Position Control between GNSS and Non-GNSS Environments using High Precision IMU

Masafumi Miwa[1,*], Masataka Shiromaru[2], Keiichi Nishikawa[3], and Hisanori Araki[4]
[1] *Tokushima University, 2-1 Minamijosanjima, Tokushima City, Tokushima, 770-8506, Japan*
[2] *AP System Co., 1-26-14, Saiji, Suita, Osaka, 565-0836, Japan*
[3] *i System Research Co., 671 Marukimoki-cho, Nakagyo-ku, Kyoto, 604-8106, Japan*
[4]*EARTH ANALYZER Co., Ebisudani27-1, Fuchgakicho, Ayabe city, Kyoto, 623-0115, Japan*
[*]Corresponding author. E-mail: miw@tokushima-u.ac.jp

Abstract

UAVs such as multicopters use GNSS to obtain position information for position control; when RTK-GNSS is used, the position accuracy is within a few centimeters. However, if a UAV enters an environment where satellite signals cannot be received, such as under a bridge or in a tunnel,

position control becomes impossible. To cope with such cases, we propose a system that combines RTK-GNSS and a high-precision IMU.

In this study, a multicopter is equipped with RTK-GNSS and an IMU. When the multicopter enters under a bridge or a short tunnel and the RTK-GNSS positioning state becomes RTK-Float, the system switches to inertial navigation using the IMU. It was confirmed that the UAV could fly with high accuracy for about 30 seconds after entering this state. The maximum error in position after disconnecting the RTK-GPS antenna was about 2.83 m. Then, when the RTK-GNSS positioning state returns to RTK-Fixed, it switches to flight using RTK-GNSS positioning information. The effectiveness of the proposal was confirmed through actual flight experiments.

Keywords Non-GNSS environment, RTK-GNSS, Precious IMU, inertial navigation

1 Introduction

UAVs such as multicopters use GNSS to acquire position information for position control, and when RTK-GNSS is used, position accuracy is within a few centimeters[1]. However, if the UAV enters an environment where satellite signals cannot be received, such as under a bridge or in a tunnel, position control becomes impossible. To address such cases, we propose a system that combines RTK-GNSS and a high-precision IMU. In this study, a multicopter is equipped with RTK-GNSS and IMU. When the multicopter flies under a bridge, inside a short tunnel, or temporarily inside a building, it switches to inertial navigation using the IMU when the RTK-GNSS positioning state becomes RTK-Float. It was confirmed that the UAV could fly with high accuracy for approximately 30 seconds after entering no-GNSS state. After that, when the RTK-GNSS positioning state returns to RTK-Fixed, the UAV switches to flight using RTK-GNSS positioning information.

In this study, flight experiments were conducted to reproduce the transition to a non-GNSS/GNSS environment by disconnecting and restoring the RTK-GNSS antenna.

2 Experimental Setup

Experiments were conducted with the following test multi-copter equipped with an IMU and other sensors. Figure 1 shows the appearance of the test multi-copter used in experiments. The Octocopter (QMO-1000 : Quest Corporation Co., Ltd.) was equipped with a CubeOrange + ArduCopter (FC) as flight controller. For GNSS, MOSAIC-X (Septentrio) with two antennas was used as the RTK-GNSS (RTK) used for navigation. Here3 (GNSS) was used as a conventional GNSS. In addition, another Mosaic-X was used as the reference RTK-GNSS (R-RTK). Ekinox-E IMU (SBG Systems)[2] was installed for non-GNSS navigation.

Figure 2 shows the configuration of the navigation system. IMU was connected to FC as the primary GNSS and GNSS as the secondary. The antenna line of RTK is switched on and off by another R/C device. If the switch is on and the RTK positioning signal (NMEA format) is transmitted to IMU with RTK-FIXED state, IMU updates and records the Kalman filter and position information while transmitting the positioning information directly to the FC. If the positioning information from RTK to IMU is cut off by a switch, the amount of movement is estimated using the acceleration and angular velocity from the point of cut off, and the position information recorded immediately before the cut off is added as an offset and transmitted to FC in NMEA format lat/long information with RTK-FIXED state.

Estimation of movement in IMU is continued until the estimation error exceeds the threshold value set in for each parameter. When the estimation error exceeds the threshold value, IMU stops outputting latitude and longitude information to FC. At this time, FC uses positioning information from the secondary GNSS, assuming that the primary GNSS has disappeared.

Next, when RTK antenna switch is turned on again and RTK becomes RTK-Fixed state, IMU transmits the positioning information from RTK to FC. At this time, FC uses the positioning information from the primary GNSS, i.e. RTK.

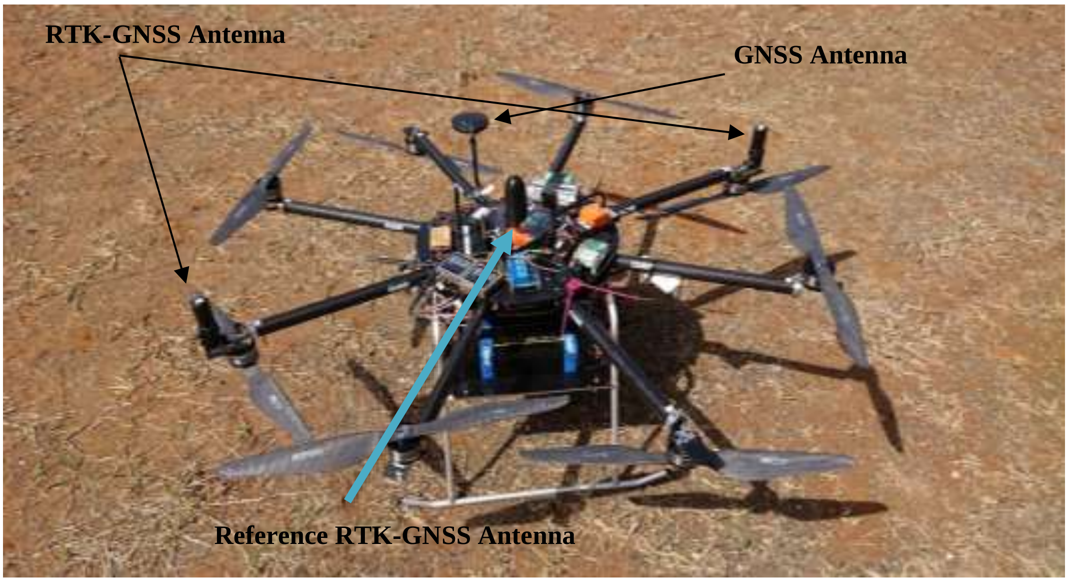

Figure 1. Experimental multi-copter

Figure 2. Experimental IMU unit

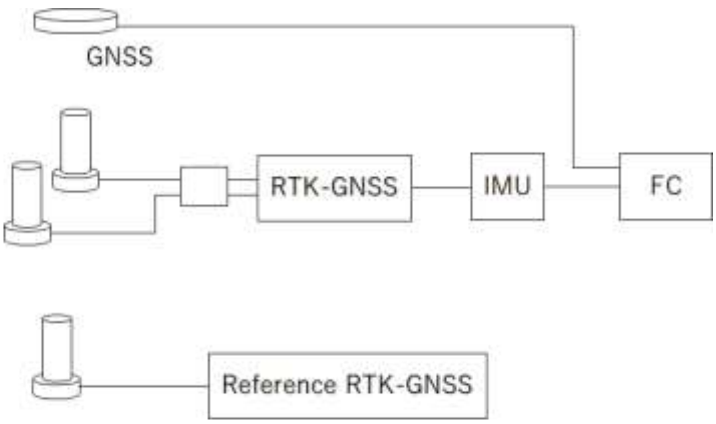

Figure 3. System configuration of navigation system

3 Experimental Method

In the experiment, the antenna of the RTK is disconnected by a radio-controlled device during automatic navigation, and test multi-copter flies with IMU output. After 40 seconds had elapsed since the antenna was disconnected, the antenna was reconnected and the behavior of test multi-copter was observed. Figure 4 shows the route used in experiments. In experiments, after taking off manually from the Home Point ('H' marker in the figure), test multi-copter's behavior was checked in position control mode. Then Automatic navigation was initiated.

In automatic navigation, test multi-copter first climbs to an altitude of 10 m, sets the flight speed to 2.0 m/s, and starts flying toward WP3 ('3' in the figure). After arriving at WP3, test multi-copter waits for 2 seconds, then changes its flight speed to 1.5 m/s and flies to WP5, at which point RTK antenna is manually disconnected. And 340 seconds later, RTK antenna is reconnected. After arriving at WP6, test multi-copter waits for 1 second and then flies to WP7. After arriving at WP7, test multi-copter waits for 3 seconds, then flies to WP8. 20 seconds after arriving at WP8, test multi-copter heads to the home point by RsTL and lands.

The experiments were recorded by video camera. At the same time, test multi-copter position was measured by the R-RTK.

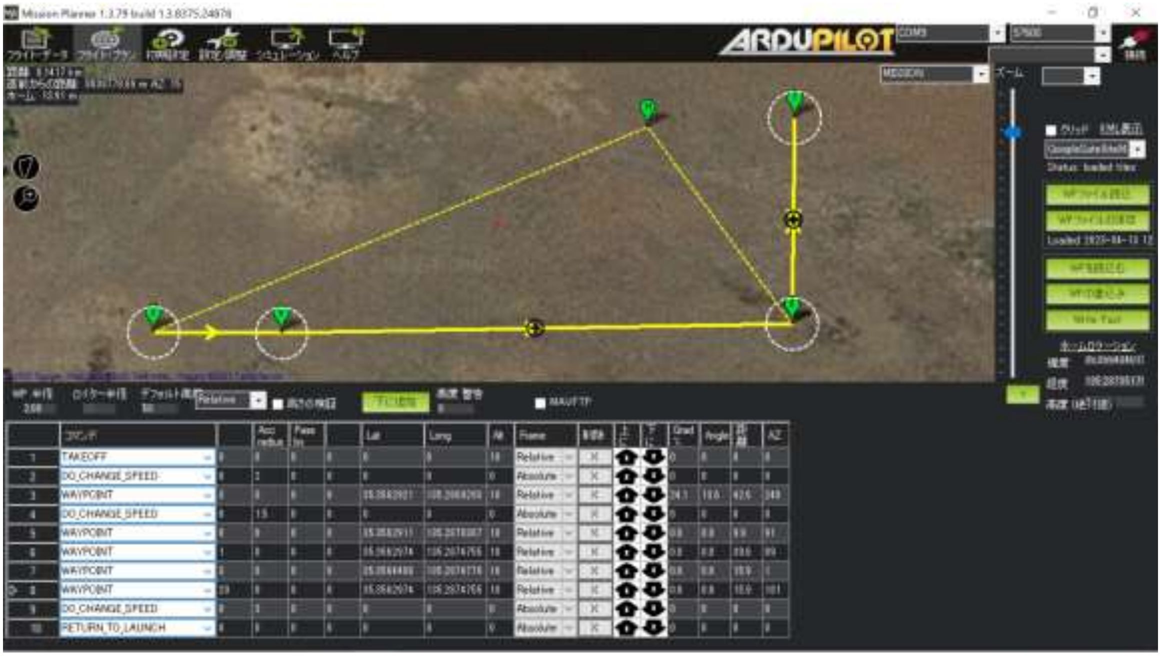

Figure 4. Way Point data setting

4 Results and Discussions

Automatic navigation was performed using the way point data set in Fig. 4. Fig. 5 shows the typical flight trajectory based on log data recorded in FC by GCS (Mission Planner). The purple line in Fig. 5 is the connecting lines of way points, the blue line is the trajectory with GNSS, and the green line is the trajectory with IMU. The red line is the trajectory adopted by FC. For the most part, the green and red lines coincide. As will be explained later, the green line is clearly visible only near point 8, where the discrepancy between IMU estimate and RTK measurement becomes large. In experiments, test multi-copter first took off manually from waypoint(WP) 0 and then started the autopilot (arrowed area in the figure). After the autopilot started, test multi-copter first climbed to 10 m and then started moving toward WP3 at a speed of 2 m/s. After passing WP3, the speed was reduced to 1.5 m/s and test multi-copter passed WP5. At WP5, the antenna of RTK was disconnected by the radio-controlled device, and the flight continued with the position information estimated by IMU.

After arriving at WP6, test multi-copter flew toward WP7, and then RTK antenna was reconnected on the way to WP8. IMU estimation error increased while waiting at WP8. IMU trajectory was near WP8, but the GNSS trajectory was shifted to the south. Review of the video at this time showed that the aircraft was gradually shifting to the south.

When RTK returned, IMU estimate jumped from the previous value. In order to avoid the danger of a sudden trajectory jump, FC took a value halfway between the previous IMU value and the new value, and used this value to gradually move the adopted position information closer to IMU estimated value. As a result, the FC's trajectory and the IMU's trajectory diverged. The FC then adopted the IMU's estimate. After the end of the wait at point 8, the aircraft headed for the takeoff point at RTL.

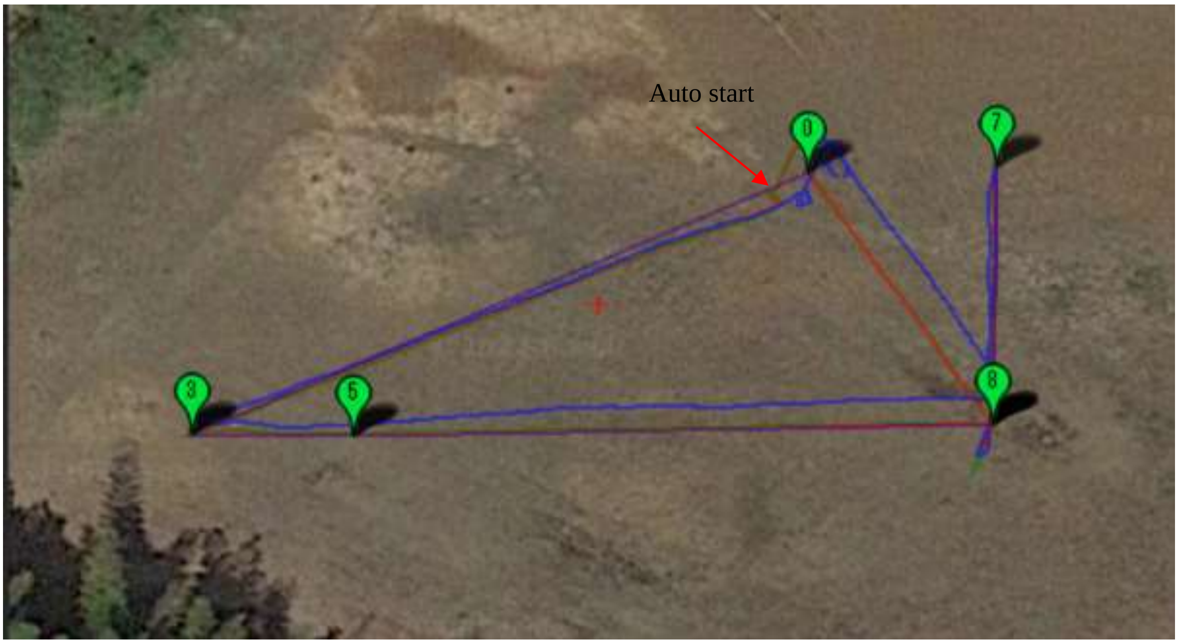

Figure 5. Trajectory of test flight by Mission Planner

Fig. 6 shows the IMU trajectory and reference RTK trajectory recorded at FC. The IMU trajectory was recorded at 5 Hz and the R-RTK at 1 Hz. The blue dots in Fig. 6 are the IMU trajectory and the orange dots are the R-RTK trajectory. Looking only at Fig. 6, the IMU trajectory and the R-RTK trajectory are in good agreement.

Fig. 7 also shows an enlarged version of the circle in Fig. 6. In Fig. 7, at arrow 1, test multi-copter was flying with the estimated value of IMU output. At the same time, IMU estimate and R-RTK output are in good agreement. In the part from WP6 to WP7 (arrow 2), IMU estimate and R-RTK output gradually begin to diverge.

While moving from WP7 to WP8, the antenna of the RTK is reconnected and the aircraft waits for 20 seconds at WP8. At this time, the IMU estimate showed a nearly constant value, but the estimation error was increasing, and the test multi-copter was moving gradually as shown by the arrow 4. Later, when RTK returned to RTK-Fixed, the IMU output became the measured value of RTK, and the aircraft moved to the vicinity of the star mark in Fig. 7. Test multi-copter then moved to WP8 on the trajectory of arrow 5 and then headed for Home Point on RTL as shown by arrow 6. The above experiment was conducted multiple times and similar results were obtained.

The same experiments were performed multiple times. The results showed that the maximum error in position after disconnecting the RTK-GPS antenna was about 2.83 cm.

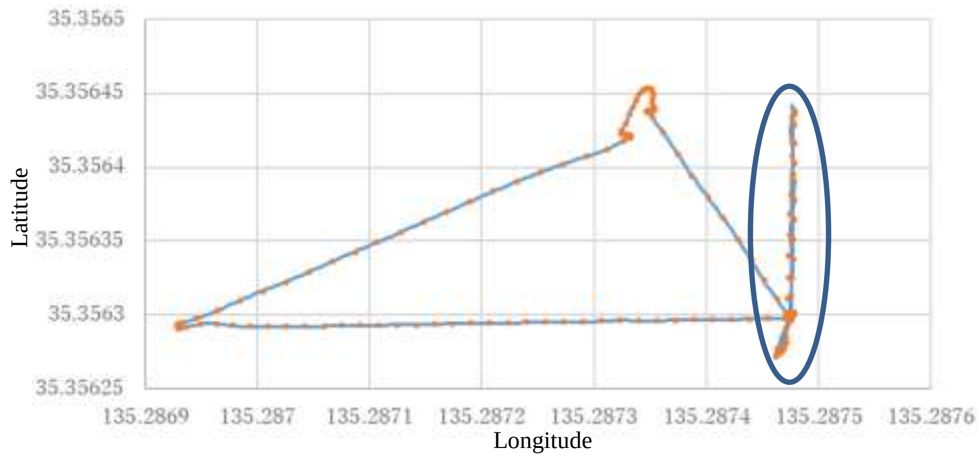

Figure 6. Trajectories of IMU and R-RTK

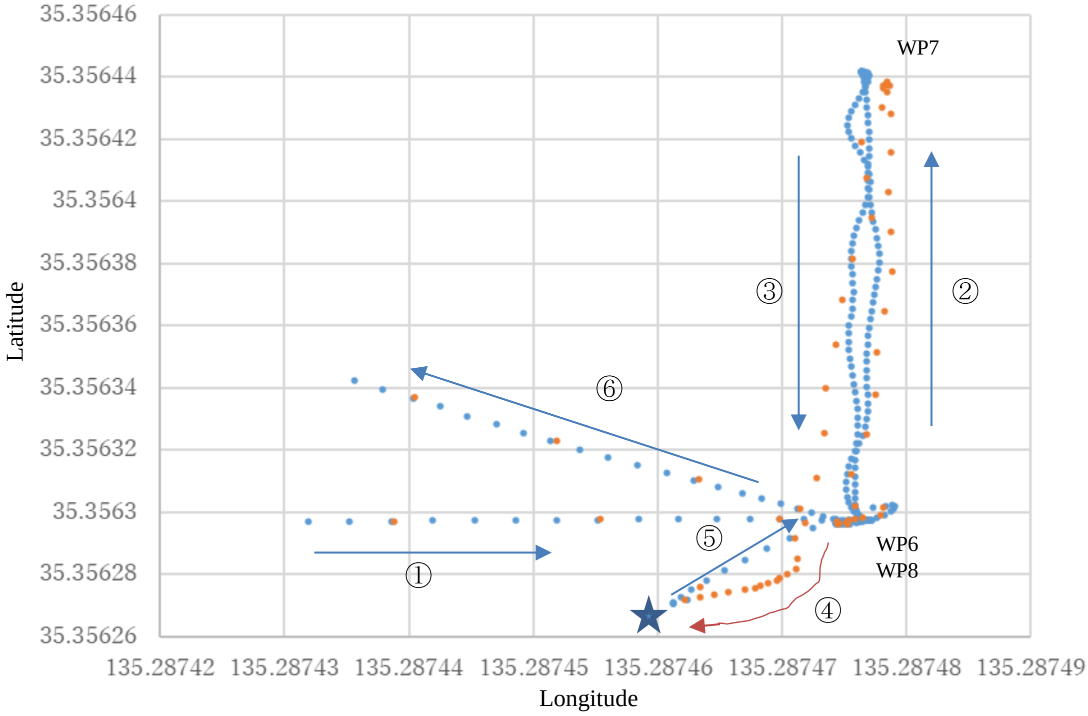

Figure 7. Enlarged Ttrajectories of IMU and R-RTK

5 Conclusion

In this study, flight experiments were conducted using IMU estimates as an alternative precision guidance device during the period until RTK-GNSS lost and recovered satellite signals. IMU received RTK-GNSS measurements and output estimated values in NMEA signal format when reception stopped. In the flight experiments, RTK-GNSS antenna was disconnected for the disruption condition. Reference RTK-GNSS was used to confirm the results, and it was found that IMU estimates could provide navigation with the same level of accuracy as RTK-GNSS up to about 30 seconds after satellite signals lost. This technology is effective for operations that move between non-GNSS/GNSS environments, for example, when flying under wide bridges, through short tunnels, or through buildings over short distances.

References

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