

Development of Drone Capable of Autonomous Flight Using GPS

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Abstract— An experimental drone capable of autonomous flight was developed by equipping the microcomputer of Raspberry Pi 2.0 (Model B) for flight control and GPS sensor on the AR. Drone 2.0 (Power Edition). The GPS was calibrated by measuring the deviation between a position where the GPS sensor was set and the ones measured by the GPS. An experiment on autonomous flight control was performed, and the autonomous flight control of drone was evaluated by comparing planned flight routes of straight and L-shaped lines and routes where the drone actually flew. Consequently, the experimental drone could fly autonomously along the planned flight routes.

Index Terms— Drone, Autonomous Flight, Global Positioning System, Calibration

I. INTRODUCTION

IN recent years, drones has been used in a wide range of fields because they have high mobility. KOMATSU Ltd. [1] have been carried out a three-dimensional measurement service of building sites by drones. In this service, photos taken from the sky by drones are converted to point cloud data, and a three-dimensional map is created with that data. These services realize cost reductions for measurements. Amazon.com Inc. [2] is planning to deliver commodities that customers order within 30 minutes by drones. Thus, drones capable of autonomous flight have been receiving a lot of attention.

In addition, the application of drones using GPS is expected in rescue work in a disaster area. In disaster sites, it is impossible for rescuers to pass due to the fragments of destroyed buildings. Therefore, swift investigations of sufferers are required regardless situations in the affected areas. It is possible to check the situation of affected areas in safety from the sky using drones capable of autonomous flight. Thereby, the sufferers will be able to find even in places where the rescuers are under risk. Therefore, the drones capable of autonomous flight are required in various fields.

Several researches on drones have been carried out. P. J. Bristeau, et al. [3] derived the equations on postures and velocities of AR.Drone during a flight and proposed methods to estimate the postures of AR.Drone during a hovering. L. V. Santana, et al. [4] derived the equations on behavior of AR.Drone during a flight and determined optimal gains for the velocity feedback control from the derived equation. Furthermore, K. Shetti, et al. [5] proposed

methods to reduce the amount of data communication between drones and computers for flight control while applying compression sensing techniques.

In addition, various methods on autonomous flight of drones have been reported. For instance, several researches on autonomous flight of drones performed by detecting markers with specific feature quantity using a camera have been reported. P. Smoczyński, et al. [6] developed a drone that can autonomously follow markers and land at the position of markers detected by a camera installed on the front and the bottom of drone using Canny edge detection algorithm. M. A. Garratt, et al. [7] performed velocity feedback control with markers detected by a camera installed on the bottom of AR.Drone as reference points, and stable hovering by the drone was performed. Moreover, M. A. Ma'sum, et al. [8] developed a drone that can autonomously follow objects detected from images taken by a camera installed on the front of drone using machine learning. Y. P. Huang, et al. [9] proposed methods to detect positions of objects using HOG (Histograms of Oriented Gradients) and linear SVM (support vector machine) algorithm.

Furthermore, researches on autonomous flight of drones in disaster environment have also been reported. A.J.A. Rivera, et al. [10] developed a drone capable of autonomously follow humans detected by optical and thermal sensors installed on the front of the drone. D. Yavuz, et al. [11] performed map creations using a panoramic image that was created from images taken by a camera installed on the front of drone using image stitching technology. Then, humans was detected from its images using the computer vision technology. Furthermore, J. P. Carvalho [12] developed a drone equipped with a microcomputer of Odriod for flight control on the top, and an autonomous flight so that the drone can fly along the route determined by PTAM (Parallel Tracking and Mapping) algorithm was performed.

In this study, an experimental drone capable of autonomous flight was developed by equipping a microcomputer for flight control and GPS sensor on the AR. Drone 2.0. Then, experiments on autonomous flight control were performed, and autonomous flight control of drones was evaluated by comparing planned flight routes and routes where the drone actually flew.

II. COMPOSITION OF EXPERIMENTAL DRONE

A. Composition of Hardware

Figures 1 and 2 shows the composition of experimental drone and the composition of control device.

AR. Drone 2.0 (Power Edition) was used as a basic drone. The three-axis gyroscope, the three-axis accelerometer, the three-axis magnetic sensor, the barometric pressure sensor and the ultrasonic sensor are equipped on the drone.

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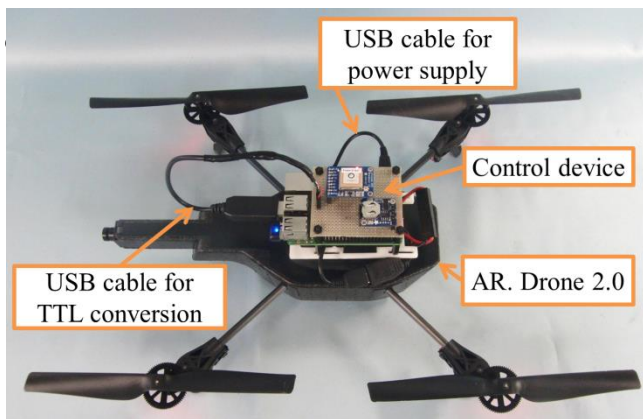


Fig.1. Composition of experimental drone

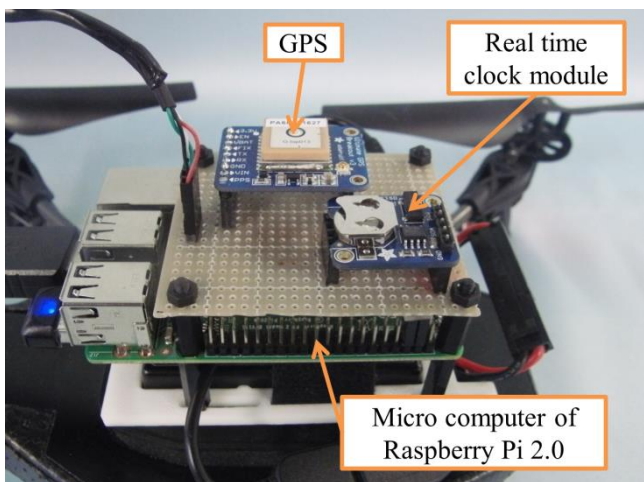


Fig.2. Composition of control device

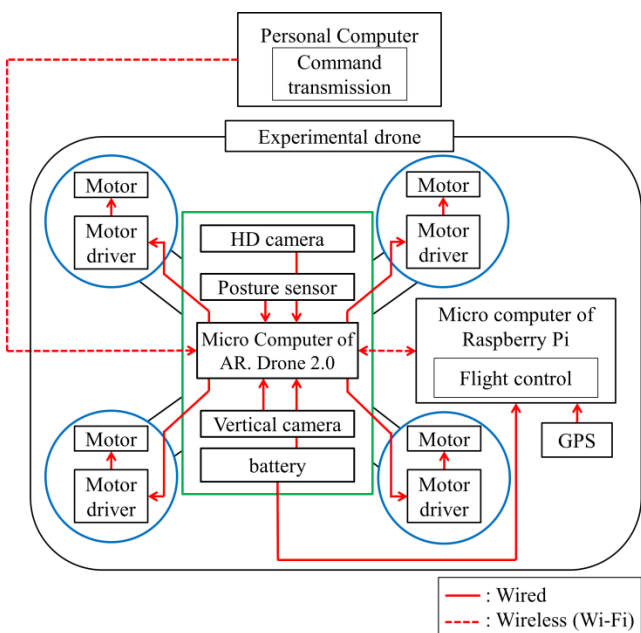


Fig.3. Configuration of control system

An experimental drone was developed by equipping a microcomputer of Raspberry Pi 2.0 (Model B) and a GPS sensor. Maximum total input current of power supplies of a Raspberry Pi 2.0 is 460 [mA] that is within the permissible current of 500 [mA] of the drone.

Ultimate GPS Breakout (Adafruit) was used as the GPS sensor. The technology using GPS is more effective than the image processing technology for the position detection in

unknown environment. Then, the GPS was used to detect the self-position of the experimental drone in this study. The sensor is connected with the Raspberry Pi 2.0 via a serial port. It is possible to receive radio wave signals sent from satellites. Self-position coordinates are estimated by distances calculated from difference between time information of the radio wave signals sent from satellites and a system clock of the Raspberry Pi 2.0. The GPS updated self-positions using radio signals received in intervals of 10 [Hz], and the self-positions are calculated receiving the radio signals from six to eight satellites at the same time. In addition, the MTK 3339 chipset (Media Tek Inc.) was used as the GPS antenna. This antenna can also use QZSS (Quasi-Zenith Satellite System) developed by the Japan Aerospace Exploration Agency.

Real Time Clock (Adafruit DS1307) was used as a real time clock module. A crystal oscillator and a battery are equipped in the module. Then, it is possible to retain accurate time even if the power supply of microcomputer is cut off. It is possible to match the system clock of microcomputer with current time when estimating self-position coordinates with the GPS. Equipping the module made possible to retain accurate time without synchronizing with NTP (Network Time Protocol) servers which are communication protocol servers for synchronizing the clock of device to correct time through Internets. Wi-Fi was used in communication between the microcomputer of AR. Drone 2.0 and the Raspberry Pi 2.0. A vertical camera is installed on the bottom of drone. A HD (High Definition) camera is also installed on the front of drone. Images captured by their cameras can be transmitted to the microcomputer of AR. Drone 2.0 by the Wi-Fi communication.

Maximum loading capacity of AR. Drone 2.0 is around 100 [g]. Total loading masses containing the Raspberry Pi 2.0, the GPS sensor, the real time clock module and the USB cable of the experimental drone is 94 [g]. Then, the experimental drone can fly stably.

B. Configuration of Software

Figure 3 shows a configuration of control system. Ubuntu 14.04 LTS (Long Time Support) was used as the OS (Operation System) in this research because it is suitable in using the ROS (Robot Operating System). The ROS was used because it is possible to easily exchange data of sensor among the Raspberry Pi 2.0, the microcomputer of AR. Drone 2.0, and the personal computer.

III. CALIBRATION OF GPS

A. Measurement of Positions Using GPS

Positions measured by the GPS had certain deviations compared to a position where the GPS sensor was set. Therefore, it was necessary to develop programs considering the deviation between the positions where the GPS sensor was set and the one measured by the GPS. Measurement experiments to find the deviations of values measured by the GPS were conducted in the campus of Ehime University. Then, calibration of GPS was performed. Figure 4 shows a position where the GPS sensor was located for its calibration. The latitude and the longitude of the position where the GPS sensor was set was 33.849586 [deg] and 132.770918 [deg], respectively. Then, the positions were measured 10 times where one time measurement means to measure them for 10 minutes every an hour by the GPS in the position shown in Fig.4. Then, the GPS was calibrated by measuring the shifts in the x and y directions



Fig.4. Position where GPS was located for its calibration

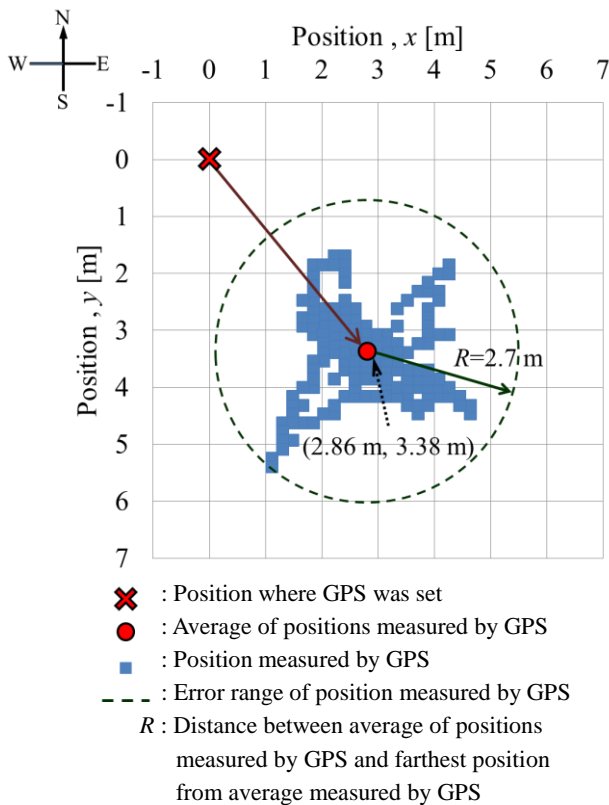


Fig.5. Position where GPS was set and average of positions measured by GPS

between the position where the GPS sensor was set and the average of positions measured by the GPS.

B. Experimental Result

Figure 5 shows a position where a GPS sensor was set and average of positions measured by the GPS. The positions measured by the GPS were out by 2.86 [m] in the x direction and 3.42 [m] in the y direction as shown in Figure 5. The distance between the average of positions measured by the GPS and the farthest position from the

average measured by the GPS was 2.7 [m]. Programs considering the shifts between the positions where the GPS sensor was set and the one measured by the GPS were developed based on calibration values obtained from the measurement experiments.

IV. AUTONOMOUS FLIGHT EXPERIMENT

A. Flight Control Method of Drone

Velocity to give to the drone was calculated by multiplying deviations between goal coordinates and self-position ones measured with the GPS and proportional gains. Flight velocity, $u(t)$ of the drone was given by the following expression.

$$u(t) = K_p e(t) \quad (1)$$

Here, K_p is the proportional gain. $e(t)$ is also a distance deviation between goal coordinates and self-position coordinates. The distance deviation, $e(t)$ was calculated using Hubeny formula given as follows.

$$e(t) = \frac{1}{\sqrt{\{M(\lambda_{GP} - \lambda_{SP})\}^2 + \{N\bar{\varphi}(\varphi_{GP} - \varphi_{SP})\}^2}} \quad (2)$$

Here, φ_{GP} and λ_{GP} are latitude and longitude of goal coordinates, respectively. The φ_{SP} and λ_{SP} are latitude and longitude of self-position ones, respectively. The $\bar{\varphi}$ is also average values of latitude between the goal coordinates and the self-position ones. The M is the curvature radius of the meridian. The N is the curvature radius of the prime vertical circle. They are given by the following expressions.

$$M = \frac{a(1-e^2)}{(1-e^2 \sin^2 \bar{\varphi})^{\frac{3}{2}}} \quad (3)$$

$$N = \frac{a}{\sqrt{1-e^2 \sin^2 \bar{\varphi}}} \quad (4)$$

Here, the e and the a mean major eccentricity and the equatorial radius, respectively. The e and the a have different definitions depending on a geodetic reference frame. The e is 0.081819 [m] and the a is 6378137 [m] because the WGS84 is used as the geodetic reference frame. In addition, directions of flight of drone are determined by positive or negative signs of deviations of latitude or longitude between positions during a flight of drone and a goal position.

B. Straight Flight

Experiments were performed in the campus of Ehime University. Figure 6 shows a planned flight route of a straight line. The experimental drone was taken off from the start position. Then, this drone was autonomously flown to the goal position. Latitude and longitude of goal position are 33.849600 [deg] and 132.770905 [deg], respectively. Figure 7 shows a flight route when the drone autonomously flew above the straight line. The experimental drone was able to autonomously fly to the position around 2 [m] from the goal position as shown in Figure 7.

C. L-shaped Flight

Experiments of autonomous flight control on planned

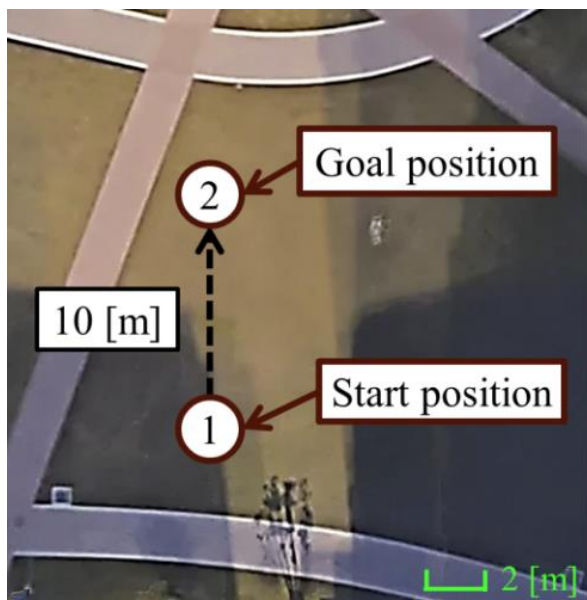


Fig.6. Planned flight route of straight line

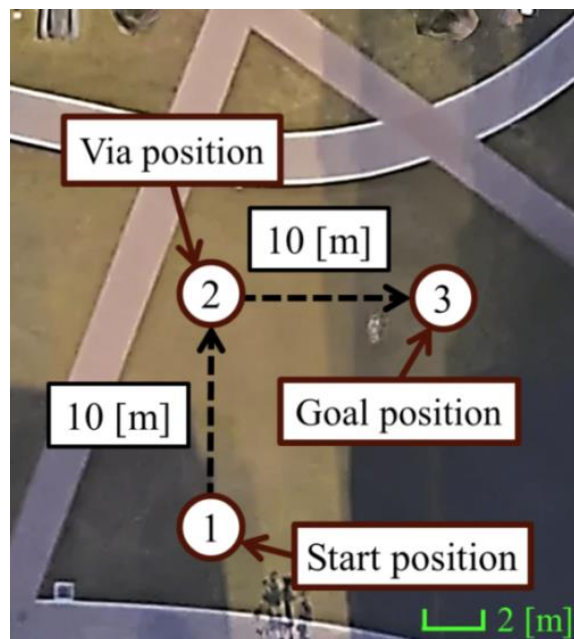
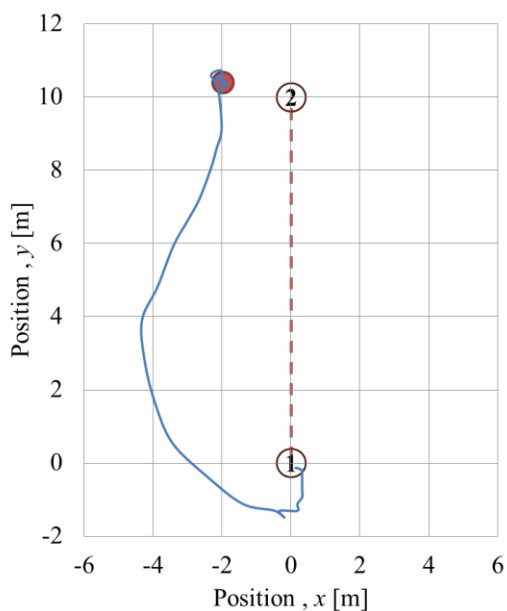
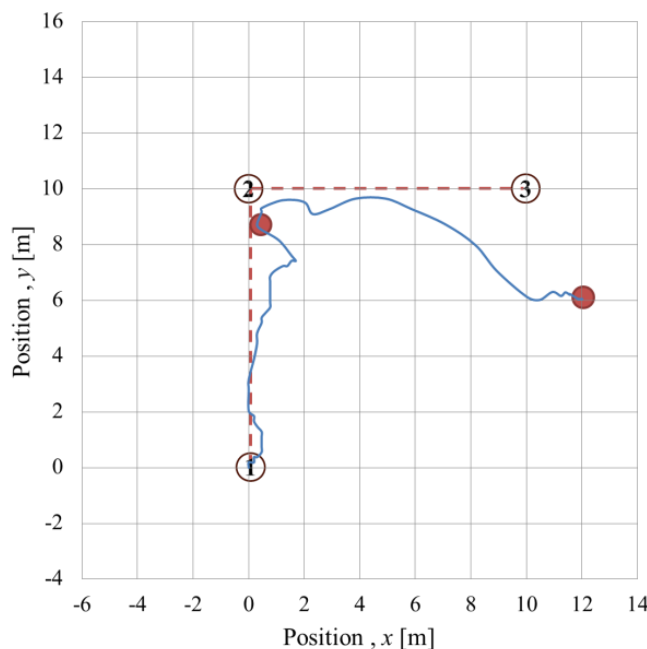


Fig.8. Planned flight route of L-shaped line



- ① : Start Position
- ② : Goal Position
- : Planned flight route
- : Route where drone actually flew
- : Position that drone hovered

Fig.7. Flight route when drone autonomously flew above straight line



- ① : Start Position
- ② : Via Position
- ③ : Goal Position
- : Planned flight route
- : Route where drone actually flew
- : Position that drone hovered

Fig.9. Flight route when drone autonomously flew above L-shaped line

flight route of a L-shaped line were performed. Figure 8 shows a planned flight route of a L-shaped line. The experimental drone was taken off from the start position. This drone was autonomously flown to the via position. Then, this drone hovered around the via position. Finally, the drone was autonomously flown to the goal one as shown in Figure 9. The experimental drone hovered at a position 1.38 [m] away from the via position. This drone was landed on 4.47 [m] away from the goal position.

V. CONCLUSION

The experimental drone was developed by equipping the microcomputer for flight control and the GPS sensor on the drone in order to verify practical effectiveness of methods about outdoor autonomous flight using GPS. The measurement experiments of GPS were performed to evaluate the GPS sensor. As a result, it was found that the sensor had certain deviations. The experiment on autonomous flight control of the drone was performed considering the results of calibration of the GPS. The usefulness of proposed method on autonomous flight controls was evaluated by comparing the planned flight routes of straight and L-shaped lines and the routes where

the drone actually flew. The experimental drone was able to autonomously fly to the goal position by using the proposed method.

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