Research Article

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Experiments on watering citrus fruits with a wire-supplied drone using RTK-GNSS

Abstract

In Japanese agriculture, pesticide-spraying drones are becoming more widespread, with the aim of saving labor in pesticide spraying. The size of aircraft has been increasing, and large aircraft capable of spraying 30 liters of chemicals in about 15 minutes have been developed. In orchards, there is a need to spray even larger quantities of chemicals over a longer period. We have developed a large drone that is wired for power and water to enable it to operate for long periods of time. The effectiveness of the system was verified through actual flight tests on citrus fruit.

Keywords: RTK-GNSS, watering drone

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Masafumi Miwa,[1] Satoshi Hishida,[2] Keiichi Nishikawa,[3] Masataka Shiromaru[4]

[1]Graduate School of Technology, Industrial and Social Sciences, Tokushima University, Japan
[2]Engineer at Hishida R&D Co., Ltd., Japan
[3]System Research, Japan
[4]AP System, Japan

Correspondence: Masafumi Miwa, Graduate School of Technology, Industrial and Social Sciences, Tokushima University, 2-1 Minamijosanjima-cho, Tokushima 770-8506, Japan, Email mi@tokushima-u.ac.jp

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Introduction

In agriculture of Japan, labor shortages have become a serious problem due to a decreasing and ageing workforce, making labor-saving, securing manpower and reducing the burden an important issue.[1] Pesticide-spraying drones are becoming widespread with the aim of saving labor in pesticide spraying. The size of the aircraft has been increasing, and large aircraft capable of spraying 30 L of chemicals in about 15 minutes have been developed.[2] However, in orchards, there is a need to spray a larger amount of chemicals over a longer period. Citrus fruits are often grown on slopes and, unlike other fruit trees, pesticides are often applied with relatively high pressure to ensure that the chemicals reach the opposite side of the spraying surface. In addition, the chemicals may not reach the fruit near the tops of fruit trees when sprayed from the ground.

On the other hand, we have developed a large drone that can be wired with electricity and water to operate for long periods of time for the purpose of dust control at building demolition sites. A reaction force cancellation system[3] has been developed for this large drone to control the reaction force generated by water spraying and to improve the stability of attitude control.

In the present study, this experience was used to improve the drone for spraying citrus fruits, and its effectiveness was verified through an actual flight test. Furthermore, the effectiveness of using RTK-GNSS[4] to improve positioning accuracy was also verified.

Experimental setup

Watering drone system

Figure 1 shows the appearance of the watering drone and Table 1 shows its specifications. The watering drone is based on a hexacopter. A flight controller (Cube Black: CubePilot) with a customized version of the open software ArduCopter was installed. A networked RTK (RTK: Real Time Kinematic)-GNSS system was used for position control of the drone body. In this case, the base station GNSS was set on the ground and the rover GNSS was mounted on the drone. The open-source Mission Planner was used for the GCS. In order to avoid the effects of voltage drops caused by power transmission, a high-voltage power transmission system with a DC voltage of 300 v was used in the wired power supply system for long-duration flights. Three-phase 200 v AC was converted to 300 v DC by an AC/DC converter and transmitted to the aircraft. A DC/DC converter mounted on the aircraft stepped down the voltage to 48 v to provide the power supply. An engine pump (Maruyama Corporation: MS417EA) was used to supply water continuously for a long period of time. In the spraying experiment, the same nozzle used by citrus farmers (Yamaho Industries: N-KZV-20) was selected.

Figure 1 Appearance of watering drone.

Table 1 Watering drone specifications

Airframe dimensions [mm]	2100×2100×450
Airframe weight [kg]	12
Maximum take-off weight [kg]	24
Propeller	6
Propeller diameter [in]	24
Functions.	Waterproof, Corded

Reaction force cancellation system with tilt mechanism

A tilt mechanism[5,6] developed at Tokushima University was mounted as a new thruster device to cancel the reaction force of water spraying while maintaining a horizontal posture during movement. The tilt mechanism is shown in Figure 2. A tilt mechanism using waterproof servomotors was added to the left and right arms of the experimental machine to enable the left and right propeller rotation surfaces to be tilted. By tilting the left and right propellers synchronously in the forward and backward directions, the aircraft can move forward and backward while keeping the aircraft horizontal. The aircraft's yaw axis was controlled by applying differential motion to the left and right propellers.

During water spraying, the aircraft is pushed backwards by the recoil. In position control, the error from the target position due to the recoil is precisely measured by RTK-GNSS. To correct the error, the position control system usually tilts the aircraft. In our reaction force cancellation system,[3] instead of tilting the aircraft, the tilt mechanism tilts the propeller rotation surface to exert horizontal thrust, thereby maintaining the aircraft horizontal for position control (see Figure 3). This enables stable hovering and watering (the watering position does not shift because the aircraft is not tilted).

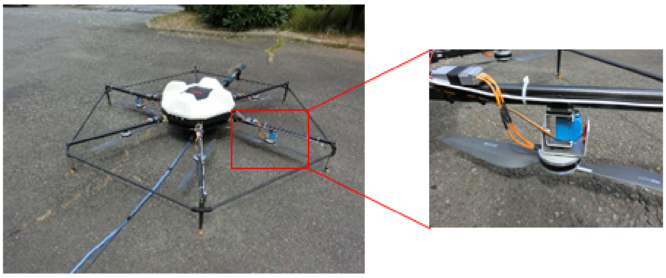

Figure 2 Appearance of tilt mechanism.

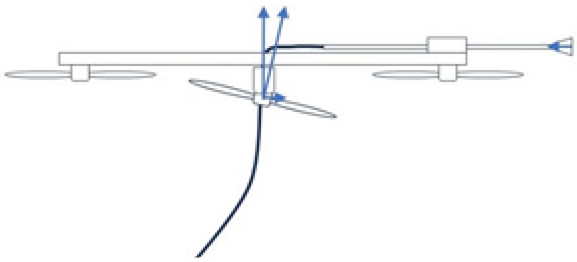

Figure 3 Relationship between tilt mechanism and aircraft during water spraying.

Experimental method and results

On 19 September 2023, an automatic watering experiment was conducted on Innoshima Island, Hiroshima Prefecture, and on 20 September, a watering experiment was conducted on Ikuchijima Island, Hiroshima Prefecture, using manual control. In these experiments, water was sprayed, but in the future, chemicals will be applied according to the fruit tree and the time of year.

Watering experiment by autopilot

With the cooperation of Sanwa Farm on the island of Innoshima, an autopilot experiment was conducted to spray water on fruit trees growing on a slope. Figure 4 shows the route data used for the autopilot (white) and the actual flight path (red). In the experiment, the aircraft first took off in PosHold mode, which performs position keeping control, and moved manually to the starting point, after which it changed to auto mode and started the automatic navigation. Water spraying was started at the same time. When the automatic navigation was completed, the watering was stopped, the mode was changed to PosHold mode and the aircraft was landed by manual control. The reason for manual control of the take-off and landing was to prevent cables and hoses from getting entangled in the fence between the take-off and landing point and the spraying area. The area where the white and red lines overlap in Figure 4 is the automatic flight section. The flight trajectory is in good agreement with the route data.

Figure 5 shows the tilt of the pitch axis in relation to the reaction force of the water spray and the tilt mechanism. The section from "Auto" to "PosHold" on the right, described in the lower part of the diagram, is the automatic flight section. During automatic flight, the attitude control system is structured to use the aircraft's velocity vector as the target value. Therefore, the velocity vector calculated according to the current pitch angle is given to the attitude control system so that the pitch angle of the aircraft becomes 0 degrees. Therefore, although the target angle in Figure 4 is not 0 degrees, the pitch angle is maintained near 0 degrees and water spraying could be carried out in stable flight. This was due to the high positioning accuracy of the RTK-GNSS and the effect of the reaction force cancellation system. In Japan, there are several services that distribute VRS and RRS signals for RTK-GNSS via the internet. These services can be used with an internet connection via LTE or STARLINK, etc. Figure 6 shows a photograph taken during automatic navigation.

Figure 4 Automatic navigation path data and flight trajectory.

Figure 5 Control of pitch angle in automatic navigation.

Figure 6 Scene during the experiment.

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Manual watering experiment

With the cooperation of Harada Farm on Ikuchishima, water was sprayed on fruit trees by manual piloting. Figure 7 shows the flight paths (light blue) plotted at regular intervals during the experiment. In the experiment, take-off, flight and landing were carried out with the flight mode set to PosHold mode. Figure 8 shows the inclination of the pitch axis during flight. In PosHold mode, the attitude control function that gives the target angle is used, so the target value in the figure is 0 degrees and the aircraft tracks well. The recoil of the water spray is also successfully cancelled. Figure 9 shows the experimental situation. In this experiment, a crawler-type UGV was used to transport the power cable and water hose. This UGV is designed to follow the spray drone when the distance between the UGV and the water drone is more than 5 m. In actual spraying operations, the UGV is considered to be an important aid when using a wired type drone.

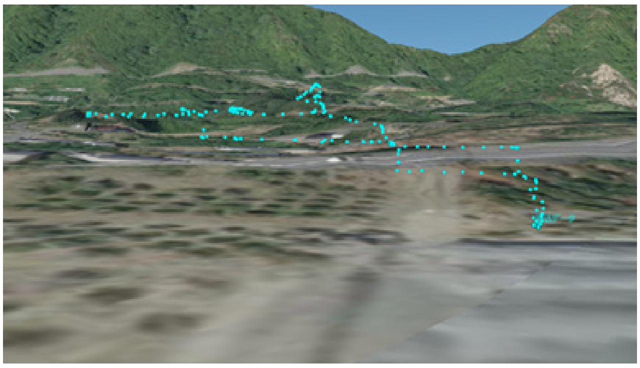

Figure 7 Flight trajectory of manual control.

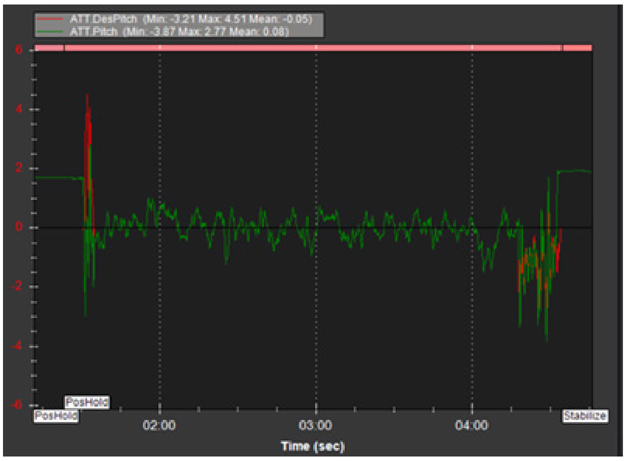

Figure 8 Pitch angle control in manual control.

Figure 9 Scene during the experiment.

Evaluation of watering results with water-sensitive paper

In this manual spraying experiment, water-sensitive paper was placed inside the fruit trees beforehand. It was observed how far the water reached during the spraying operation, i.e. whether it was effective as a spray. Figure 10 shows the chemical adhesion standard table and Table 2 shows the adhesion area of the adhesion standard table. Figure 11 shows example results of water-sensitive paper after spraying, Figure 12 shows the arrangement of the water-sensitive paper and the results. A number of adhesion indices of 10 were observed, indicating that the sprayed water adhered well.

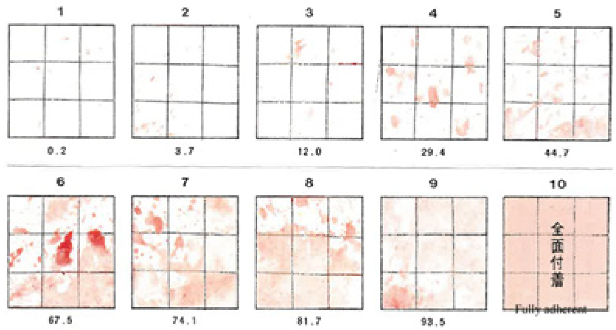

Figure 10 Standard chart of chemical adhesion.[7]

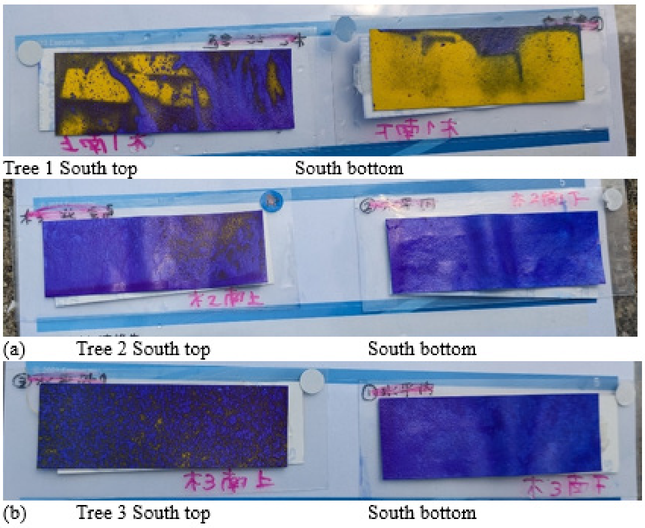

Figure 11 Example of water-sensitive paper after spraying.

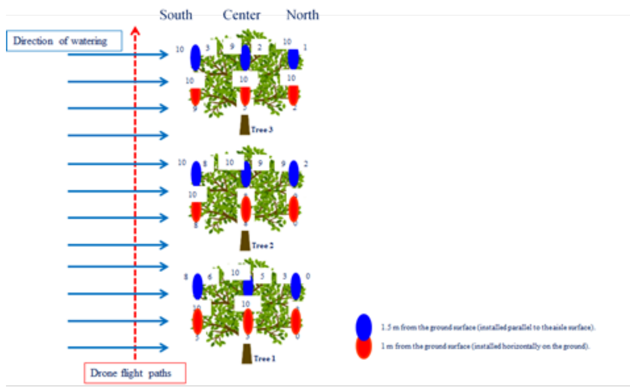

Figure 12 Water-sensitive paper test results of inclined nozzles experiment.

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Table 2 Area of adhesion in the standard table of adhesion per 90m^2.[7]

Reference point	1	2	3	4	5	6	7	8	9	10
Adherence area (%)	0.1~2.5	2.6~5.0	5.1~20.0	20.1~40.0	40.1~60.0	60.1~70.0	70.1~80.0	80.1~90.0	90.1~99.9	100

Conclusion

As a pesticide spraying drone for citrus fruits that are sprayed with chemicals at relatively high pressure, an RTK-GNSS and a tilt mechanism were added to the wired water-supply drone developed so far, and experiments were conducted on actual spraying of citrus fruits with water. As a result, the tilt mechanism cancelled the recoil of the water spray and maintained the attitude near the target value of the pitch angle, while successfully controlling the position precisely. The water spray was evaluated using water-sensitive paper attached to citrus fruits and found to adhere well.

In the future, the operability and downsizing of the machine will be examined, and the results will be evaluated in actual experiments using pesticides.

Acknowledgments

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Conflicts of interest

Authors declare that there is no conflict of interest.

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