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Development Report:

Precision Flight Drones with RTK-GNSS

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An RTK-GNSS was introduced to realize the precision flight of a drone system for transporting harvested loquats and spraying pesticides to suppress the rotting of fruits. Transportation and spraying experiments were conducted. Precision automatic navigation flights were realized in transportation experiments. In addition, precision landing was performed within approximately 10 cm of the target position. Sufficient spraying flights were performed during the spraying experiment.

Keywords: RTK-GNSS, precision flight, transporting flight, spraying flight, automatic flight

1. Introduction

Multicopters, popularly known as drones, are increasingly being used in industrial applications such as aerial photography and pesticide spraying. For aerial photography and pesticide spraying over a wide area, aerial work using automatic navigation based on GPS location information has been put to practical use. In aerial photography, information such as the latitude, longitude, and angle of view at the time of shooting can also be used; therefore, the accuracy of output data such as orthoimages can be improved by using this information in post-processing. Furthermore, GPS location information is important for applications that require maintaining the accuracy of the flight path, such as pesticide spraying and transportation.

The Nagasaki BIWA Production Consortium is developing a drone system for transporting harvested loquat fruits and spraying pesticides to control the rotting of fruits. The goal is to use drones to reduce the time required to transport fruits at harvest by up to 80%, and for pest control, to reduce the time required to apply pesticides by up to 75% of manual spraying. To achieve this goal, it was determined that precision flight must be achieved, and an RTK-GNSS was introduced to this drone system.

In this paper, we report the results of the flight test using RTK-GNSS in the demonstration test conducted by the Nagasaki BIWA Production Consortium.

2. Experiment Equipment

2.1. Drone System

In our experiments, we used MBP Japan's hexa-rotor multicopter SKY CAP H1000 Hosaku 55 as the base aircraft. The flight controller (FC) used was Holybro Pixhawk 4 (firmware: ArduPilot ArduCopter 4.0.3 [a]). We used i-System Research's Sept-SOI (base station: Septentrio AsteRx-m2 UAS; rover station: Septentrio AsteRx-m2a UAS) [1] as the GPS to measure and control the aircraft position. For compass and comparison purposes, we also used a regular GPS unit (GPS receiver: U-blox NEO-M8N) that came with Pixhawk 4. Microhard P2400 was used for the correction data communication of the RTK-GNSS and telemetry communication between the aircraft and GCS (Ground Control Station). The Futaba T10J transmitter and R3008SB receiver were used as the radio-controlling equipment. In the transport experiment, the pesticide spraying device was removed from the experimental machine, and a basket for transporting loquats was mounted.

The experiment was conducted by automatic navigation, for which the route data were generated using Mission Planner [b], a GCS software on note PC. The experiment was recorded using a video camera and checked using telemetry data from the Mission Planner and flash data of the FC. **Fig. 1** depicts the appearance of the experimental machine with a transport basket.

2.2. RTK-GNSS

This section describes the RTK-GNSS used in this study. **Fig. 2** demonstrates a schematic view of the RTK-GNSS. The base station obtains the correction information of the virtual reference station from the cell phone line via the Internet to determine the position of the base station, which is then linked to the rover station as RTK-GNSS. This method enables highly accurate positioning even in areas with hinterland, where the positioning accuracy is degraded with a conventional GPS. The RTK-GNSS is used in several applications that take advantage of its measurement accuracy, for example, in high-precision automatic operation, including navigation of automated tractors on farms, in the creation of DEM models

Fig. 1. Test drone with RTK-GNSS.

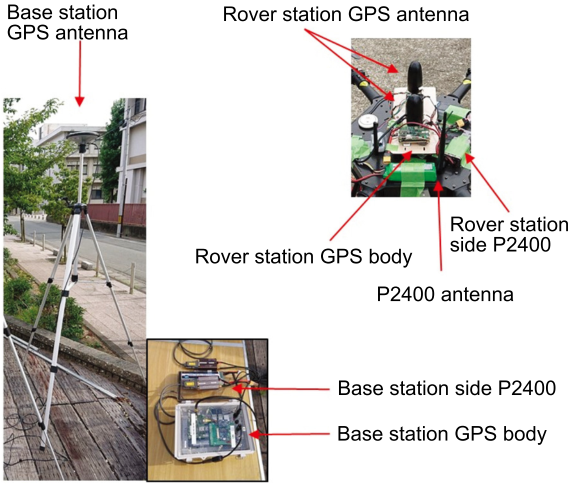


Fig. 2. RTK-GNSS used in the test.

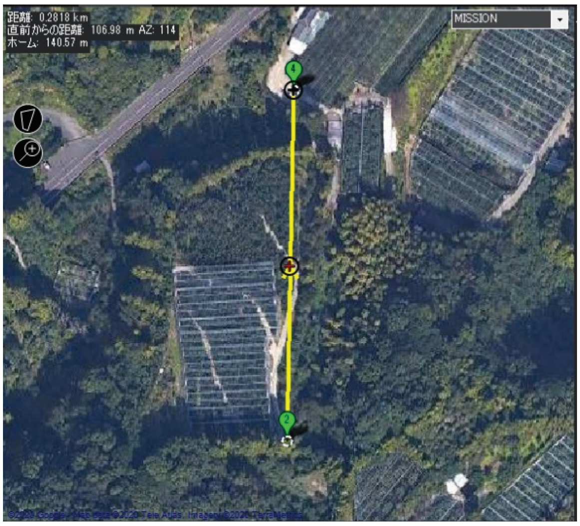


Fig. 3. Example of flight route data used in the experiment.

Fig. 4. Drone transporting the harvested fruit.

for automatic operation [2], and in the creation of reference data for the evaluation of maps automatically generated by other methods [3].

3. Precision Flight Experiment with RTK-GNSS

The Nagasaki BIWA Production Consortium is developing a drone system with the expectation that in the future, it will be safely operated by people who are not experts in drones, such as farmers and the employees of agricultural cooperatives. This system requires precise automatic navigation. This system is used in a loquat field in a mountainous area, and it is difficult to obtain positioning with sufficient accuracy using a conventional GPS. Therefore, collisions owing to positioning errors are expected in automatic navigation. To avoid this risk, we believe that precision flight using the RTK-GNSS is essential. In this study, we conducted a transport experiment and pesticide spraying experiment using an experimental aircraft equipped with the RTK-GNSS by automatic navigation. The coordinates of the takeoff and landing points of each route used in the automatic navigation were measured by the RTK-GNSS with the drone placed at the points in advance.

3.1. Transportation Experiment

First, we conducted an experiment on the transport of loquats using drones. The transportation experiment was conducted at Mori Farm in Nagasaki City. **Fig. 3** presents the route data (outbound) used in the experiment. In the experiment, the route was set up, assuming a flight from the loquat harvesting site to the collection site. Both locations had a height difference of approximately 20 m and a distance of approximately 143 m.

To evaluate this method of transport, in the basket, we placed harvest bags containing the actual harvested loquats and transported it by flight using an experimental aircraft. The harvest bags in the basket were photographed before and after the flight. Transport by walking was also performed for comparison purposes. **Fig. 4** illustrates the drone transporting the harvested fruits, and

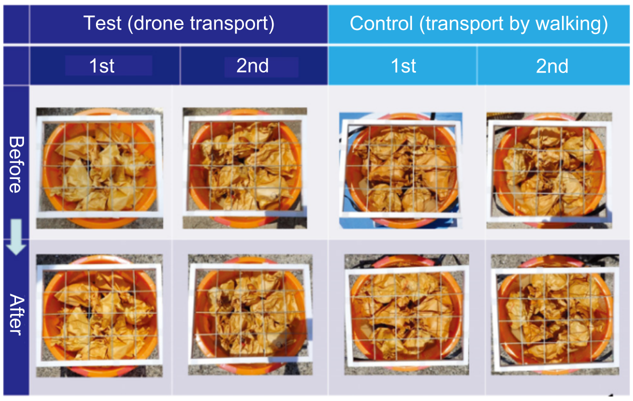


Fig. 5. Loquat storage bag before and after transport.

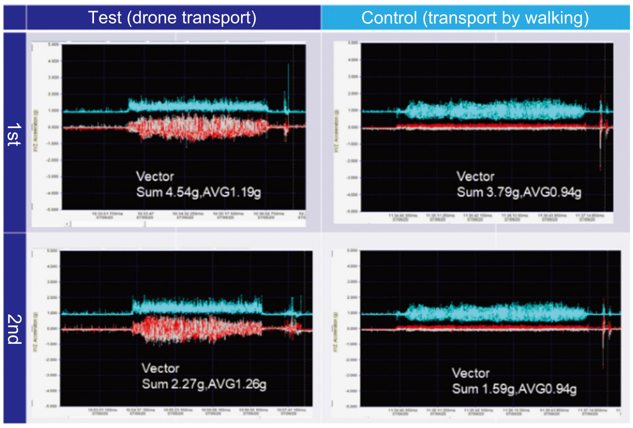


Fig. 6. Measurement results of vibrations inside the basket.

Fig. 5 depicts the loquat storage bags before and after transport. The left side shows the basket transported by the multicopter, and the right side shows the basket transported by walking as a comparison. The position of the loquat storage bag changed during the second walk-and-carry operation, but no significant change was observed in the other operations.

Figure 6 illustrates the results of the vibration measurements inside the harvesting basket. The blue graph in the figure shows the vibrations in the Z-axis (vertical) direction, and the red and white graphs show the vibrations in the X and Y axes (horizontal) directions, respectively. In the Z-axis direction, the vibrations were larger for transport by walking. However, in the X- and Y-axis directions, the vibrations were larger for drone transport. This was because of the vibration of the main motor and the effect of attitude control.

Consequently, we noted that, based on the appearance of the inside of the basket and the loquats after transport, drone transport could be used without any problems. Vibrations could be suppressed using an insulator, such as an alpha gel.

Next, for transport from a hillside loquat field, we conducted a transport experiment on a shipping route that included an relay point. The experiment was conducted with a spare machine with sprayer specifications owing to machine problems. **Fig. 7** demonstrates the route between the ground (collection site) and the relay point, and **Fig. 8** demonstrates the route between the relay point and the harvesting site. The flight route in **Fig. 7** has an altitude difference of approximately 40 m and a horizontal distance of approximately 185 m, and that in **Fig. 8** has an altitude difference of approximately 43 m and a horizontal distance of approximately 214 m.

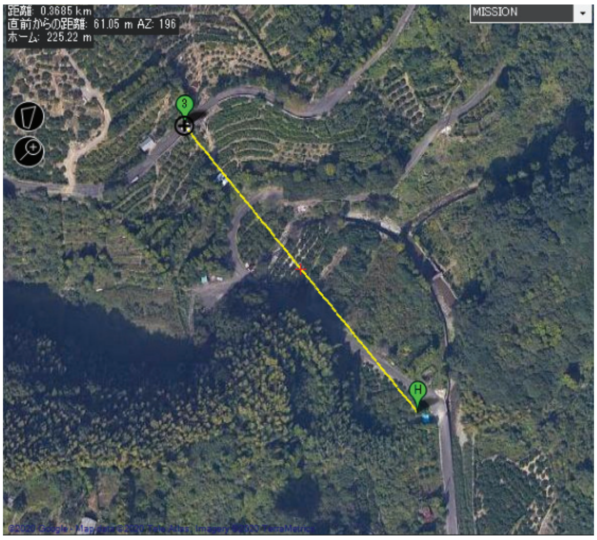


Fig. 7. Route from the collection point to the relay point.

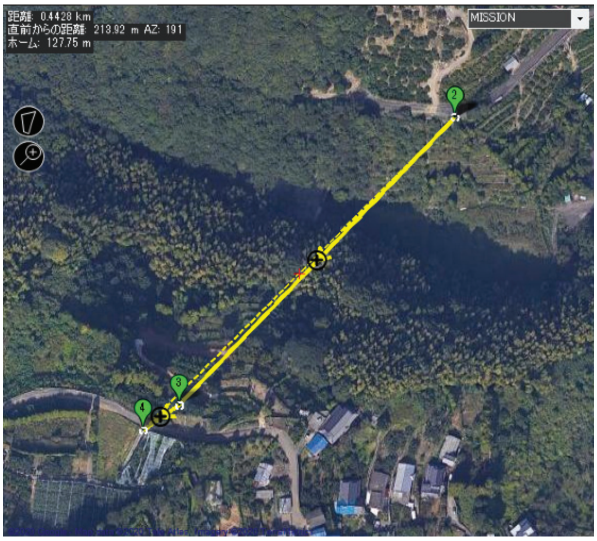


Fig. 8. Route from the relay point to the harvesting station.

Figure 9 illustrates the trajectory of the experimental machine in the transport experiment, and **Figs. 10–12** illustrate the trajectories near the collection point, relay point, and harvesting site, respectively. In each figure, the blue line shows the positioning results with a conventional GPS, the green line shows the positioning results with the RTK-GNSS, and the red line shows the position adopted by the FC. The purple line is the waypoint (passing point) data, including past data that remained in the FC's memory.

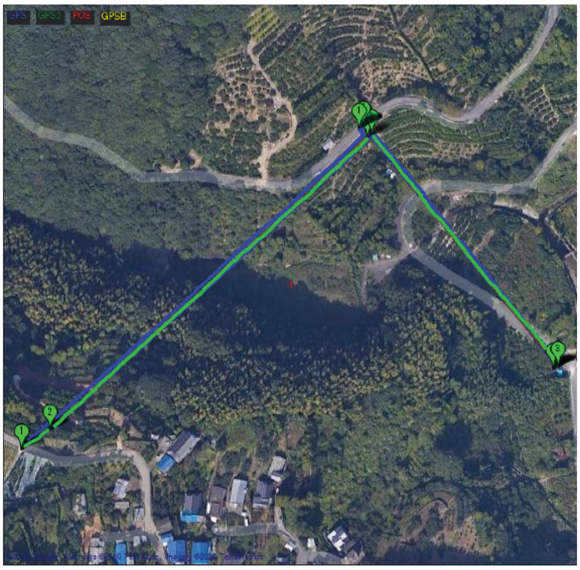


Fig. 9. Automatic navigation trajectory.

Fig. 10. Automatic navigation trajectory near the collection point.

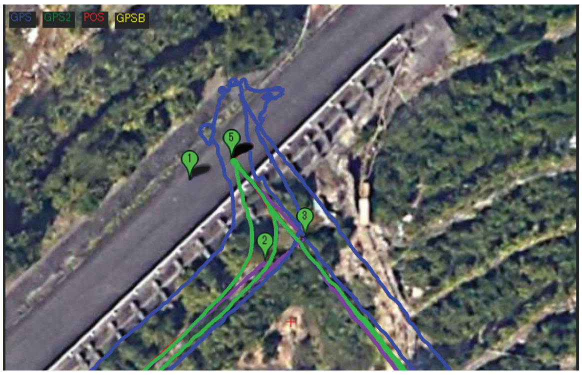


Fig. 11. Automatic navigation trajectory near the relay point.

Fig. 12. Automatic navigation trajectory near the harvesting station.

Fig. 13. Landing at the relay point on the outbound flight.

Fig. 14. Landing at the relay point on the inbound flight.

Figures 10–12 demonstrated that while the ordinary GPS positioning was very erratic, the RTK-GNSS positioning was stable and almost identical on outbound and inbound trips.

Figures 13 and **14** show what happens after the automatic landing at the relay point on the outbound and inbound routes. The tapes in **Figs. 13** and **14** are markers indicating the position of the aircraft during the latitude and longitude positioning of the relay point. For both outbound and inbound flights, the displacement during landing by automatic navigation was approximately 15 cm.

In the transport experiment, automatic navigation using the RTK-GNSS positioning was successfully performed for both outbound and inbound flights, including relay points, and safe flights, including takeoff and landing, were also achieved. However, the positioning of the conventional GPS always has an offset to the RTK-GNSS positioning results. In addition, the positioning results

Table 1. Comparison of flight time in the transport experiment with the time of transport by vehicle and on foot.

Work	Direct distance [m]	Road distance [m]	Difference of elevation [m]	Flight time [min/sec]	Vehicle [min/sec]	Reduction rate [%]	Walk [min/sec]	Reduction rate [%]	Remarks
Transport	185	700	33	1′50″	1′58″	6.8	8′40″	78.8	From lowland to hillside (A–B)
	221	2200	41	1′35″	6′16″	74.7	26′40″	94.1	Over a valley (B–C)

varied significantly near the takeoff and landing sites. In this experiment, the takeoff and landing sites were surrounded by tall trees (collection sites), intersections were surrounded by banks (harvesting sites), and there were mountain slopes at the back (relay sites). Therefore, regarding the altitude change of the aircraft during takeoff and landing, the higher the altitude, the lower was the effect of obstacles such as slopes, and the better was the reception of radio waves. The results demonstrated that altitude changes had a significant impact on positioning.

A comparison of the flight time in this transport experiment with the time of transport by vehicle and on foot between the same points is presented in **Table 1**. The results demonstrated that drone flights were not affected by the terrain and were effective in reducing the transport time. A goal of this drone system, that is, "reducing the transportation time of harvested fruits by up to 80%," was almost achieved.

3.2. Spraying Experiment

To realize the spraying of pesticides on loquats by automatic navigation, we conducted a spraying experiment using water instead of chemicals. We decided to spray from at least 3 m above the top of the fruit trees to prevent the drone's propeller wake from pushing the leaves of the fruit trees. The flight conditions during spraying were a flight altitude of 8 m and a travel speed of 2 m/s. The spraying experiment was conducted on 29 fruit trees grown in the Fujitao Chemical Spraying Test Field in Nagasaki Prefecture. To detect the results of spraying on the fruit trees, eight sheets of water-sensitive paper were attached to each of the five fruit trees. **Fig. 15** illustrates an orthoimage of the field based on aerial images, **Fig. 16** depicts the field, and **Fig. 17** shows the water-sensitive paper attached to the fruit trees. The field was built by reclaiming a valley. There is a mountain slope to the west, but the land is open to the north, east, and south.

To prepare for the spraying experiment, we first manually operated the drone to record waypoints above each fruit tree while moving it around the field to obtain route data. The data are presented in **Fig. 18**. After organizing the obtained route data, we conducted an experiment using the route data set to fly over the relatively aligned fruit trees, as shown in **Fig. 19**. In the spraying experiment, automatic navigation was used from takeoff to landing. The spraying was manually operated, and water spraying

Fig. 15. Orthoimage of the field.

Fig. 16. Fruit trees in the field with water-sensitive papers attached.

Fig. 17. Attached water-sensitive paper.

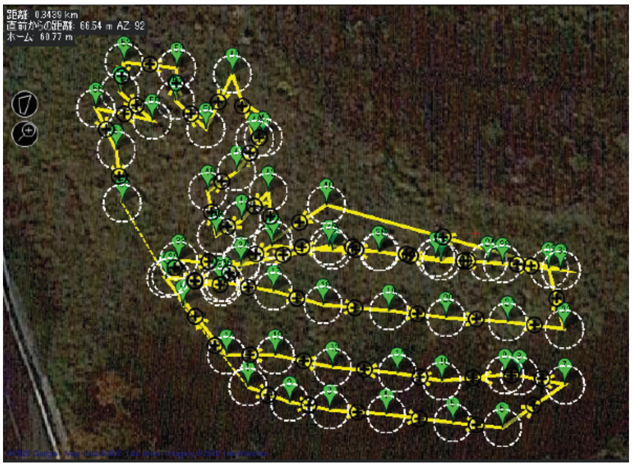


Fig. 18. Waypoint data manually set.

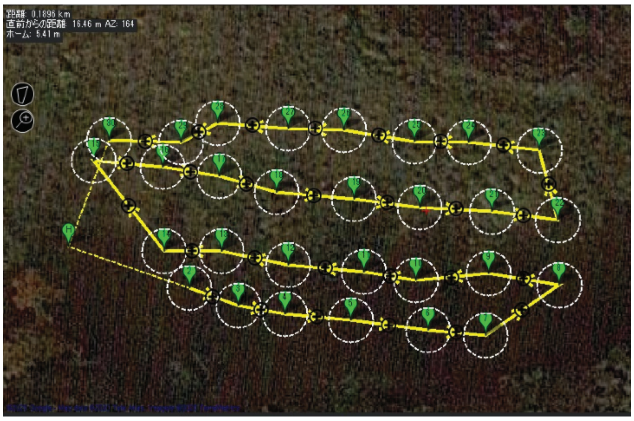


Fig. 19. Waypoint data actually used.

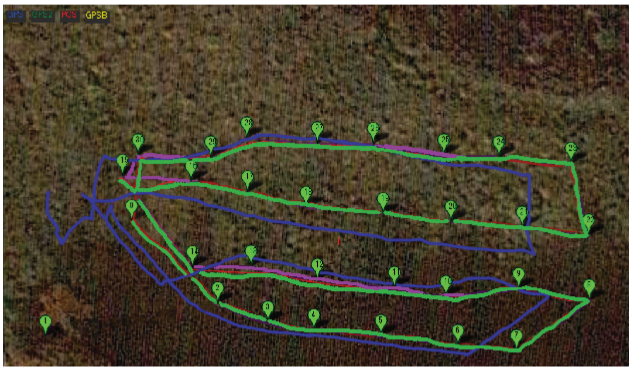
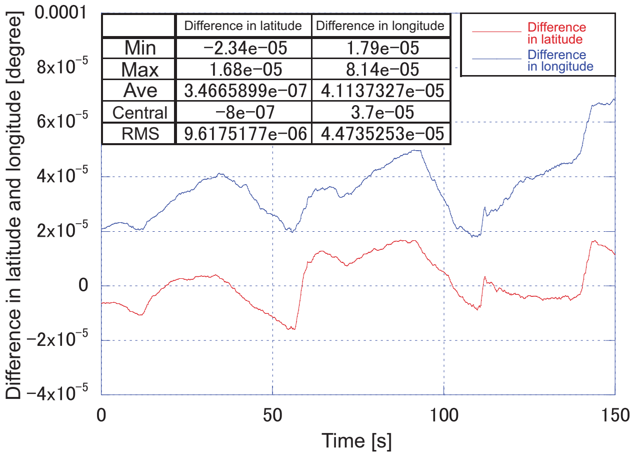


Fig. 20. Trajectory of spraying flight.



	Difference in latitude	Difference in longitude
Min	−2.34e−05	1.79e−05
Max	1.68e−05	8.14e−05
Ave	3.4665899e−07	4.1137327e−05
Central	−8e−07	3.7e−05
RMS	9.6175177e−06	4.4735253e−05

Fig. 21. Difference in positioning results between the RTK-GNSS and the conventional GPS during spraying flight.

Table 2. Signal receiving of the conventional GPS and RTK-GNSS.

	GPS	RTK-GNSS
HDOP	0.77–1.0	0.6–0.93
Number of satellites	12–16	23–27

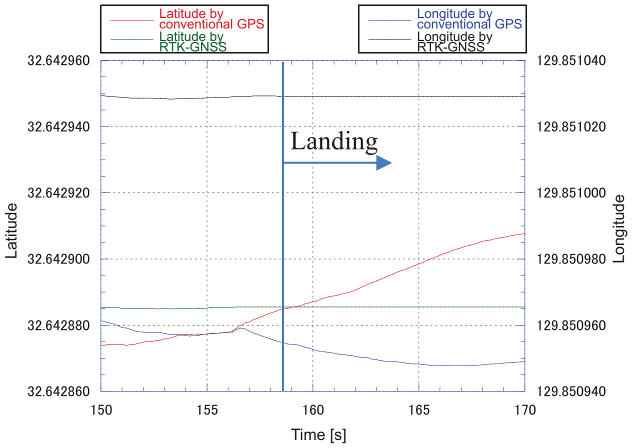


Fig. 22. Positioning results before and after landing.

started in front of the first fruit tree and stopped after the flight over the last fruit tree was completed.

Figure 20 illustrates the trajectory during the spraying flight, and **Fig. 21** depicts the difference in the latitude and longitude measured by the RTK-GNSS and conventional GPS at this time. **Table 2** presents the HDOP for the conventional GPS and RTK-GNSS and the number of satellites used for positioning at this time. The number of satellites used by the RTK-GNSS was approximately twice that used by the conventional GPS, and the HDOP was also small, resulting in a large difference between the positioning results of the RTK-GNSS and the conventional GPS.

After spraying, vertical descent landing was performed under position-holding control. The positioning results before and after landing are presented in **Fig. 22**. The latitude and longitude measured by the RTK-GNSS were constant after landing, whereas that measured by the conventional GPS fluctuated even after landing, with a range of approximately 3 m. According to our experience, the maximum error between the takeoff point and the landing point using a return to launch (RTL: automatic navigation to the takeoff point and automatic landing by vertical descent) function is about 10 cm for an RTK-GNSS

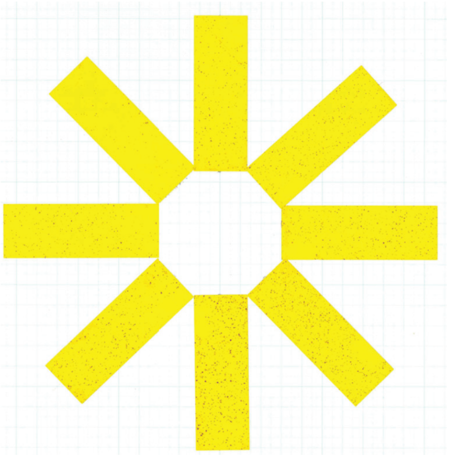


Fig. 23. Coloring status of water-sensitive paper.

Fig. 24. Example of the coloring of water-sensitive paper.

Table 3. Comparison of spraying time between drone spraying and manual spraying.

Work	Area	Drone		Manual spraying		Reduction rate [%]	Remarks
		Spraying time	Amount of sprayed liquid	Spraying time	Amount of sprayed liquid		
Spraying of pesticides	13 a	4′30″	3 L	78′	390 L	94.2	Adult tree area
	10 a	3′30″	3 L	45′	150 L	92.2	Young tree area

and about 3 m for a conventional GPS. The same error is expected to be present during automatic navigation using the conventional GPS, and the possibility of unexpected contact or collision owing to this is a concern.

As mentioned above, positioning using a conventional GPS has variable errors even in fields with good visibility, and the use of an RTK-GNSS is desirable for automated spraying flights.

Figure 23 depicts the typical coloring of a water-sensitive paper. Coloration was almost evenly distributed in each direction. **Fig. 24** displays an example of a sheet of water-sensitive paper. According to the expert who accompanied us for the spraying experiment, the amount of adhering water was comparable to that of pesticides in conventional pest control, which was sufficient under this spraying condition. Automatic navigation at an altitude of 8 m and a speed of 2 m/s was shown to be sufficient for spraying. **Table 3** presents a comparison of the spraying time between spraying by drone and manual spraying. We were able to achieve a goal of our drone system, that is, to reduce the time required for spraying pesticides by up to 75% compared to manual spraying.

4. Conclusions

The RTK-GNSS system was introduced to achieve precision flight as a drone system for transporting harvested loquat fruits and spraying pesticides to control the rotting of fruits, and it was designed to be operated safely by non-drone experts such as farmers and agricultural cooperative workers. We conducted a transport experiment and a spraying experiment using a drone system.

In the transport experiment, the drone was able to fly using the RTK-GNSS according to the route data with autopilot. In addition, it could land within 10 cm of the target position. Little change was observed in the position of the loquat storage bags in the basket before and after transport. Although the transport time varied depending on the distance and terrain, the goal was achieved with a 45%–94% reduction in transport time compared to walking or driving.

In the spraying experiment, we also confirmed that precise spraying flight directly over the fruit trees could be realized using the RTK-GNSS. The evaluation using the water-sensitive paper confirmed that sufficient spraying could be performed with the proposed system. In addition, the spraying time was reduced by 90% compared to manual spraying, thus significantly achieving the target.

In the future, we will work to simplify the safety management system and operations, as well as create manuals, to put the system into practical use.

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Supporting Online Materials:

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[b] ArduPilot, "Mission Planner Home." https://ardupilot.org/planner/index.html [Accessed April 5, 2021]

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