50 m-range distance and position measurement method by using two searchlights for autonomous flight device

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Abstract— *In the present study, 50 m-range distance and position measurement method for autonomous flight device such as four-rotor drone by using two searchlights was proposed, and the precise distance/position measurement performance was evaluated in an outdoor situation. To realize over 10 m long-distance flight of the drone under unstable GPS signal situations such as under the bridge or inside tunnels for periodic inspections, the correct self-position measurement is important for the stable control. This study is to propose a simple method of over 50 m range autonomous four-rotor helicopter movement control using high power 300W two searchlights as InfraRed sources on the ground and the direction of the searchlights sets to the investigation target position such as bridge side. High power light sources of the two searchlights are enabled to measure the correct drone position via an attached drone's camera with an InfraRed filter, and it realizes 1.5 m standard deviation position estimation error when 50 m distance in an outdoor daylight situation. In addition, the limitation of the position detectable condition also measured and analyzed in other experiments. Our proposed method would be effective in the situation that there is no skilled the drone control operator and the flight by visual confirmation of man are hard conditions, and useful to develop the position measurement system with low cost.*

Keywords— Four rotor helicopter, long distance / position measurement, InfraRed filter, two searchlights.

I. INTRODUCTION

In this paper, 50 m-range distance and position measurement method for autonomous flight device such as four-rotor drone by using two searchlights was proposed, and the precise distance/position measurement performance was evaluated. Such as under the bridge, inside tunnels and buildings for the periodic inspection at unstable GPS signal situations, to realize over 10 m long-distance flight of the drone, since it is unable to confirm the real-time drone posture by the naked eye, easy and correct self-position measurement method is necessary for the stable inspection work [1,2] (Fig.1). Even if a human controls the drone, the flight by the naked eye of man is difficult in the over 10 m long distance flight [3-11], and another supporting mechanism of the position measurement and the control method would be necessary [12-25]. This study aims to propose a simple method of 50 m range distance and position measurement method for autonomous four-rotor helicopter using high power 100V AC two searchlights as InfraRed sources on the ground and evaluate the practical measurement ability of the distance/position in case of 50 m distance outdoor situation.

1.1 Previous study

Four-rotor helicopter does not include autonomous "position" controlling process as itself, and the positioning system is necessary to realize an inspection work [2]. To realize the position measurement, InfraRed 3D cameras or GPS sensor system generally have been used [9,14,26]. In the case of the InfraRed 3D camera, the precision of the position measurement is 1 mm order; however, the area of the using this method is within 10 m and the indoor situation only [5]. On the other hand, if the drone would be controlled in the outdoor situation, the GPS signal can be used that there are almost no obstacles upper direction (sky) and movement direction. However, to use the drone for the periodic inspection of under the bridge or inside tunnels, the two approaches could not be adopted since the instability of the GPS signal under the bridge or tunnel sites [2].

In our previous study [8], basic features of about 10 m area position measurement method using two searchlights had been proposed and analyzed, but the stability of the position measurement at a distance from 20 to 50 m with low reliability of the GPS signal was not discussed. This paper described the positional measurement performance of the proposed method until 50 m range, and the optical characteristics of each item of the camera, laser, searchlight with the geometric arrangement were summarized.

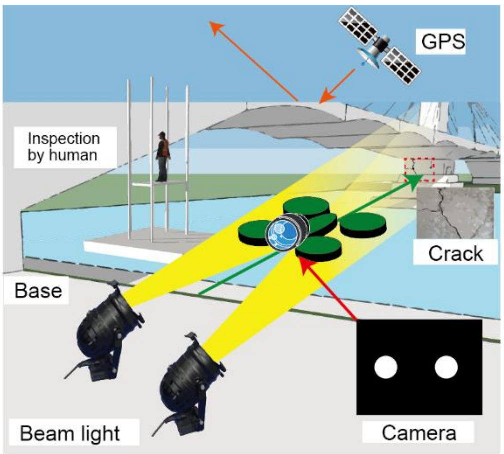

FIGURE 1. Proposed 50 m range distance/position measurement method using high power 100V AC two searchlights on the ground for autonomous four-rotor helicopter.

II. METHOD

Fig.2 illustrates an idea of the proposed method. High power two searchlights (Stage Evolution, PAR56SBG and SYLVANIA light, 0.16 m diameter light PAR56 300 W, SOUND HOUSE Corp.) were used for the InfraRed light sources on the ground. The camera (Ai-ball, QVGA 320x240 dots, 30 fps) at the front of the drone was tuned to the two searchlights direction, and it was controlled by using two searchlights positions on the camera image (using the center of gravity and the distance of the two points). There is an InfraRed filter (IR76,82,88, FUJI FILTER, FUJIFILM Corp.) in the front of the camera lens. The reason for using Ai-ball wireless camera is a considerable time delay of the drone's internal camera image transfer process, and control command transmitting (>around 100 msec). When the two bright spot positions are (x_1, y_1) and (x_2, y_2) on the camera image and the center of the gravity of the two points is $(G_x, G_y) = \left(\frac{x_1+x_2}{2}, \frac{y_1+y_2}{2}\right)$, the camera position (R_x, R_y) iscalculated as,

$$(R_x, R_y) = \left(\frac{G_x r}{\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}}, \frac{\alpha r}{\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}}\right) \quad (1)$$

where, the r is the distance between the searchlights and the α is the conversion factor between dot and real distance. The α is calculated when the distance between two searchlights and the camera was positioned 1 m apart and the camera is moved 1 m to the left or right. In this study, the α was calculated as 340.

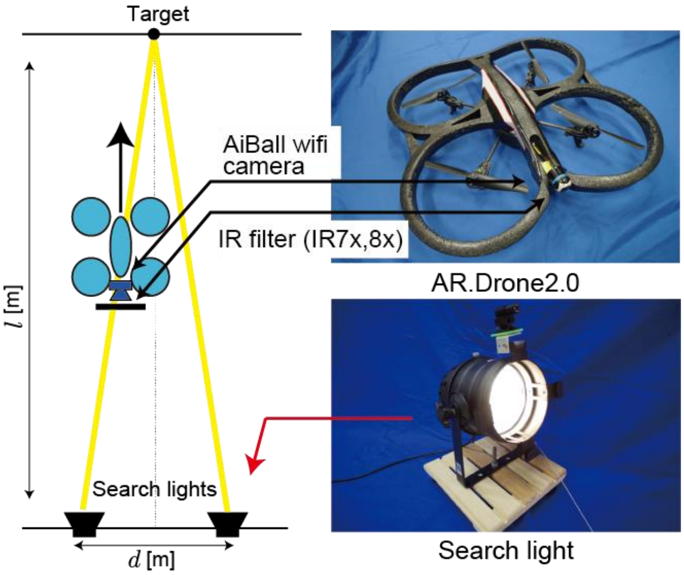

FIGURE 2. Basic concept of 50 m range position measurement method of the autonomous flight device. Two searchlights (Stage Evolution, PAR56BSG) were used for the position measurement of the drone in the space

III. EXPERIMENT

Experiment 1 confirmed the stability of drone's position measurement by measuring a camera image bright spot by changing the InfraRed filter in 10 m distance outdoor situation (Fig.3). This experiment reveals which wavelength of the InfraRed filter is effective in the experimental condition.

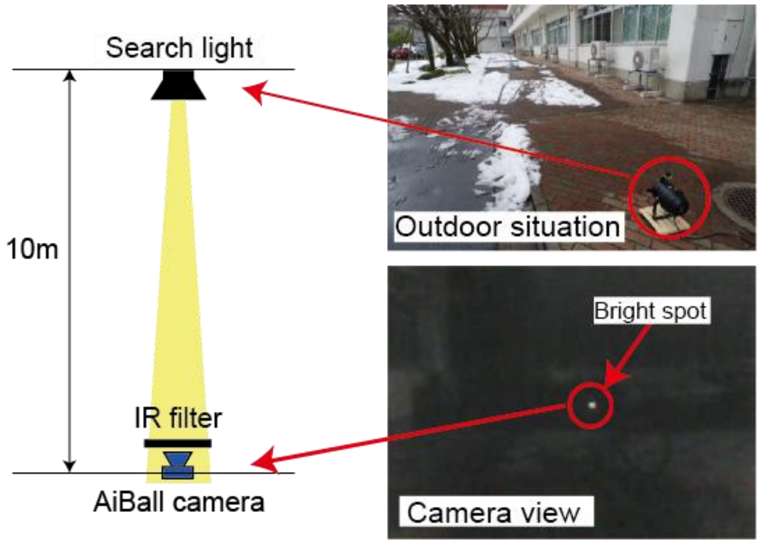

FIGURE 3. Experiment 1 setup of the 10 m distance bright spot measurement by Ai-ball camera at outdoor situation in case of IR76, 82, 88 InfraRed filter (passes wavelength below 760, 820, 880 nm respectively).

Experiment 2 measured the distance where the bright spots of the two searchlights do not merge in the camera image (Fig.4a). When the distance between the bright spots is less than six dots (almost all the cases, the area of each spot is about ten dots), the bright spots of the two searchlights are merged, and it is unstable to extract the two center of gravity points at the same time. This experiment reveals which distance the light of the searchlights reaches, and the drone (camera) can be measured.

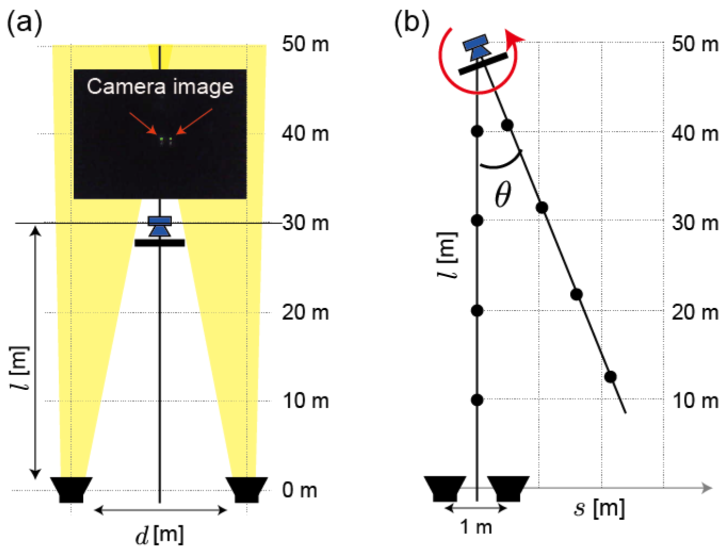

FIGURE 4. (a) Experiment 2 setup of the distance where the bright spots of the two searchlights do not merge in the camera image. (b) Experiment 3 setup of the distance by using the two spotlights when the angle of the camera was changed from 0 to 16 deg.

In the practical situation of the inspecting work by the drone, the angle of the camera on the drone would be fluctuated. Experiment 3 (Fig.4b) measured the distance by using the two spotlights when the angle of the camera was changed from 0 to 16 deg. In this experiment, the distance from the camera and the spotlights was changed from 10 to 50 m, and the distance of the two spotlights d sets as 1 m.

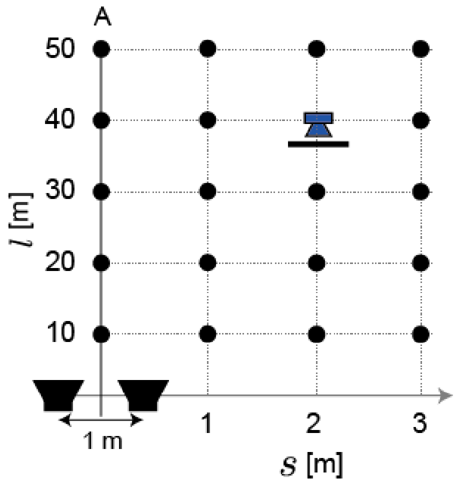

FIGURE 5. Experiment 4 setup of the 3 m×50 m range position / distance detectability measurement in outdoor situation. The distance of the two searchlights was fixed as d=1 m.

In the last experiment 4, the practical position measurement accuracy in the outdoor environment was confirmed(Fig.5). Setup of the experiment was same with Fig.4a such that d=1 m, the distance between the camera and the searchlights takes l=10, 20, 30, 40, 50 m, and the distance from the center of two searchlights is changed s= 0, 1, 2, 3 m. It represents the total performance of the positional measurement accuracy of the proposed method.

IV. RESULT

Figure 6 represents the dependency of the InfraRed filter in 10 m distance outdoor situation. In Fig.6a, an example of the effect of the InfraRed filter was shown. The searchlight was positioned at (A), and it was extracted clearly by the IR filter (IR88 case). The dependency of the kind of IR filter was summarized in Fig.6b. Black solid bar and the error bar mean the average and the standard deviation of the brightness of the point (A) on the camera image. Without filter condition, the brightness takes a low value (avg. 55, maximum 255) and it was caused by the high brightness area such as snow via auto gain control mechanism of the camera. On the other hand, with IR filter condition, the brightness of the point (A) take over 200 with low error. Fig. 6c means the brightness of the point (B), it was white colored snow area. In without filter condition, even though the brightness takes over 200 (it was white), the brightness of the point (B) with IR filter was reducing with increasing of the wavelength. As the conclusion, the IR88 filter represents a good performance compared with other filters. After this experiment, the IR88 filter was used in below experiments.

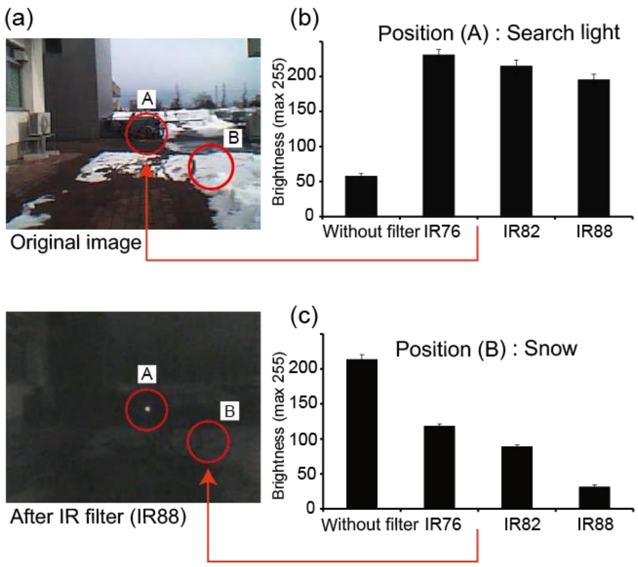

FIGURE 6. Result of the dependency of the InfraRed filter (IR76, IR82, IR88). (a) Original image and after IR filter image. (b) The brightness measurement result of thesearchlight position (N=5). (c) The brightness measurement of the snow area (other area of the searchlight).

Figure 7 represents the result of the distance where the bright spots of the two searchlights do not merge in the camera image (experiment 2). Black circle dot means the spotlights distance d when the distance between two bright spots was seven dots in the camera image. For example, to detect the position/distance around 50 m, it is necessary to set d=0.75 m or above as the searchlights distance d. The black circle dots show the minimum distance d of the two searchlights in each distance l from 10 to 50 m, and the linear approximation was calculated as $d = 0.017l$ ($R^2 = 0.999$). It means that when the position/distance measurement was needed around l m, the distance between two searchlights d is necessary above $d = 0.017l$ (green area of Fig.7).

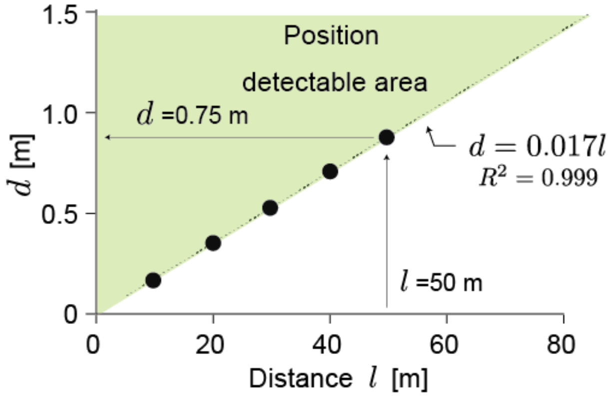

FIGURE 7. Result of the limitation of the distance / position measurement (experiment 2). Black dots mean that the distance between two searchlights equals to 7 dots in the camera image when the distance *l* is changed from 10 to 50 m.

Figure 8 shows the result of the camera angle dependency where the l=10, 20, 30, 40, 50 m, and the camera angle was changed from 0 to 16 deg. The plots mean the estimated positions (s, l) from the camera image analysis, and dotted circles are the ideal positions. As shown in small black arrows, the positional shift from the ideal position was increased with the camera angle. For example, the estimated distance l was 46.7 m (S.D. is 0.59 m, N=5 times experiment) in the case of camera angle 16 deg when ideal distance was l=50 m. The displacement was 50-46.7=2.8 m in this case. On the other hand, if the displacement would be suppressed within 1 m when 50 m distance (that means 50-1=49 m), since the approximation equation was calculated as $l = -0.212\theta + 50.23(R^2 = 0.96)$ from Fig.8, it is necessary to limit the camera angle within $\theta = (49 - 50.23)/-0.212$=5.8 deg as one side (right or left).

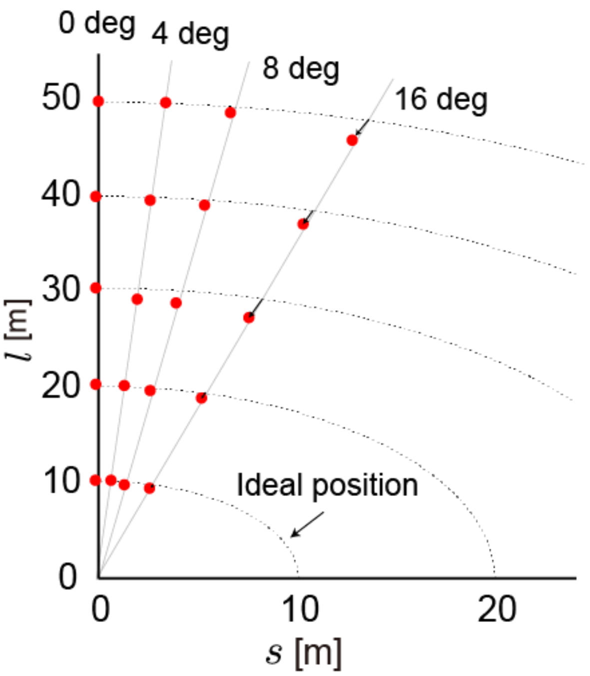

FIGURE 8. Result of the position estimation displacement when the camera angle was changed from 0 to 16 deg (experiment 3). The dotted lines mean the ideal position if there are no errors by changing the camera angle

In Fig.9, the practical position measurement accuracy in the outdoor environment by the proposed method was summarized (N=5). The blue dots and the error bar of l and s axis shows the average and the standard deviation. S.D. takes small value in the small range of l, and there was (s, l)=$(3.1 \pm 0.08, 52.1 \pm 1.5)$ m (avg.±S.D.) in the point of B (correctly, the position is $(s, l) = (3{,}50)$ m). Since the error rates of each axis were calculated as $0.08/3.1$=2.58% of s axis and $1.5/52.1$=2.88% of l, there are about 3% errors in the position measurement process in l=50m point. Above result would be useful for unstable GPS situation such as under the bridge, inside tunnels and buildings for the periodic inspection to realize easy setup and low cost 50 m range position/distance measurement method.

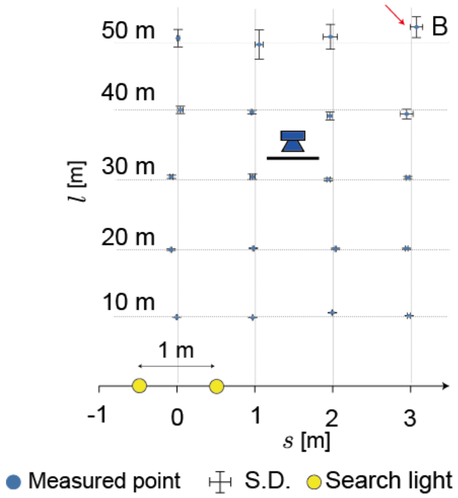

FIGURE 9. Result of the 3 m× 50 m area position estimation performance (experiment 4). Blue dots represent the average estimated position from the two searchlights position on the camera image (N=5 times experiment average). Error bars show the S.D. of the measurement.

V. DISCUSSION

In our previous study [8], the four-rotor drone (using AR Drone model helicopter) was controlled and flighted by the two searchlights system from 5 to 10 m distance area. However, the position control of the drone was unstable especially when the long-distance flight over 10 m. In the study [8], the unstable reason could not be cleared, and it would be concluded as there are two factors (1) the drone position control theory itself, (2) the position measurement method. This study aims to clear the effect of the position measurement method using the two searchlights.

One of the general solutions of the position measurement is to use a large area colored marker board, however, by attaching the large area red marker board would cause the wind flow instability and could not acceptable especially in the far distance inspection sites such as bridges or tunnels. The advantage of the proposed method would be easy to find the searchlight points by using the InfraRed regions, and it would realize the correct 50 m range position measurement just by attaching a small wireless camera on the drone. In our experiment, the resolution of the attached camera was low resolution 320×240, but it could be realized more precise position measurement by using a high-resolution camera.

VI. CONCLUSION

In this paper, 50 m-range distance and position measurement method for autonomous flight device such as four-rotor drone by using two searchlights was proposed, and the precise distance/position measurement performance was evaluated in an outdoor situation. This study is to propose a simple method of 50 m range distance / position measurement using high power 300 W two searchlights as InfraRed sources on the ground. In experiment 1, the IR88 (wavelength is 880 nm) InfraRed filter extracts only the light of the searchlights and it is not affected by ambient light such as light reflected on the white snow. Experiment 2 measured the maximum distance/position detectable area of the drone (camera position), and it was affected by the d of the distance between two searchlights (the l and d take a linear approximation relationship $d = 0.017l$ at least 50 m). The result of experiment 3 shows the distance/position displacement by the camera angle changes from 0 to 16 deg, and the displacement was extended by increasing of the camera angle θ, and there was 2.8 m displacement when 50 m distance and 16 deg condition. In the last experiment 4, the positional measurement accuracy in the area of 3 m × 50 m was confirmed when d=1 m condition. There were about 3% displacement errors in each axis s and l, and this evaluation results would be useful to develop the position measurement system with low cost.

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