Design of Intelligent Pineapple Spraying Device Based on Multi-Sensor Fusion

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Abstract: Aiming at the problems of low efficiency, dangerous operation and uneven spraying in pineapple spraying technology, an intelligent spraying device based on multi-sensor fusion was designed. Through real-time acquisition of the driving speed and pineapple plant height data of the intelligent spraying device, adaptive Kalman algorithm was used to filter and improve the system accuracy, and the relationship model of spraying flow, vehicle speed and pineapple height information was constructed, so as to achieve the goal of accurate spraying. Through experimental tests, the TOF detection module can make the error less than 3cm by integrating the new generation adaptive Kalman filtering algorithm. The fusion weighted filtering algorithm of GPS positioning system can reach the accuracy of 0.1m/s. The relative error between the actual flow rate and the theoretical flow rate of the spraying device is within 5%. The experimental results show that the intelligent spraying device based on multi-sensor fusion can realize accurate spraying of pineapple and solve the problems of low spraying efficiency, dangerous operation and uneven spraying of pineapple.

Keywords: Spraying Machine; Adaptive Kalman Filter; Weighted Filtering; Multi-Sensor Fusion; Precise Spraying

1. Introduction

Pineapple is widely planted in more than 80 countries and regions around the world, and it is a popular tropical fruit. With the rapid development of global economy and the increasing demand and living standard of people, the proportion of pineapple consumption has increased year by year. However, there will be many pests in the vegetative growth period of pineapple, so it is necessary to spray pesticides to eliminate pests. However, the manual spraying of pesticides is labor-intensive and labor-intensive, which is not conducive to the sustainable development of agriculture. At the same time, because the top leaves of pineapple are serrated, farmers need to wear protective clothing, solid pants, thick gloves and goggles in the process of manual spraying to avoid being scratched by nail-like pineapple leaves, which shows the hardships of farmers in planting pineapple. Therefore, the intelligent pineapple spraying device is of great significance to pineapple production.

At present, the research level of pineapple spraying device at home and abroad has been gradually improved, involving mechanical structure, spraying technology, automatic control and many other aspects. In domestic research, after years of practice and exploration, China has developed some efficient and intelligent pineapple spraying devices. In foreign countries, developed countries have also made great efforts in the research of pineapple spraying device. For example, some research institutions in the United States specialize in the study of pineapple spraying, and developed a spraying system that can be intelligently adjusted according to different forms of pineapples. However, there are few studies on the integration of the speed of spraying device, plant height and spraying flow in China.

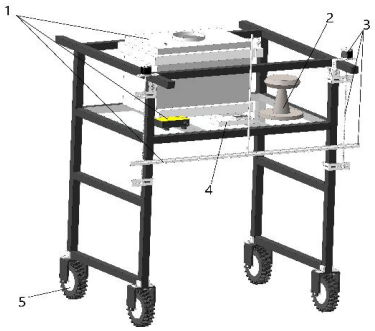
In this paper, speed, flow and height are combined to design a brand-new intelligent pineapple spraying device. The device can not only improve the effective utilization rate of pesticides and the mechanization degree of agricultural production, but also promote the high yield and harvest of pineapples, and is

conducive to promoting the development of local pineapple industry in Zhanjiang, Guangdong. In the future, the intelligent pineapple spraying device will be oriented by farmers and driven by technological innovation to promote the agricultural transformation and upgrading in China.

2. overall Structural Design and Working Principle

2.1 Overall Structural Design of Spraying Machine

Pineapple applicator is mainly composed of spraying device, spray rod lifting device, sensor device, control device and walking device, as shown in Figure 1. The whole machine is a ridge-crossing pineapple spraying machine. The spraying device includes a liquid storage tank, a conduit, a water pump, a spray bar, etc. Some of them are installed on the top acrylic board, and some of them are in front of the machine. The spray bar lifting device is installed in front of the machine, the walking device is installed at the lower end of the machine bracket, and the sensor and control device are placed on the top acrylic board.



1. Drug spraying device 2. Sensor device 3. Lifting device 4. Control device 5. Walking device

Figure 1. Design of Spraying Device

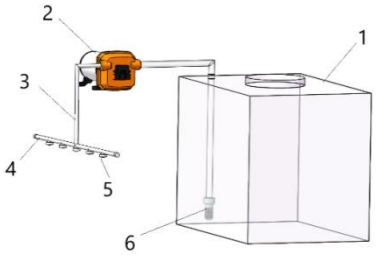
2.2 Working Principle

The application process of pineapple applicator is divided into four stages: height detection of pineapple plants, speed detection of car body, automatic adjustment of spray bar height and flow variable control. When the machine is working, the laser radar dot matrix sensor is installed on the machine, which can detect the height of pineapple plants under the car and then feed it back to the main control system; The GPS sensor detects the real-time vehicle speed of the machine and feeds it back to the main control system. The main control system calculates the appropriate spray bar height and flow rate according to the plant height and the walking speed of the machine at this time, and then sends control commands to the spray bar device and the spray bar lifting device to realize the variable adjustment of the spray bar height and the spray bar flow rate, and complete the whole variable application process.

3. Design of Spraying Device

The principle of the spraying device of this device is shown in Figure 2. The spraying device mainly comprises a liquid storage tank, a filter, a high-pressure water pump, a connecting guide, a spray bar and the like. The spray bar of this spraying device is equipped with six atomizing nozzles, and the spray bar can move vertically to meet the needs of different heights of pineapple plants. The start and stop of high-pressure water pump is controlled by single chip microcomputer.

The spraying system consists of a solution storage tank installed on an acrylic flat plate above the frame and a pipeline connecting the water tank and the spray bar. The filter, high-pressure water pump, conduit and spray bar constitute the whole spraying system. The pesticide solution is stored in the liquid storage tank, connected with the filter through the water outlet pipe, and then pressurized by the high-pressure water pump and sent to the spray bar for spraying. The filter can filter out impurities and maintain the normal operation of spraying equipment. The single chip microcomputer controls the start of the water pump to realize the control of spraying action. This design can ensure the uniform spraying of pesticides to all parts of the plant, and improve the spraying efficiency and pesticide utilization rate.

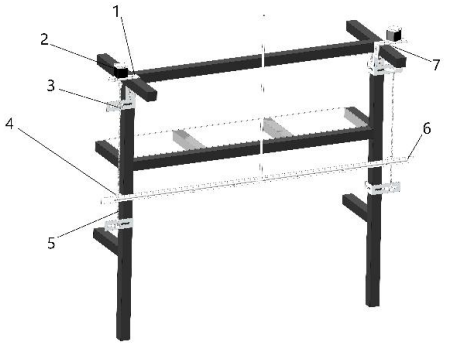


1. Liquid storage tank 2. High pressure water pump 3. Conduit 4. Spray bar 5. Atomizing nozzle 6. Filter.

Figure 2. Principle of Spraying Device

4. Design of Lifting Device

The lifting device is shown in Figure 3. The lifting device mainly includes a stepping motor, a coupling, a lead screw, a triangular bracket, a linear motion bearing and a nut seat. The stepping motor is fixed above the frame through a triangular bracket, and its output shaft is connected with the lead screw through a coupling; The screw rod is installed on both sides of the frame through a triangular bracket and a linear motion bearing; The spray rod is fixedly connected with the nut seat, and the nut seat and the screw rod are connected through matched threads. After the motor rotates, the screw rod drives the nut seat and the spray bar to move up and down in a straight line to realize the height adjustment function.



1. Triangular bracket 2. Stepping motor 3. Linear motion bearing 4. Nut seat 5. Lead screw 6. Spray bar 7. Coupling

Figure 3. Schematic Diagram of Lifting Device

5. Design of Lifting Device

5.1 Speed Signal Acquisition and Processing

5.1.1 GPS Principle of GPS Weighted Filtering Algorithm

This system reads GPRMC sentence in NMEA-0183 format data output by DGPS receiver to time, locate and measure the speed of spraying machine. The format of GPRMC statement is:

$ gprmc, 013946.00, a, 4351.101496, n, 12519.821271, e, 0.05, 218.30, 111105, 4.5, w, a * 20. $ gprmc sentence consists of 77 characters, and each data segment is in the sentence. Among them, the time information is located in the 8th-16th byte, the latitude information is located in the 20th-30th byte, the longitude information is located in the 34th-45th byte, and the speed information is located in the 49th-52nd byte. Read the corresponding byte data to get the time, latitude, longitude and speed information of the working position of the machine.

In the precise point positioning algorithm, the filtering settings include the parameters to be estimated, covariance matrix, state noise and initial setting of observation noise, and the state vector x of filtering estimation can be expressed as:

$$X=[x\ y\ z\ \delta\ d\ N1\ N2\ \ldots\ N\ n] \quad (1)$$

In equation (1), x, y, z are the coordinate increments of the phase center of the receiver antenna, δ is the deviation of local time from IGST, D is the zenith tropospheric delay, and N1, N2 ⋯ Nn are the integer ambiguity of the observed n satellites.

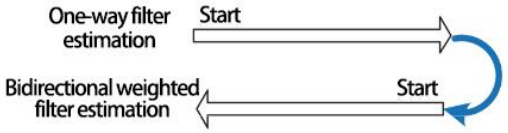


Figure 4. Process

According to the bidirectional calculation process in fig. 1, the updated state covariance matrix of unidirectional and bidirectional weighted filtering can be used as the weighting factor. In the parameter estimation of Kalman filter, the state covariance matrix reflects the error of clock error and tropospheric time delay estimation. By using the weighting method based on variance matrix in the two-way filtering process, the estimation results with small errors can be better selected, thus reducing the unreliable estimation values at the end. The specific weight calculation method is as follows:

$$w = \frac{1}{\frac{1}{w_f} + \frac{1}{w_b}} \quad (2)$$

$$X = \left(\frac{X_f}{w_f} + \frac{X_b}{w_b}\right) * w \quad (3)$$

In equations (2) and (3), wf represents the state covariance matrix of the first filtering (forward) and wb represents the state covariance matrix of the second filtering (reverse). Xf stands for forward filtering estimation and Xb stands for backward

filtering estimation. Through weighted calculation, the final two-way weighted estimation result X can be obtained.

5.1.2 PID algorithm principle of speed control

The speed of the two sensors is fused by Kalman filter, and the system obtains the real speed estimation value, which is used as the input value of PID control program to control the travel of pineapple machine.

PID controller is a widely used feedback controller, which consists of three controllers: proportional controller, integral controller and differential controller. The main function of PID control algorithm is to control the controlled system, make its output value stable near the expected value, and cancel the interference and noise. PID control program flow is as follows Fig. 5 flow chart of PID control program as shown. as shown.

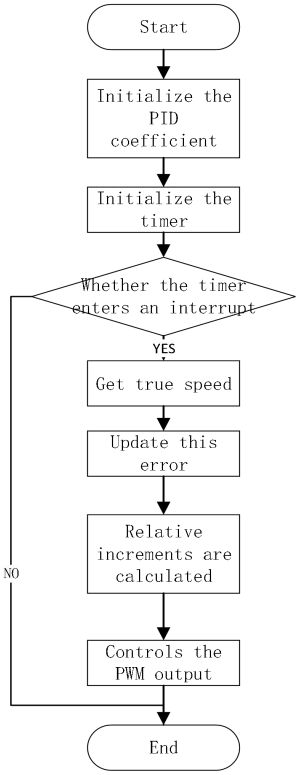


Figure 5. Flow Chart of PID Control Program

This pineapple applicator uses incremental PID algorithm, and the true speed estimated value obtained by Kalman filter data fusion is used as the input value, and the error value e(k) is obtained by the difference with the target value, and the relative increment of the control quantity is output by Kalman filter. The algorithm formula is as follows:

$\Delta u(k)$

$$u(k)=u(k-1)+\Delta u(k) \quad (4)$$

$$\Delta (k)=K\_P*[e(k)-e(k-1)]+K\_I* e(k)+K\_D* [e(k)-2e(k-1)+e(k-2)] \quad (5)$$

K_P-Proportional coefficient

K_I-differential coefficient

K_D-integral coefficient

E (k)-this error.

u(k)—Output value

When the incremental PID method is used to control, the deviation of the first, middle and last three measurements is used to get the control, and the control effect is improved by adjusting the three parameters.$K_P K_I K_D$

5.2 Flow Signal Processing

By calibrating the relationship between nozzle inlet pressure, voltage controlled by PWM of STM32 single chip microcomputer and nozzle spraying amount, the functional relationships between nozzle spraying amount and voltage, PWM control voltage and nozzle inlet pressure are fitted.

$$V = 0.0139q^{-3.226} \quad (6)$$

$$P = 0.2766V^{1.4756} \quad (7)$$

Where: v-control voltage, v; P-theoretical value of pressure, MPa.

5.3 Velocity, Flow and Height Signal Fusion Processing

During the operation of the sprayer, there is a functional relationship between the spraying amount of the sprayer, the traveling speed of the sprayer and the height of the sprayer:

$$y = \frac{Q \cdot h}{v} \cdot k \quad (8)$$

Q-nozzle water flow;

H—— nozzle height;

K-linear coefficient;

V-driving speed;

The intelligent pineapple spraying machine can solve the problems of low spraying efficiency, dangerous operation and uneven spraying by controlling the speed, flow and the height of the spraying rod.

6. Field Experiment and Result Analysis

6.1 Test Conditions

The spraying experiment was carried out in

xiashan district Nanya Institute, Zhanjiang City, Guangdong Province, China. As shown in Figure 12, the experimental field and the prototype were 850 ridges, with an average height of 180 meters and a height of 400 mm. The soil moisture content and compactness at the bottom of the ditch were measured by a soil moisture tester and a soil compactness meter, and the soil moisture content was 25% and the soil compactness was 13.02kg/cm².

Figure 6. Experimental Field and Prototype Diagram

7. Experimental Design and Results

In the experimental field, by measuring the width, thickness and height of pineapple plants, and adjusting the driving speed, nozzle flow and spray bar height of pineapple device, the relationship between them was explored. In order to better understand these relationships, a series of experiments were carried out in the experimental field, and the data of speed, flow rate and spray bar height of the experimental machine were recorded.

The maximum flow rate of the intelligent pineapple spraying device is 8400 ml/min. Under the condition that the intelligent pineapple spraying device carries 60kg of pesticides and the height range of pineapple in the test field is 0.4m-0.6m, the following three experiments are done, namely, the speed range experiment, the height adjustment experiment of spray bar and the flow rate experiment at different speeds, and it is concluded from the experiments that the driving speed range of the intelligent pineapple spraying device is 4 km/h-12 km/h. The adjustable height range of the intelligent pineapple spraying device is 90cm-145cm, and the height error is controlled within 3cm. See Table 4 for the average flow at different speeds, and the flow error is within 5%.

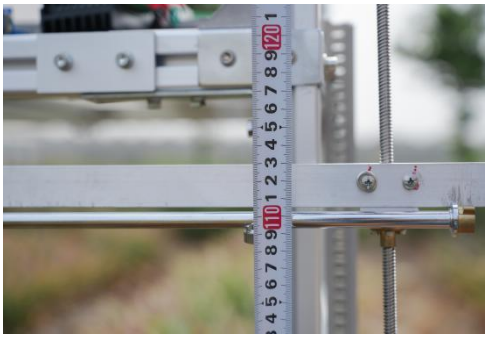


Figure 7. Height of Spray Bar

Figure 8. Measuring Cylinder Receives the Amount of Spray from a Single Nozzle

When the speed of intelligent spraying device is 4.3km/h and the height of pineapple is 52cm, the height of spraying rod is 108cm (Figure 7), and the error is 2cm. The measuring cylinder is used to receive the amount of spray from a single nozzle within 8 seconds, and the read scale is 142mL (Figure 8).

Table 1. Velocity and Flow Height Data Sheet

Speed (km/h)	Theoretical flow (ml/min)	Average flow (ml/min)	Flow error %	Height of spray bar (cm)	Height error (cm)
4	6551.3	6348.2	3.2	108	1.8
4.5	6524.7	6452.4	3.4	112	1.6
5	6355.2	6558.5	3.1	111	2.3
5.5	6408.2	6645.3	3.7	108	2.2
6	6496.3	6762.7	4.1	107	2.6
6.5	6598.5	6895.5	4.5	107	2.9
7	6691.1	6985.6	4.4	106	2.8
7.5	6959.2	7237.6	4.0	108	2.5
8	7051.1	7382.4	4.7	107	2.7
8.5	7108.3	7435.3	4.6	108	2.6

From the experimental data in Table 1 above, it can be concluded that under the above conditions, with the gradual increase of speed, the average flow rate of the intelligent pineapple spraying device also

increases gradually.

8. Conclusion

Intelligent pineapple spraying device plays an important role in agricultural production. The load of this work can reach 60-70kg, the maximum flow rate can reach 8400mL/min, the flow error is controlled within 5%, and the adjustable height of the spray bar is 90-145cm. The intelligent pineapple spraying device uses TOF depth sensing and GPS positioning technology to improve and upgrade the existing spraying device, so as to improve the effective utilization rate of pesticides, reduce the use of pesticides and alleviate the problem of labor shortage.

First of all, this spraying machine adopts TOF depth sensing technology, which can control the error within 3cm. By measuring the time of light propagation, the distance between the spraying device and pineapple plants can be obtained, and the accurate identification of pineapple plants with different heights can be realized. This accurate identification technology can classify pineapple plants, and accurately control quantitative spraying according to plant height and density.

Secondly, this spraying machine uses GPS positioning technology, the accuracy can reach 0.1m/s, and the speed of the intelligent pineapple spraying device can be accurately measured, and then the driving speed is adjusted by the brushless DC motor controlled by fuzzy PID, so as to achieve the effects of adjustable speed and stable driving.

Finally, through the combination and cooperation of the above two technologies, the pineapple plants with different heights can be accurately identified, and the pineapple plants can be sprayed efficiently according to different heights, which improves the efficiency of the intelligent pineapple spraying device. At the same time, this work can be remotely controlled through the Bluetooth terminal of the mobile phone, realizing unmanned operation, making it more suitable for modern agricultural production.

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References

[1]Valentyn T ,I. Y V . Investigation of aerodynamic properties of louver distribution of heat carrier in spray-drying complexes[J]. Food Reviews International,2023,39(9).

[2]Li F ,Bai X ,Su Z , et al. Development of a Control System for Double-Pendulum Active Spray Boom Suspension Based on PSO and Fuzzy PID[J]. Agriculture,2023,13(9).

[3]Rekha R ,C. D S ,A. S F , et al.Real-time control of high-resolution micro-jet sprayer integrated with machine vision for precision weed control[J].Biosystems Engineering,2023,228

[4]İnan Remzi,Aksoy Bekir,Salman Osamah Khaled Musleh. Estimation performance of the novel hybrid estimator based on machine learning and extended Kalman filter proposed for speed-sensorless direct torque control of brushless direct current motor[J]. Engineering Applications of Artificial Intelligence,2023,126(PC).

[5]Liangsheng J ,Yinchu W ,Li M , et al. Integrated Positioning System of Kiwifruit Orchard Mobile Robot Based on UWB/LiDAR/ODOM.[J]. Sensors (Basel, Switzerland),2023,23(17).

[6]Li L ,Wang J ,Chen Z , et al. Application of Adaptive Robust Kalman Filter Base on MCC for SINS/GPS Integrated Navigation[J]. Sensors,2023,23(19).

[7]Haihong T ,Yanmin T ,Yuxiang S , et al. Feature extraction of multi-sensors for early bearing fault diagnosis using deep learning based on minimum unscented kalman filter[J]. Engineering Applications of Artificial Intelligence,2024,127(PA).

[8]Xiaobin W ,Yuanxi Y ,Bo W , et al.Resilient timekeeping algorithm with multi-observation fusion Kalman filter[J].Satellite Navigation,2023,4(1):

[9]Recep Y ,Ridvan D ,Murat B . Online estimations for electrical and mechanical parameters of the induction motor by extended Kalman filter[J]. Transactions of

the Institute of Measurement and Control,2023,45(14).

[10]Ali A ,Jinling W ,Abdulla A . An integrated adaptive Kalman filter for improving the reliability of navigation systems[J]. Journal of Applied Geodesy,2023,17(3).

[11]Qi Z ,Nischal B ,Hong C , et al.Vehicle Trajectory Tracking Using Adaptive Kalman Filter from Roadside Lidar[J].Journal of Transportation Engineering, Part A: Systems,2023,149(6):

