Key Technologies of Spraying Machine with Wireless Remote Control

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***Abstract*—In this research, a wireless remote-controlled (RC) spraying machine is developed based on the S3C6410 embedded controller. This spraying machine is composed of a rotary pesticide selection unit, a real-time mixing unit, a multi-angle spraying unit, an image acquisition module, an embedded control module, a wireless communication module, and an intelligent mobile platform. It is especially designed for hilly areas, greenhouses, orchards, and other environments that are not accessible to large and medium-sized spraying machines. The wireless RC machine achieves precise proportional and multi-angle flexible spraying while avoids liquid waste and direct operator–liquid contact.**

***Index Terms*—Wireless remote control, Spraying machine, Embedded controller, Rotary pesticide selection, Real-time mixing, Multi-angle spraying**

I. INTRODUCTION

Chemical control, as a major agro-technology, plays a significant role in agricultural production. According to the statistics of the Food and Agriculture Organization of the United Nations, chemical pesticides save 20%–25% and regain four to five times the value of agricultural products per year worldwide[1-4].

China is an agricultural country; thus, improving the spraying technology not only increase the efficiency of pesticide application, but also reduce pesticide residues and environmental pollution[5-8].

To date, 90% of the spraying equipment in China is manual or semi-automatic, and intelligent agricultural spraying comprises only a small proportion in plant protection. The technology in China is relatively behind compared with that in foreign countries. Extensive spraying causes pesticide waste and environmental pollution, as well as health hazards to operators. Moreover, unreasonable ways of spraying result in extremely high amounts of pesticide residues in agricultural products, which causes serious damage to human and livestock health as well as to the environment[9-13].

In this study, a wireless remote-controlled (RC) spraying machine is developed. It is designed for use in hilly areas, greenhouses, orchards, and other environments that are not accessible to large and medium-sized spraying machines. This wireless RC machine achieves precise proportional and multi-angle flexible spraying while avoids liquid waste and direct operator–liquid contact[14-15].

II. OVERALL SCHEME OF DESIGNING THE WIRELESS RC SPRAYING MACHINE

The overall process involves mechanical structure and control system designs. The mechanical structure design process includes the rotary pesticide selection unit, real-time mixing unit, and multi-angle spraying unit. The control system design process includes the embedded controller module, image acquisition module, wireless communication module, and intelligent mobile platform. The rotary selection device determines the pesticides and nutrient solutions. The preparing and spraying unit performs accurate real-time proportioning and prevents excessive spraying, and the multi-angle flexible spraying unit increases the range and improves the spraying efficiency. The image acquisition module performs real-time acquisition of environmental information and determines the pesticide selection, as well as the spraying height and angle. The wireless communication module communicates with close monitoring tablet PC and RC PC in real time and gives wireless instructions for acquisition and control of the images in the operating area. Figure 1 shows the overall technical route of the spraying machine, which is performed on the intelligent mobile platform.

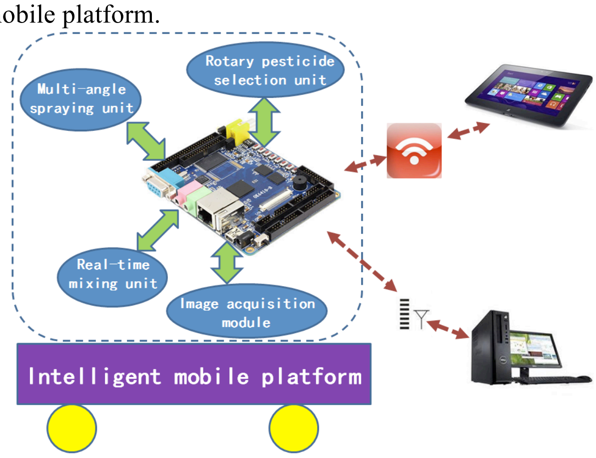
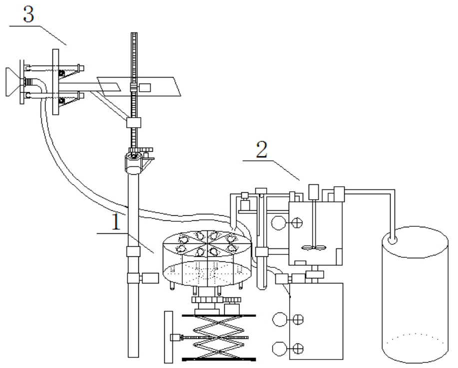


Figure 1. Overall technical route

III. MECHANICAL STRUCTURE DESIGN

Figure 2 shows the mechanical structure design of the wireless RC spraying machine. This machine is composed of pesticide selection unit, real-time mixing unit and multi-angle spraying unit.

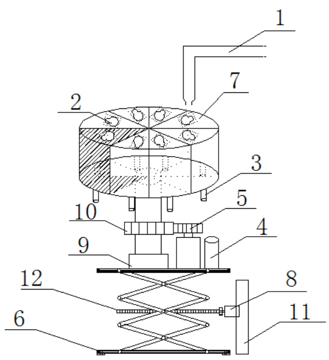


1. Rotary pesticide selection unit; 2. Real-time mixing unit; 3. Multi-angle spraying unit

Figure 2. Mechanical structure design of the wireless RC spraying machine

A. *Rotary pesticide selection unit*

Figure 3 shows the structure of the rotary pesticide selection unit. This unit is composed of dosing conduits, pesticide-collecting holes, laser photoelectric sensors, motor #1, lifting platform, solution tanks, motor #2, bearing, gear, motor chute, and rotating shaft. The control motor of the S3C6410 embedded controller enables correct selection of pesticides and nutrient solutions, and the laser photoelectric sensors realize the positions of the eight types of pesticides or nutrient solutions in the solution tanks. The pesticide-collecting holes located above the pesticides or nutrient solutions correspond to the dosing conduits. The transmitting ends of the laser photoelectric sensors are fitted at the base of the solution tank, and the receiving end is fitted on top of the lifting platform.



1. Dosing conduit; 2. Pesticide-collecting holes; 3. Laser photoelectric sensor (transmitting end); 4. Laser photoelectric sensor (receiving end); 5. Motor #1; 6. Lifting platform; 7. Small solution tank; 8. Motor #2; 9. Bearing; 10. Gear; 11. Motor chute; 12. Rotating shaft

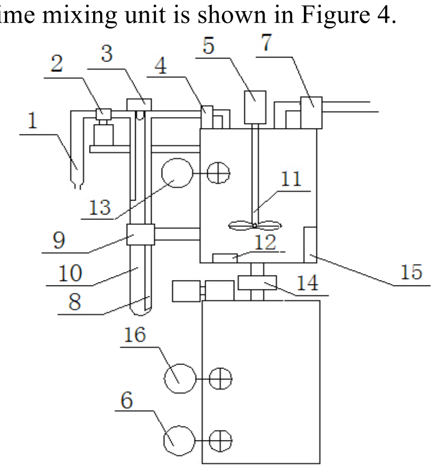
Figure 3. Structure of the rotary pesticide selection unit

The rotary pesticide selection unit needs to be reset when replacing the pesticide or nutrient solution. The transmitting ends of the eight laser photoelectric sensors are fitted at the bottom of the solution tank to determine the eight points of the tank. The S3C6410 embedded controller opens the corresponding transmitting ends of the laser photoelectric sensors based on the type of pesticide or nutrient solution selected, and when motor #1 engages the gear, the solution tank rotates. The bearing in the lower end of the solution tank reduces the resistance in rotation. Motor #1 stops running when laser signals are detected in the receiving end as the selected pesticides or nutrient solutions are right below the conduit. Motor #2 drives the lifting platform to rise, and the dosing conduit inserts in and extracts the pesticide or nutrient solution.

B. *Real-time mixing unit*

The unit is mainly composed of a mixing tank and a temporary storage tank. The water and pesticide pumps are fitted in the mixing tank to pump up the selected pesticides or nutrient solutions into the respective tanks. The real-time mixing unit is fitted with an ultrasonic liquid level sensor and a liquid level switch that is used to measure the required volumes of pesticides or nutrient solutions for the mixing tank. The mixing tank is equipped with a heater and an agitator that guarantees intensive mixing.

A 2-L mixing tank is fitted with a blender, a heater, and a liquid level switch. A 2.5-L temporary storage tank is placed right below the mixing tank. A 50 L/min magnetic valve that connects the mixing tank and the temporary storage tank is adopted. Thus, the magnetic valve can fully transfer the mixing solution to the temporary storage tank within 2.5 s. The K1 and K2 liquid level switches are fitted on the 1.25-L and 0.25-L temporary storage tanks, respectively. The structure of the real-time mixing unit is shown in Figure 4.



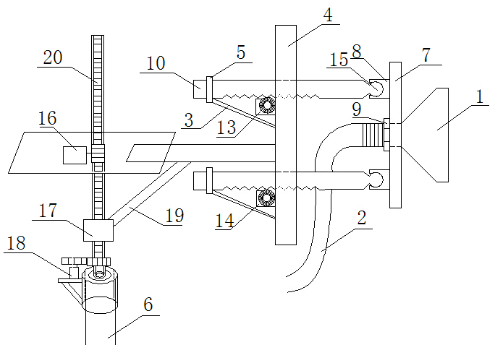
1. Dosing conduit #1; 2. Pesticide-collecting pump; 3. Laser photoelectric sensors; 4. Pesticide pump; 5. Motor; 6. Liquid level switch K2; 7. Water suction pump; 8. Mixing #2; 9. Measuring cylinder bracket; 10. Mixing measuring cylinder; 11. Holder; 12. Blender; 13. Heater; 14. Liquid level switch K3; 15. Electromagnetic valve; 16. Temperature sensor; 17. Liquid level switch K1

Figure 4. Structure of the real-time mixing unit

The S3C6410 embedded controller calculates the amounts of pesticide or nutrient solution required according to the type and mixing ratio. The pesticide or nutrient solution is pumped into the measuring cylinder. The ultrasonic liquid level sensor measures the pumped volume, and the liquid is then back-fed to the S3C6410 embedded controller in real time. When the required volume is reached, the S3C6410 embedded controller turns off the in-taking pump and turns on the pesticide pump to transfer the pesticide or nutrient solution from the measuring cylinder into the mixing tank. The water pump is simultaneously turned on with the pesticide pump to transfer the required amount of water into the mixing tank. The volume of the mixing liquid is tested with a level switch and back-fed to the S3C6410 embedded controller. When the mixing liquid reaches 2 L, the S3C6410 embedded controller shuts down the water and pesticide pumps. The blender is simultaneously turned on with the water pump, and the heater is turned on or shut down according to the temperature of the mixing liquid.

C. *Multi-angle spraying unit*

The multi-angle spraying unit is composed of vaporific nozzle, hose, studdle, square alloy plate, circular ring, hollow rod, disc, rotating node, nut, loop, rack, shelf bracket, four sliders, six motors, and spherical salient point. Motor #7 drives the shelf bracket to move up and down the rack and adjusts the height. Motor #8 drives the horizontal rotation of the rack and enables the vaporific nozzle to spray on both sides of the intelligent mobile platform. Motors #3, #4, #5, and #6 function in a time-sharing manner and for different slider expansions and contractions, thus allowing multiple-angle spraying of the vaporific nozzle fixed at the center of the disc. The structure of the multi-angle spraying unit is shown in Figure 5.



1. Vaporific nozzle; 2. Hose; 3. Studdle; 4. Square alloy plate; 5. Circular ring; 6. Hollow rod; 7. Disc; 8. Rotating node; 9. Nut; 10. Sliders; 11. Motor #3; 12. Motor #4; 13. Motor #5; 14. Motor #6; 15. Spherical salient point; 16. Motor #7; 17. Loop; 18. Motor #8; 19. Shelf bracket; 20. Rack

Figure 5. Structure of the multi-angle spraying unit

Operators send RC signals to the S3C6410 embedded controller based on monitoring images, Wi-Fi based tablet PC, and 3G module of PC monitor. The controller of motor #7 then adjusts the height by moving the shelf bracket vertically. Motor #8 drives the rack to rotate horizontally to adjust the direction. Motors #3, #4, #5, and #6 function in a time-sharing manner and control the four sliders to move horizontally. The spherical convex point at the end of the slider is connected to the rotating node of the disk. The motor engages with the thread tooth of the slider and controls the length of four sliders. The slider drives the disc to swing in multiple angles. The spherical convex points are engraved at the end of four sliders and fitted in the spherical groove of the rotating disc nodes. The motor gear tightly engages with the dentation of the slider to elongate or shorten the slider and allows flexible swing of the control disk. According to the mode of combination and time series of operation, six kinds of spraying actions can be executed as follows:

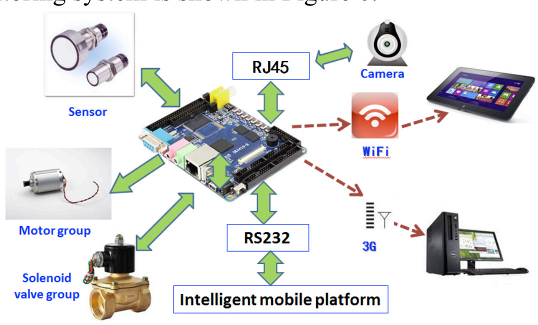
(1) Four motors are divided into left and right groups in vertical direction. The two groups work alternately to control the length of the slider. The slider drives the disc to swing left and right, thus performing left and right spraying.

(2) Four motors are divided into upper and lower groups in vertical direction that work alternately to control the length of the slider. The slider drives the disc to swing up and down, thus realizing left and right spraying.

(3) Four motors work clockwise or counterclockwise to control the length of the four sliders and drive the disk to swing clockwise or counterclockwise, thus realizing clockwise or counterclockwise spraying.

IV. SCHEME FOR DESIGNING THE CONTROL SYSTEM

The S3C6410 high-performance embedded controller is adopted as the core in the design. The position signals of the solution tank are collected by the laser photoelectric sensor. The temperature, volume, and liquid level data of the mixing tank are collected by the digital temperature sensor, the liquid level switch and ultrasonic liquid level sensor. Water pump, pesticide pump, liquid pump, blender, and heater are controlled by the S3C6410 embedded controller to achieve precise proportion and guarantee complete mixing. Control relay drives the motor to carry out automatic selection through collecting position signals of the solution tanks. The motor is driven by the control relay, and the height of the unit and the direction of spraying are adjusted. The image data of the operating site are collected by a camera with platform regulating functions. Wireless monitoring consists of two modes. Mode 1 involves Wi-Fi-based communication wherein short-distance wireless monitoring is realized through a tablet PC The operator can reliably operate the spraying machine within 150 m. Mode 2 involves 3G wireless communication module wherein remote wireless monitoring is realized through a remote PC monitor. The structure of the wireless monitoring system is shown in Figure 6.



1. Sensors; 2. Motor group; 3. Solenoid valve group; 4. Camera

Figure 6. Structure diagram of the wireless monitoring system

The control system works in four steps as follows:

Step 1: The camera is switch on to start video monitoring and remote controlling the intelligent mobile platform as well as allows the spraying device to access the work zone.

Step 2: Shooting images in the work zone: operators determine the types and proportion of pesticides or nutrient solutions based on the information of expert system and practical experience, as well as adjust the height of unit and determine the direction of spraying.

Step 3: Work mode selection:

Step 3.1 Fixed-point automatic mode: the machine moves in fixed points, and the nozzle sprays up, down, left, and right according to the fixed order, time, and points.

Step 3.2 Moving and spraying automatic mode: the machine moves forward at a constant velocity, and the spraying unit works homogeneously at fixed height and fixed angle.

Step 3.3 Manual mode: The RC intelligent mobile platform selects the appropriate spraying unit, height, and direction based on the video images as well as selects corresponding spraying actions according to the actual needs. After spraying at a position is completed, RC intelligent mobile platform selects the next suitable position for spraying operation.

Step 4: Steps 1–3 are repeated for the next work zone.

V. SYSTEM TESTING

The mechanical structure of the wireless RC spraying machine adopts the professional mechanical drawing software CAD/3Dmax modeling analysis, which strives to realize a rational construction of all parts by reconciling the dimension and scale of the structure with the spraying demand. The control system adopts a modular design, a separate test for each module, and then a co-test for the assembly. After repeated experiments and corrections, research of key technologies of the wireless RC spraying machine is completed.

All parameters of the spraying machine are shown in Table 1.

TABLE I.
WHOLE PARAMETERS

Net weight of the whole machine/kg	61.8
Dimensions of the whole machine/*m*	0.85×0.66×0.80
Rated power/*w*	100
Rated voltage/v	12
Capacity of the water storage tank/*L*	50
Capacity of the mixing tank/*L*	2
Spray gauge pressure/*MPa*	0.2～0.6
Capacity of the temporary storage tank/*L*	2.5
Accumulator capacity/*VAH*	1200
Type/class of the pesticides selected	8
Volume of a single pesticide selection zone/*L*	1
Adjustable height of the spraying unit/*m*	0.8～2.8
Volume of spray of the vaporific nozzle /$L.min^{-1}$	0.6～1.5
Adjustable angle of the vaporific nozzle /(°)	360

The mixing accuracy of the real-time mixing unit of the machine is shown in Table 2. According to the data (volume of a single mixing is 2.0 L), the mixing accuracy of this machine is significantly higher than that of the traditional methods.

TABLE II.
COMPARISON OF THE MIXING CONCENTRATION

Proportion	Traditional accuracy	Accuracy of the spraying machine
1：25	0.90～0.94	0.97～0.99
1：50	0.88～0.92	0.95～0.98
1：100	0.85～0.90	0.93～0.96
1：150	0.82～0.88	0.92～0.94
1：200	0.80～0.85	0.90～0.92

Performance parameters of the multi-angle spraying unit of the spraying machine are shown in Table 3. The spraying unit reaches up to 2.8 m and even 3.5 m considering the range of the spraying liquid. The machine can be used for fruit trees, flowers, vegetables, grass, and crops below 3.5 m through adjusting the height of the unit, direction of spraying, and angle of the nozzle.

TABLE III.
PERFORMANCE PARAMETERS OF THE MULTI-ANGLE SPRAYING UNIT

Spray gauge pressure/*MPa*	0.2～0.6
Volume of spray of the nozzle/$L.min^{-1}$	0.6～1.5
Volume of spray of the spraying unit/*m*	0.8～2.8
Adjustable angle of the nozzle/(°)	360
maximum spraying area of a single point/m^2	18

Spraying efficiencies of the machine, obtained through calculating practical spraying area within a unit of time, are shown in Table 4. According to the data, the spraying efficiency of the spraying machine in time unit is 2–3 times of that in artificial spraying.

TABLE IV.
SPRAYING EFFICIENCIES

Working environment	Lawn	Greenhouses	Orchard
Manual operation /$m^2.h^{-1}$	1900	1200	1000
Machine operation/ $m^2.h^{-1}$	6000	3500	3000

VI. CONCLUSIONS

The wireless RC spraying machine developed in this paper performs automatic selection of eight types of pesticides or nutrient solutions, achieves precise mixing (93% or higher in proportion of 1:100), and can adjust height of the unit and direction of spraying. RC spraying within 150 m is operated by using Wi-Fi, whereas long-distance operation relies on the 3G module. This machine can be used in orchards, vegetable bases, crops, greenhouses, flowers, compound banding interplant bases, and other environments, thus greatly saves labor costs, avoids wasted spray, and reduces environmental pollution.

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