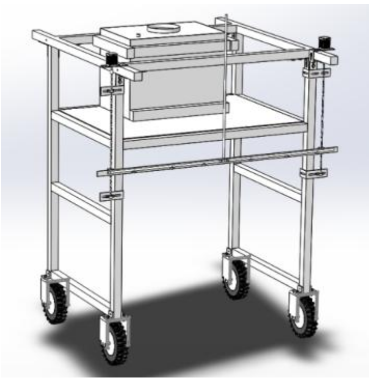

Figure 1. Pineapple Pesticide Application Machine Platform

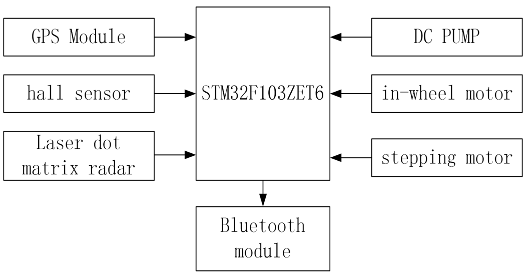

Figure 2. System Block Diagram

3. System Hardware Design

3.1 Selection of Main Control Chip

The control platform core of the pineapple pesticide applicator is the STM32F103ZET6 microprocessor, which is the analysis and control core of the entire pineapple pesticide applicator. The STM32F103ZET6 adopts the ARM Cortex-M3 core architecture, with a maximum clock frequency of 72MHz and a data bus width of 32 bits. This microcontroller has 512KB flash memory and 64KB SRAM, with a large storage capacity that can store a large amount of data and code. Its internal chip supports 2.0-3.6V power supply and can be driven by a 5V input/output interface. The working temperature requirement is between -40 ℃ and 85 ℃, and three low-power modes are provided: standby, stop, and sleep. This provides significant energy-saving advantages, and users can choose the appropriate energy-saving mode according to their needs. STM32F103ZET6 supports multiple peripheral interfaces, including USB 2.0, CAN, SPI, I2C, USART, SDIO, ADC, etc. These interfaces can communicate with various external devices, expanding the functionality of the microcontroller. It supports serial debugging and JTAC debugging modes, and has a highly integrated design that reduces the need for external components.

3.2 GPS

This spraying device adopts the BD-280 GPS positioning module (see Figure 3) to obtain the real-time speed of the machine. Based on the positioning technology of BD-280GPS module, the speed accuracy can reach 0.1m/s, which can accurately measure the real-time speed of the spraying device. It can also integrate filtering algorithms to make the calculated speed information closer to the real speed, thus making the collaborative control of spraying more accurate.

Figure 3. GPS Module

3.3 Water Pump

The SL-DP16 high-pressure water pump used in this device can convert low water pressure into high water pressure, providing high flow rate. The pump has efficient conveying capacity and reliable performance. In this work, precise spraying is achieved by measuring the speed and adjusting the pressure and flow rate of the high-pressure water pump according to the speed, improving the effective utilization rate of pesticides and reducing environmental pollution, as shown in Figure 4. The device uses L298 to drive the DC water pump and utilizes the timer in STM32F103ZET6 for PWM control. The PWM signal is output through the PA9 pin of the microcontroller, and the duty cycle is changed by adjusting the preset value of the timer, thereby changing the output voltage of the L298 module to control the water pump voltage and the flow rate of pesticide application.

Figure 4. Water Pump

3.4 In-Wheel Motor

The DC brushless motor used in this device can control the speed and direction by controlling the current, thereby achieving mechanical motion. At the same time, it has the characteristics of high precision and fast response, so we use a DC brushless motor to control the driving speed of the spraying device. Rated torque of DC brushless motor: 4N. m, maximum torque: 7N. m. In mechanized spraying, in order to load more pesticides at once and improve the spraying efficiency of the machine, the torque of the motor needs to be large enough to drive the load, as shown in Figure 5.

Figure 5. In-Wheel Motor

3.5 Stepper Motor

One of the advantages of the DQ-57HB76C stepper motor used in this device is that it can rotate in a very precise manner, which makes it popular in applications that require continuous high precision and repeatability. This is due to the fact that its rotation angle can be controlled within small steps, which is not possible in other types of motors. In addition, it also has characteristics such as high torque, high starting current, low noise, and low vibration, which make it suitable for many different applications. The DQ-57HB76C stepper motor is a type of motor that can achieve high precision and controllable rotation. Although it has some limitations, it performs well in applications that require repeatability and stability, and can meet many different needs, as shown in Figure 6.

Figure 6. Stepper Motor

4. Software Design of the System

4.1 Extraction of GPS Data

To extract GPRMC data from GPS signals and obtain speed information, it is necessary to first initialize the serial port and set the baud rate to match the baud rate and determine whether GPS signal data can be received. After receiving GPS signal data, it is necessary to check whether the GPRMC data is valid, extract the speed data from it, and store the obtained data in an array. Note that the speed is measured in nautical miles, and unit conversion is needed to obtain the speed value in kilometers per hour. The extracted speed data can be used in subsequent applications. The program flow extracted by the GPS program is shown in Figure 7.

4.2 Pulse Frequency Detection

The pulse frequency detection pineapple pesticide applicator uses a DC brushless motor, which is equipped with a three-phase Hall sensor. When the magnetic pole on the motor rotor rotates through the Hall sensor, a Hall potential signal is generated. As long as a microcontroller is used to measure the frequency of the pulse of the Hall potential signal, the speed of the wheel can be calculated. There are various methods for measuring frequency, mainly including speed measurement (M) and periodic speed measurement (T). However, the speed measurement method used in this design is the speed measurement method: it calculates the number of pulses output by the Hall sensor at the same time T to calculate the speed. Assuming that the Hall sensor outputs M pulses within T time, the formula is:

$$W=\frac{M}{NT} \tag{1}$$

N--Hall sensor outputs N pulses per revolution
W--rotational speed, unit (r/s)

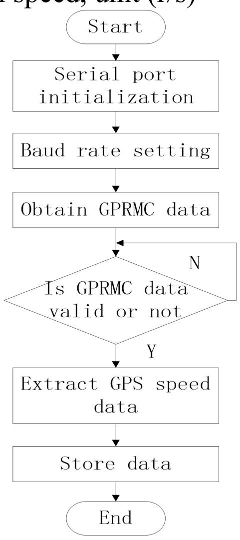

Figure 7. GPS Program Flowchart

Calculate the speed based on the relationship between rotational speed and speed, using the following formula:

$$V = WR \tag{2}$$

V-- Speed
R--Wheel radius, R=10cm

4.3 Kalman Filter Fusion Velocity Data

In this article, we use two different sensors to detect the speed of an object. The first method is to obtain the movement speed of the pineapple pesticide applicator through the GPS positioning module, and the second method is to calculate the speed by measuring the rotation speed of the motor through the Hall sensor of the DC brushless motor.

Due to the objective movement characteristics and external noise interference of sensors, there is a significant difference between the obtained data and the true value. Therefore, this article uses Kalman filtering of wheel speed and GPS speed to obtain fused data, that is, two sensors are used to measure the vehicle speed. Therefore, this article uses recursive Kalman filtering to fuse the vehicle speed of the two sensors.

The estimation process of Kalman filter can be represented by the following formula:

① Prediction stage:

State variables:

$$X_k=AX_{k-1} \tag{3}$$

X_k is the predicted estimated speed of the pineapple pesticide applicator at time k; X_{k-1} is the estimated speed of the pineapple pesticide applicator at time k-1; A is the state transition matrix.

Error covariance matrix:

$$P_k^- = AP_{k-1}^- A^T + Q \tag{4}$$

P_k^- is the predict covariance at time k; P_{k-1}^- is the system state covariance at time k-1; Q is the system process noise; A is the state transition matrix.

In the prediction phase, Kalman filtering predicts the values of system state variables by using the dynamic model of the system and estimating the error covariance matrix. The reliability of the prediction results depends on the size of the error covariance matrix, that is, the larger the covariance matrix, the lower the reliability of the prediction results.

② Update phase:

Kalman gain:

$$K_k = \frac{P_k^- H^T}{HP_k^- H^T + R} \tag{5}$$

K_k is the Kalman gain coefficient; H is the observation matrix; R is the observing noise variance.

State variables:

$$\widehat{X}_k = X_k + K_k(Z_k - HX_k) \tag{6}$$

$\widehat{X}_k$ is the optimal estimated value of the system at time t; H is observation matrix; Z_k is the sensor measures the value at time t.

Error covariance:

$$P_k = (I - K_k H)P_k^- \tag{7}$$

I is the identity matrix.

4.4 PID Control

Through Kalman filtering, the vehicle speed of the two sensors is fused, and the system obtains the true speed estimation value, which is used as the input value for the PID control program to control the movement of the pineapple machine. PID controller is a widely used feedback controller, which consists of three controllers: proportional, integral, and derivative. The main function of PID control algorithm is to control the controlled system, stabilize its output value near the expected value, and cancel out interference and noise. This pineapple pesticide applicator uses an incremental PID algorithm, and the true velocity estimation value obtained by fusing Kalman filter data is used as the input value. The error value e (k) is obtained by subtracting it from the target value. The Kalman filter outputs the relative increment of the control quantity, and the algorithm formula is as follows:

$$u(k) = u(k-1) + \Delta u(k) \tag{8}$$

$$\Delta u(k) = K_P \cdot [e(k) - e(k-1)] + K_I \cdot e(k) + K_D \cdot [e(k) - 2e(k-1) + e(k-2)] \tag{9}$$

K_P is the proportional coefficient, K_I is the differential coefficient, K_D is the integral coefficient, $e(k)$ is the error value, and $u(k)$ is the output value, $\Delta u(k)$ *is the output increment* .

5. System Testing and Analysis

5.1 Error Analysis of Kalman Filter Velocity Data Fusion Experiment

This device will conduct three experimental groups, setting the target speed of the pineapple pesticide applicator to 2km/h, 4km/h, and 6km/h respectively, to verify the data fusion effect of the Kalman filter. During the experiment, the obtained vehicle speed signal and GPS speed signal of the wheels are output in real time through Bluetooth communication of the main control microcontroller.

Table 1. Analysis of Maximum Absolute Error in Kalman Data Filtering Fusion

Set speed	GPS speed km/h	Wheel speed km/h	Fusion speed km/h
2km/h	1.051	0.612	0.336
4km/h	1.014	0.685	0.394
6Km/h	1.181	0.730	0.410

Table 2. Analysis of Average Error in Kalman Filter Data Fusion

Set speed	GPS speed km/h	Wheel speed km/h	Fusion speed km/h
2km/h	0.509	0.345	0.112
4km/h	0.533	0.295	0.109
6km/h	0.643	0.325	0.101

Table 3. Standard Deviation Analysis of Kalman Filter Data Fusion

Set speed	GPS speed km/h	Wheel speed km/h	Fusion speed km/h
2km/h	0.396	0.299	0.173
4km/h	0.433	0.295	0.159
6km/h	0.403	0.325	0.151

From Tables 1, 2, and 3 above, it can be seen that the maximum absolute errors between the GPS speed and the preset speed of the pineapple pesticide applicator at preset speeds of 2km/h, 4km/h, and 6km/h are 1.051km/h, 1.014km/h, and 1.181km/h, respectively. The maximum absolute errors between the wheel speed and the preset speed are 0.612km/h, 0.685km/h, and 0.730km/h, respectively. After data fusion using the Kalman filtering algorithm, the standard deviation of speed data decreased by more than 56%. The pineapple pesticide applicator control platform utilizes the Kalman filtering fusion algorithm to effectively integrate wheel speed and GPS speed, greatly reducing noise interference and making the fused speed closer to the preset value.

5.2 Flow Error Experiment

The experimental water pump's water flow data per minute will be conducted at speeds of 2km/h, 4km/h, and 6km/h, as shown in Figures 8, 9, and 10.

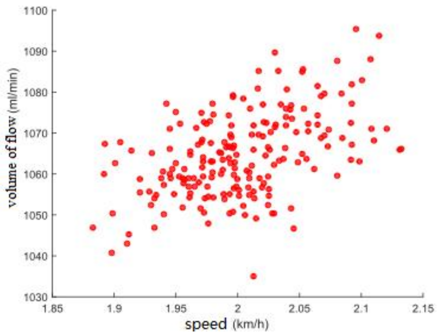

Figure 8. 2km/h Speed and Flow Relationship Diagram

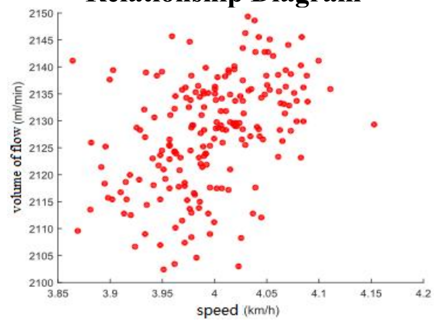

Figure 9. 2km/h Speed and Flow Relationship Diagram

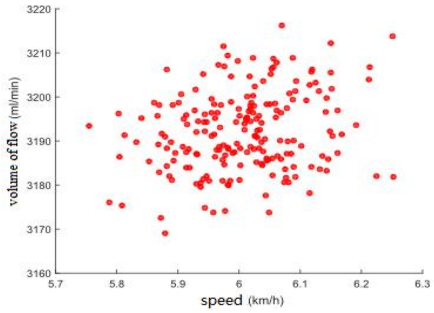

Figure 10. 2km/h Speed and Flow Relationship Diagram

According to statistics, under the set speeds of 2km/h, 4km/h, and 6km/h, the average water flow rates are 1070ml/min, 2135ml/min, and 3192ml/min, respectively. The errors with the set values of 1100ml/min, 2200ml/min, and 3300ml/min are 2.72%, 2.95%, and 3.27%, respectively.

6. Conclusion

(1) The design of the control platform for pineapple pesticide applicator in this article uses multi-sensor methods to detect the speed information of the pineapple pesticide applicator. The traveling speed of the pineapple pesticide applicator is obtained by analyzing the GPRMC data returned by the GPS module. The wheel speed is calculated by detecting the feedback pulse of the Hall sensor, and the data is sent to the upper computer for analysis through the Bluetooth module.

(2) By using the Kalman filter data fusion algorithm, this article adopts the Kalman filter and Bauman data fusion algorithm, which can fully utilize GPS data and feedback pulses from Hall sensors to obtain a fusion speed that approximates the actual speed. After data fusion using the Kalman filter algorithm, the standard deviation of the speed data is reduced from 0.295-0.433 to 0.151-0.173, a decrease of 56% -64%, greatly reducing noise interference and making the fused speed closer to the actual value.

(3) By controlling the PWM output of the microcontroller and the output voltage of the motor drive, the water flow rate of the water pump is controlled to form a linear mapping relationship with the driving speed of the pineapple pesticide applicator, thereby achieving the same spraying amount per unit area and precise spraying.

Acknowledgements

This work was supported by Guangdong Province Higher Vocational Education Reform Research and Practice Project "Construction of the Immersive"2+2" Collaborative Educa-tion Curriculum System for Electrical Engineering and Automation" (GDJG2021-368), Ling Shi Jiao Wu [2021] No.165 Document No.34 "Lingnan Normal University - Beijing Sanqing Internet Technology Co., Ltd. Practical Teaching Base", 2019 Campus level Talent Special Project of Lingnan normal university"Research on Sensor Angle Compensation and Noise Reduction Methods for Flow Method Production Measurement"[grant numbers ZL2005, ZL2007], College Student Innovation Program of Lingnan normal university"Fruit tree targeted precision variable fertilization robot based on YOLOv5 deep vision algorithm"[grant numbers X202410579025] and"Design of Spray Device Based on Laser SLAM and Adaptive Kalman Filter Control"[grant numbers S202410579010].

References

[1] He Xiongkui. Research progress and developmental recommendations on precision spraying technology and equip-ment in China[J]. Smart Agriculture, 2020, 2(1): 133-146. (in Chinese with English abstract).

[2] SINGH B, AWASTHI A M, SINGH D P. Effects of pesticides on environment and human health[J]. Inter J Modern Agric, 2021,10(2): 4089-4095.

[3] WANG C, ZHU H X, LI N J, et al. Dinotefuran nano-pesticide with enhanced valid duration and controlled release properties based on a layered double hydroxide nano-carrier[J]. Environ Sci: Nano, 2021, 8(11): 3202-3210.

[4] Cui Dezhen, et al.Current Status and Prospects of Research and Application of Mechanized Pineapple Planting Equipment in China[J].Modern Agricultural Equipment, 2024,45(05):2-7.

[5] Hasan Seyyedhasani, Chen Peng, Wei-jiunn Jang, Stavros G. Vougioukas. Collabo-ration of human pickers and crop-transporting robots during harvesting – Part I: Model and simulator development[J]. Computers and Electronics in Agriculture, 2020:105324-105324.

[6] Liu Wei, Liu Tianhu,Zeng Tingjun, Ma Ruijun, Cheng Yifeng,Zheng Yan, Qiu Jian,

Qi Long. Prediction of internal mechanical damage in pineapple compression using finite element method based on Hooke's and Hertz's laws[J]. Scientia Horticulturae, 2023.

[7] Liu Tianhu, Liu Wei, Zeng Tingjun, Cheng Yifeng, Zheng Yan, Qiu Jian. A Multi-Flexible-Fingered Roller Pineapple Harvesting Mechanism[J]. Agriculture,2022(8):1175-1175.

[8] Wang Binbin, Liu Wei, Deng Wenping, etc Design and experiment of a multifunctional field management machine based on pineapple mechanized field management technology [J] Southern Agricultural Machinery, 2024, 55 (02): 1-5+25.

[9] Du Yagang, Zhang Yu, Sui Xin, etc Research progress on variable spraying technology and equipment [J] China Agricultural Machinery Equipment, 2024, (09): 2-4

[10] Liu Hong. Application of Beidou Naviga-tion in Agricultural Machinery Autonomous Driving Technology [J] Agricultural Engineer-ing Technology, 2024, 44 (17): 38-39.

[11] Tang Sijia, Wang Qi, Ma Yunpeng, etc Application of Adaptive Unscented Kalman Filter Based on Threshold Filtering in Agricultural UAV Integrated Navigation [J] Journal of Anhui University of Science and Technology, 2024, 38 (06): 94-103.

[12] Zhang Jingbo, Fu Qiang Research on Intelligent Combustion Control of Steel Rolling Heating Furnace Gas Based on PID Algorithm [J] Modern Manufacturing Technology and Equipment, 2024, 60 (10): 194-196.