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Development of Microcomputer-Controlled Uumanned Air Blast Sprayer

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Abstract

A microcomputer-controlled unmanned air blast sprayer was developed to avoid the operator's exposure to agricultural chemicals or mechanical noise, and to improve the work efficiency during application for pest control in orchards. The developed sprayer moves automatically without a driver along a guiding cable, which is set up along the work course between the tree rows of the orchard. Unmanned application system developed controls automatically steering gears of the sprayer by detecting a magnetic field, which was generated by feeding an alternating current to the guiding cable. The cable can be installed underground (at a depth of less than 30 cm), on the ground surface, or at a height of 150 to 200 cm from the ground along the work course. The maximum total length of the cable is about 1,000 m. During unmanned application, the machine sprays agricultural chemicals automatically along the work course. However, if it is unnecessary to spray outward at the end of the tree rows where the sprayer turns, the machine is able to stop spraying outward while turning, due to a special system. All the functions of the sprayer stopped automatically when the sprayer reached the end point of application work. The sprayer has several safety devices controlled by the unmanned application system to avoid any accidents during unmanned application work. As a result of the performance test, deposition of sprayed chemicals on the fruit trees and work efficiency by this sprayer were as good as in any conventional manned air blast sprayers.

Discipline: Agricultural machinery
Additional key words: guiding cable, unmanned pest control, unmanned traveling, orchard

Introduction

Since the application of chemicals for pest control in orchards involves upward spraying, exposure of the operators to agricultural chemicals during the application has become a cause for concern. Protective wear, therefore, is used, but it is extremely unpleasant during hot months. A cabin may be attached to an air blast sprayer to avoid exposure, but for trellis fruit trees, for example, where the space is limited between the upper part of the equipment and the overhead branches, cabins may not be practical. Also the blower and other mechanical noises cause problems for the operators. As a result, a safe and comfortable work environment should be created.

The microcomputer-controlled unmanned air blast sprayer was developed to alleviate these shortcomings. In addition, this type of sprayer is the first unmanned air blast sprayer for orchards ever to be commercialized in Japan.

Purpose of development

Various systems of unmanned traveling can be used. In the current studies, we installed a guiding cable along the work course in the orchard, and when an electric current was fed to this cable, it generated a magnetic field around, which then could be detected by an electromagnetic sensing system[1,2].

Magnetic field is generated around the cable in which the current runs and around the coils placed within the magnetic field where the magnetic flux varies. As a result, electromotive force is generated according to the change of speed of the flux. These basic principles of electromagnetics were applied in this system.

The unmanned application system in the sprayer controls automatically steering gears of the sprayer depending on the degree of deviation from the guiding cable detected by an electromagnetic sensor, which is referred to as "guiding sensor" described later in this paper.

Compared with the standard application of chemicals with a conventional manned air blast sprayer, the application procedures for the unmanned sprayer are as follows:

(1) The sprayer is brought manually to the starting point for the spraying operation.
(2) Electric current is fed to the guiding cable.
(3) The unmanned operation system of traveling and spraying is activated.
(4) Unmanned operation continues until the liquid tank becomes empty.
(5) The sprayer is then transported by an operator to an area where the chemicals may be replenished and then to the area where the application is to resume.
(6) At the end of the entire application work, all the functions of the sprayer should come to an automatic stop.

We expected that the sprayer would be as efficient as the current manned air blast sprayer used for pest control in orchards.

Specifications of the unmanned sprayer

The specifications of the unmanned sprayer are listed in Table 1, and a diagram of the major parts is shown in Fig. 1[3,4]. A photograph of the sprayer, the guiding signal generator (referred to as "signal generator" in this paper), guiding cable set up on the ground, and palm-sized remote control transmitter (referred to as "transmitter" in this paper) are shown in Fig. 2.

Guiding cable

The guiding cable is laid along the work course. Examples of cable installation are shown in Fig. 3.

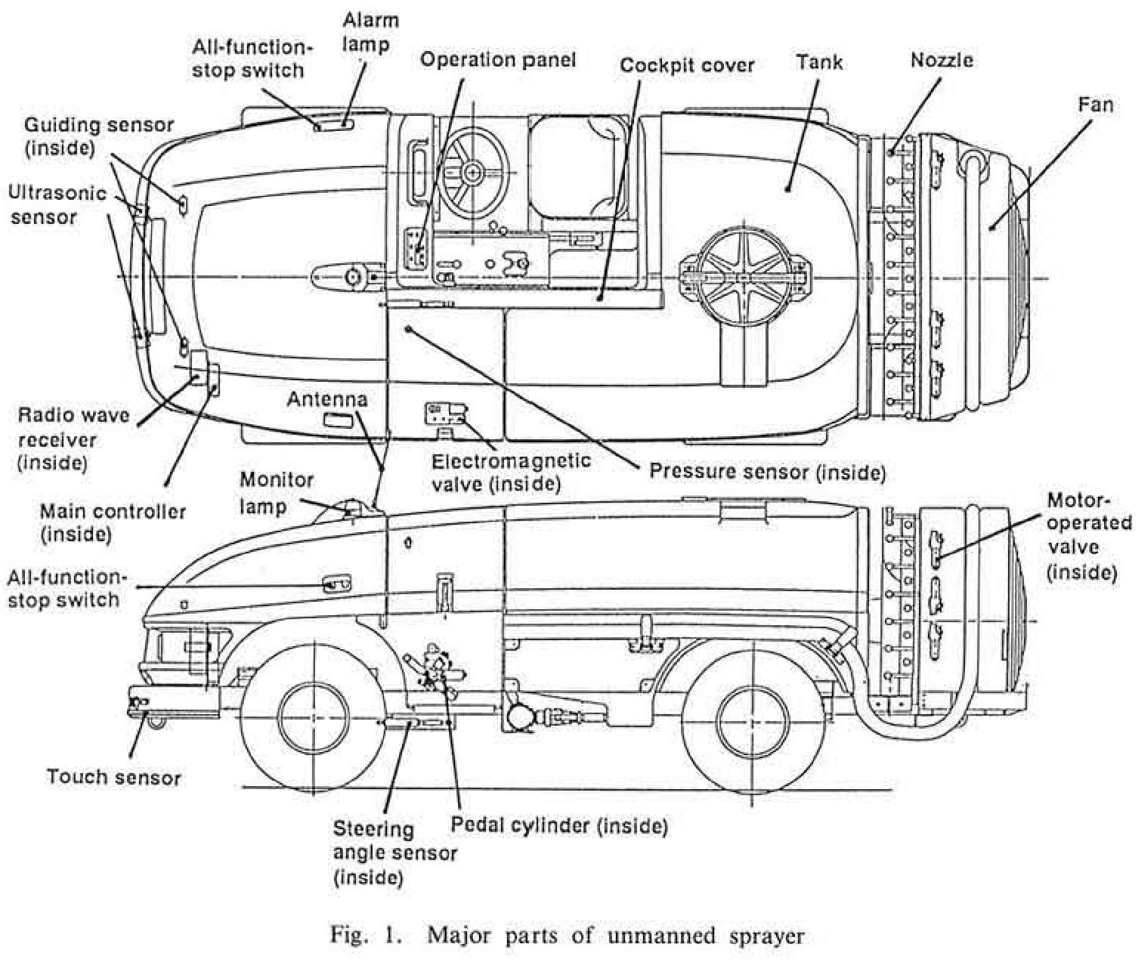


Fig. 1. Major parts of unmanned sprayer

Table 1. Specifications of the unmanned sprayer

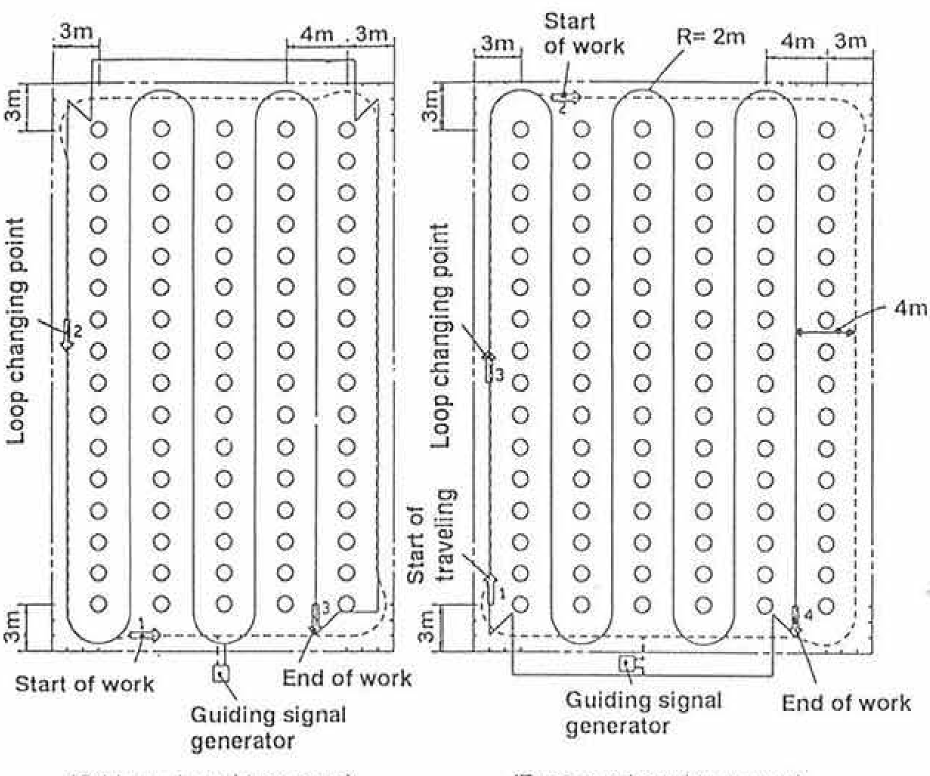
Dimensions	Length: 399 cm, Width: 145 cm Height: 129 cm (except for antenna) Weight: 1,350 kg (with empty tank)
Engine	Diesel engine: 31.8 kW/2,800 rpm
Traveling apparatus	Type: 4 driving wheels/4WD/4WS Shift range: Main: 1/2/3, Sub.: H/M/L/R Forward: 9 steps (0.9-13.2 km/h) Backward: 3 steps (1.2-7.5 km/h)
Tank capacity	1,000 L
Fan	Revolution: 2,280 and 1,550 rpm Air volume: 726 and 494 m^3/min
Pump	Type: Plunger type (3 cylinders) Discharge rate: 108 L/min
Nozzle	Type: Disk nozzle (31 pieces)

Fig. 2. Unmanned sprayer, guiding cable, guiding signal generator and palm-sized remote control transmitter

The depth at which the cable should be buried is either right under the surface or up to 30 cm beneath the surface for apple or other upright fruit trees, or the cable may be installed overhead at a height of 150 to 200 cm from the ground for trellis fruit trees such as pears and grapes.

Any parts of the cable should be about 1.5 m apart, considering the distance between dwarfed apple trees. Although the standard-specification cable is an automotive low-voltage wire (JIS cord: AV3), any electric cable larger than 3 mm^2 in cross-section can be used.

The length of the cable to be installed is limited by the capacity of the signal generator or electric resistance of the cable, and in the present stage of technology, the maximum length of the cable is



Fgi. 3. Examples of guiding cable installation

about 1,000 m. A cable of this length is capable of covering 30 to 40 a, including turning radii, in the case of dwarfed apple orchards where the trees are planted 4 to 4.5 m apart from each other.

The guiding cable is fed with an AC current of 1.5 kHz and 185 mA as the guiding signals from the signal generator. This signal generator is powered with a rechargeable battery that can be recharged in 5 h, using an exclusively built charger, and then it may be used for 8 consecutive hours. The signal generator provides 2 output-terminals, and the machine may be used for 2 cable systems by changing the switch.

Unmanned application system[3,5]

Fig. 4 shows a block diagram of the unmanned application system of the sprayer. The major sensing devices of the system consist of a guiding sensor (Fig. 1 and Fig. 5) and steering angle sensor (Fig. 1).

The guiding sensor has 2 sensing heads placed on both right and left sides of a radiator in the forward portion of the sprayer. This sensor detects the degree of deviation of the sprayer from the guiding cable by sensing the magnitude of the magnetic field generated around the guiding cable.

The steering angle sensor installed in the steering gear detects the angle of steering, i.e. the direction of the wheels.

An oil hydraulic cylinder actuated by an electromagnetic valve actuates the 4-wheel steering gears, traveling clutch and brake of the sprayer.

Based on the output of the sensors, the microcomputer (CPU: 20 MHz/16 bits, ROM: 32 Kbytes, RAM: 1 Kbytes) inside the unmanned traveling and spraying control device (referred to as "main controller" shown in Fig. 5) calculates the target steering range, in other words, the angle of turning for the steering in the case of a manned operation, based on which the steering gear is controlled just as the human operator would steer his/her wheels. Thus the unmanned sprayer may travel without any human attendance along the work course where the guiding cable is installed.

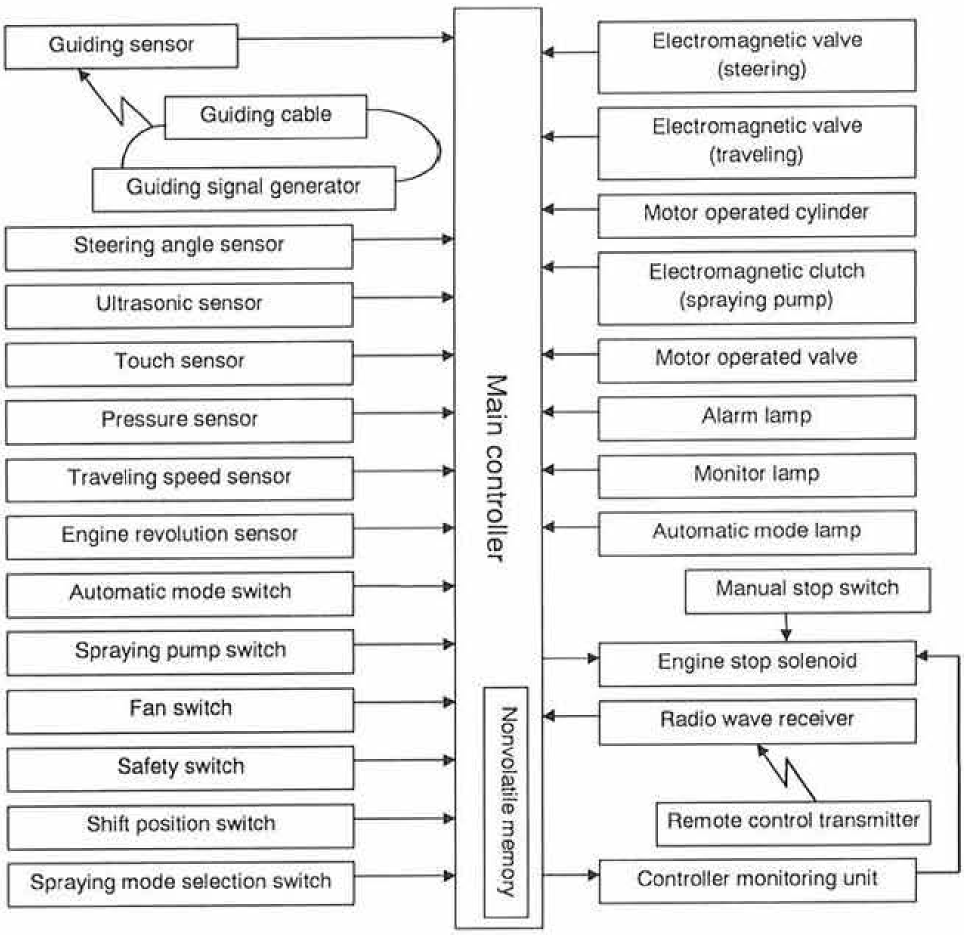


Fig. 4. Block diagram of unmanned application system

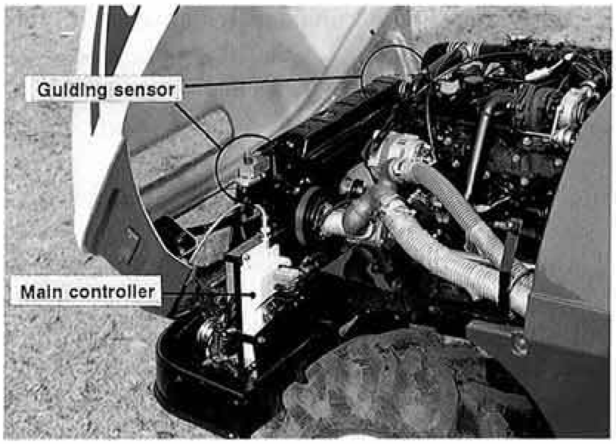


Fig. 5. Guiding sensor and main controller

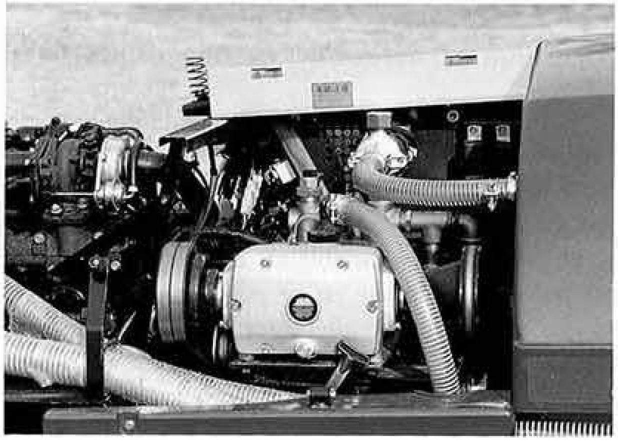


Fig. 6. Pressure sensor for sensing when the tank is empty

Fig. 8. Unmanned application test (dwarfed apple orchard)

Fig. 9. Unmanned application test (trellis grape orchard)

Algorithm of automatic steering control[3,4)]

If variable Vd is the output of the guiding sensor, variable Vdm is the moving average of Vd, variable Voff is the offset value from Vdm to the center of the sprayer body, $\triangle$Vd is the displacement of Vd, $\triangle$Vs is the control variable of steering, displacement of the body from the target position is represented by variable (1), and the direction of the body is represented by variable (2), as follows:

$$Vd - (Vdm + Voff) \quad \cdots\cdots (1)$$
$$\triangle Vd \quad \cdots\cdots (2)$$

Then, $\triangle$Vs was obtained using those variables with the following 6 rules of fuzzy reasoning.

Rule 1: If the body is on the right side and the direction is right, steer left.

Rule 2: If the body is on the right side and the direction is straight, steer left.

Rule 3: If the body is on the right side and the direction is left, don't steer.

Rule 4: If the body is on the left side and the direction is right, don't steer.

Rule 5: If the body is on the left side and the direction is straight, steer right.

Rule 6: If the body is on the left side and the direction is left, steer left.

Then, variable Vsr is the actual steering angle and variable Vsg is the target steering angle, Vsg is expressed as follows:

$$Vsg = Vsr + \triangle Vs \quad \cdots\cdots (3)$$

The actuators for automatic traveling control of the unmanned application system are controlled by Vsg.

Auxiliary remote control system[3,4)]

The start of the unmanned operation (onset of the application work) is controlled by the transmitter (Fig. 2) of the auxiliary remote control system so that the operator may be protected from any exposure to the chemicals or noise. Radio waves of the system are in the range of specific low-power radio waves, requiring no particular license, and the accessible distance of radio waves is guaranteed at 150 m in common orchards. This system is capable of starting or stopping the traveling, blowing and spraying functions of the sprayer, as well as application work.

In addition, a single operator can control simultaneously more than 2 unmanned sprayers with this system in every adjoining orchard. Application work is more efficient and labor-saving than in any of the conventional manned air blast sprayers.

Functions during unmanned operation[3,5)]

Functions during unmanned operation are as follows:

(1) During application by unmanned operation, chemicals are sprayed in all directions between the tree rows (right, left and upward of the sprayer). However, when the sprayer turns at the end of a tree row, it is designed to automatically stop spraying chemicals unnecessarily outside of the turning area without trees. In this instance, the steering condition is constantly monitored by the unmanned application system. The system proceeds straight or turns based on the output of the sensors for steering angle, for velocity, etc. and controls the spraying device of the sprayer. Automatic spray stopping function may be disengaged when spraying is desired even during turns.

(2) When the chemicals in the tank run out during the unmanned operation, traveling, blowing and spraying stop automatically through the effect of the pressure sensor (Fig. 6) installed with the spraying pump built inside the sprayer. This device detects the reduction in the discharge of the pump, signaling the depletion of the chemicals, thus automatically halting traveling, blowing and spraying.

(3) When the application work is complete, the cable installed is bent at a certain sharp angle, which allows the magnetic fields to interfere with each other. As a result, the guiding sensor is unable to detect the specific magnetic field at this spot, and all the functions stop automatically.

It may be noted that the release of the unmanned application system enables manned operation of the sprayer as required, just as in any other conventional manned air blast sprayers.

Safety devices

Since emphasis must be placed on safety in unmanned operation, unmanned application system of the sprayer incorporates safety devices as follows:

(1) A couple of obstacle-detecting sensors (2 ultrasonic sensors shown in Fig. 1 and Fig. 4) built in the front bumper, upon detecting an obstacle about 1 m ahead, halts traveling, blowing and spraying.

(2) A touch sensor (Fig. 1 and Fig. 7) built in

Fig. 7. Ultrasonic sensors and touch sensor

the bumper, in the case of an obstruction, stops all functions of the sprayer including the engine automatically.

(3) Should the system be out of control in emergency, the engine may be stopped by all-function-stop switches (Fig. 1) which are located on both sides of the bonnet (hood) of the sprayer body.

(4) In case of the interruption of the transmission of radio waves because of the exhaustion of the battery in the transmitter of the auxiliary remote control system, or due to trouble or accidental switch-off, traveling, blowing and spraying come to a halt automatically.

(5) When the guiding sensor is unable to detect the magnetic fields generated around the guiding cable, since the battery of the signal generator is exhausted (battery exhaustion is indicated through a gauge set in the signal generator), the cable is broken, or the sprayer is derailed from the cable, the engine is automatically put to a stop, i.e. all functions of the sprayer come to an end.

Performance tests and results[3-5]

1) Functional confirmation tests

Functional confirmation tests in which the range of velocity was 0.9 to 2.7 km/h were conducted on flat ground in several test courses and orchards. An example of the results of the functional confirmation tests is shown in Table 2.

The unmanned sprayer could travel smoothly along the guiding cable on the work course. It was confirmed that the system stopped spraying outward outside of the tree rows while turning, stopped traveling, blowing and spraying when the tank became empty, and stopped all functions at the end point of the work course. Moreover, each safety device was functioning during the unmanned operation.

2) Deposition performance

Deposition performance tests based on IAM test code No.12-1989 were conducted in a range of application velocities of 1.8 to 2.5 km/h, and the application rates ranged from 310 to 450 L/10 a in an orchard of dwarfed apple trees (variety: "Fuji", age: 18 years, height: 4 m, width: 3 m, planting

Table 2. Results of tests for function confirmation

unit: m

Items	Shift range	
	L-1	M-2
Displacement from the cable (straight traveling)	0.08	0.14
Stopping distance when the tank becomes empty	0.25	0.56
Minimum turning radius of cable	1.70	1.50
Allowable distance from cable to cable	1.50	1.50
Stopping distance upon detection of an obstacle	0.50	0.31
Stopping distance upon contact with an obstacle	0.05	0.21
Stopping distance by operation with the transmitter of auxiliary remote control system	0.09	0.20
Stopping distance with inaccessible remote control radio wave	0.90	2.51
Stopping distance with breakdown of guiding signal on the guiding cable	0.31	1.12
Stopping distance with all-function-stop switch "on"	0.61	1.78
Maximum accessible distance of radio wave	850	

All the data listed above were derived from the tests conducted on a test course (soil surface).

pattern: 4 × 2.5 m). The results of the tests were satisfactory and similar to those with a conventional manned air blast sprayer.

3) Work efficiency

Work efficiency tests were also conducted in several orchards of dwarfed apple trees (Fig. 8), trellis pears and trellis grapes (Fig. 9). According to the test results, the rate of work with the unmanned sprayer was almost the same as or higher than that with any conventional manned air blast sprayers.

However, the application work with the unmanned sprayer was more labor-saving and efficient than that with a conventional manned air blast sprayer, because the operator himself/herself of the unmanned sprayer could prepare agricultural chemicals to replenish the empty liquid tank during the unmanned operation without any assistant.

Conclusions

Advantages of the unmanned sprayer developed are as follows:

(1) This newly developed sprayer prevents operator's exposure to agricultural chemicals, noise or danger involved.

(2) During the operation of the unmanned sprayer, the operator may carry out himself/herself other activities such as preparation of agricultural chemicals, hence the reduction of labor and enhancement of work efficiency.

(3) Theoretically, a single operator can manipulate simultaneously more than 2 unmanned sprayers, thus contributing to labor-saving and timely pest control.

In consequence, introduction of the unmanned air blast sprayer ensures efficient and labor-saving application work of chemicals for pest control in a comfortable environment.

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