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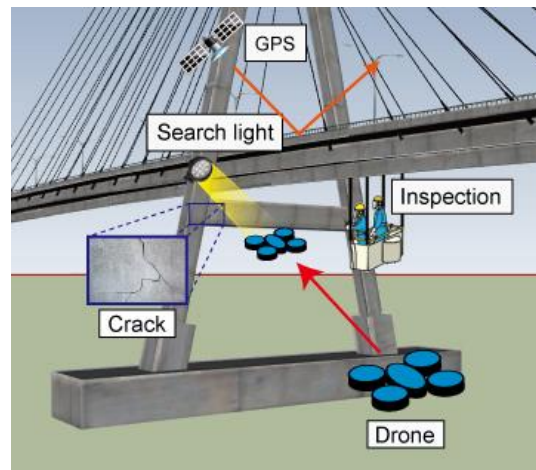**Naoki Kasamatsu[1,*] and Hideki Toda[1]**

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Abstract. In the present study, 50 m-range autonomous 4 rotor helicopter movement control method by using single search lights was proposed, and the autonomous flight test evaluation was performed. To realize over 50 m long distance flight of the drone under unstable GPS signal situations such as under the bridge or inside tunnels for the periodic inspection, the correct self-position measurement and improvement of the control method are indispensable for stable control. The aim of this study is to compare three control methods of over 50 m range autonomous 4 rotor helicopter movement using a high power 100V AC single search light as InfraRed sources, and the searchlight is positioned at near the investigation target such as bridge handrail. By comparing the standard deviation (S.D.) from the central orbit divided by the moving distance, a proposed control method using 2nd order velocity factor and a control method using boundary condition of both sides represents high performance against general optimized P-D control. The proposed 2nd order velocity factor control and the control method using boundary condition realized 12% and 45% small S.D. comparing with the optimized PD control respectively.

1. Introduction
In this paper, 50 m-range autonomous 4 rotor helicopter movement control method by using single search lights was proposed, and the autonomous flight test evaluation was performed. To realize over 50 m long distance flight of the drone under unstable GPS signal situations such as under the bridge, inside tunnels and buildings for the periodic inspection, easy and correct self position measurement method and the control theory (strategy) of the drone are indispensable. Even if the drone would be controlled by human being, the flight by visual confirmation of man is difficult in the over 10 m long distance flight. In that situation, other supporting mechanisms of the position measurement and the control method would be necessary [1]. The aim of this study is to compare three control methods of over 50 m range autonomous 4 rotor helicopter movement using a high power 100V AC single search light as InfraRed sources, and the searchlight is positioned at near the investigation target such as bridge handrail (Fig. 1). By comparing the standard deviation (S.D.) from the central orbit divided by the moving distance, a proposed control method using 2nd order velocity factor and a control method using boundary condition of both sides represents high performance against general optimized P-D control.

Figure 1. Proposed over 50 m range autonomous four rotor helicopter movement control using high power 100V AC single search light.
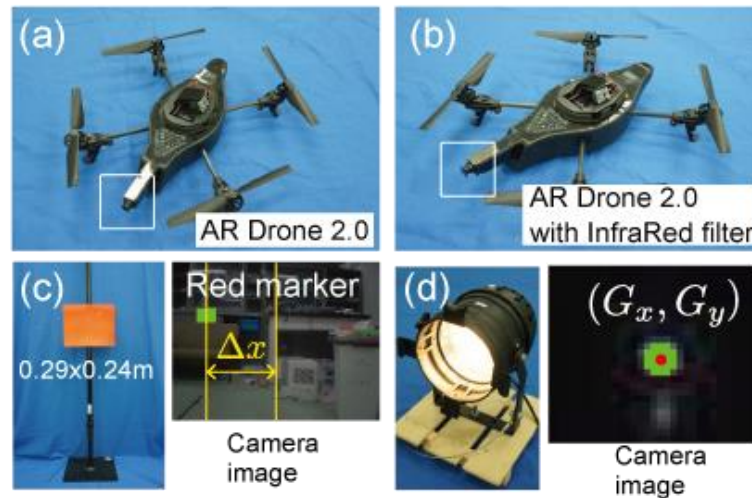
2. Previous Study

Four rotor helicopter would not be included autonomous position controlling program as itself, and the positioning system is necessary in the space using InfraRed 3D cameras or GPS sensor system at least to control the drone position [1]. 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 indoor situation only. On the other hand, if the drone would be controlled in the outdoor situation, the GPS signal can be used in the situation that there is almost no obstacles upper direction (sky) and movement direction. However, in order to use the drone for the periodic inspection of under the bridge or inside tunnels, the two approaches could not be adopted. In addition, attitude estimation and autive for the position control of the drones. In this study, we used three types oftonomous flight control are an important topics in the study field of the drone system. It is not clear that what kind of the flight control law (algorithm) is effec the controller design (1) optimizing gain adjusted PD control, (2) a method using 2nd order velocity factor and (3) a control method using boundary condition of both sides. Especially, the control strategy (2) has been discussed in previous our studies [2].

3. Method

3.1. Experimental Devices and the Setup

Figure (fig2) shows the experimental setup devices, (1) AR Drone 2.0 quad rotor helicopter (Parrot Corp.), (2) same AR Drone with InfraRed filter (IR76, FUJI FILTER, FUJIFILM Corp.) attached on the front camera, (3) fluorescent red color sheet (0.29 ×0.24 m, 5065 fluorescent sheet red, Myst Corp.), and (4) high power search light (Stage Evolution, PAR56SBG and SYLVANIA light, 16 cm diameter light PAR56 300W, SOUND HOUSE Corp.) was used for the InfraRed light source. The camera (320 ×240 image with 10 Hz) at the front of the drone was used to find the fluorescent marker or search light position, and the drone was controlled by the fluorescent marker or search light position on the camera image (using the center of gravity of the point). The drone was controlled by ARDroneForP5 library by Y.Shigeo.

(1) AR Drone 2.0 (parrot Corp.) and (2) with InfraRed (IR76) filter at the front camera. (3) Red colored target marker (size 0.29×0.24 m). (4) Search light (combination of PAR56SBG and PAR56 300W).

Figure 2. Experimental setup devices.

3.2. Three Control Methods

The drone was controlled by three different control strategy in this study. When the center of the gravity of the red target object was (G_x, G_y), the drone's movement roll and pitch speed commands F^r, F^p were described as,

$$F^r = -\gamma_r(160 - G_x) - \eta_r V_r \tag{1}$$

$$F^p = \gamma_p \tag{2}$$

where the meaning of $\gamma_r, \eta_r, \gamma_p$ were constant, and V_r was drone roll velocity. Roll direction used simple P-D feedback control, and pitch direction was feed forward control process. The feedback parameters γ_r, η_r were determined by continuously measured 30 sec flight control experiments (N=over 50) in order to minimize the S.D. σ_x. The speed of the control command transfer was same with the camera frame rate (10 Hz). It is the first control strategy (it denoted as P control) of the three methods denoted in Figure 3a.

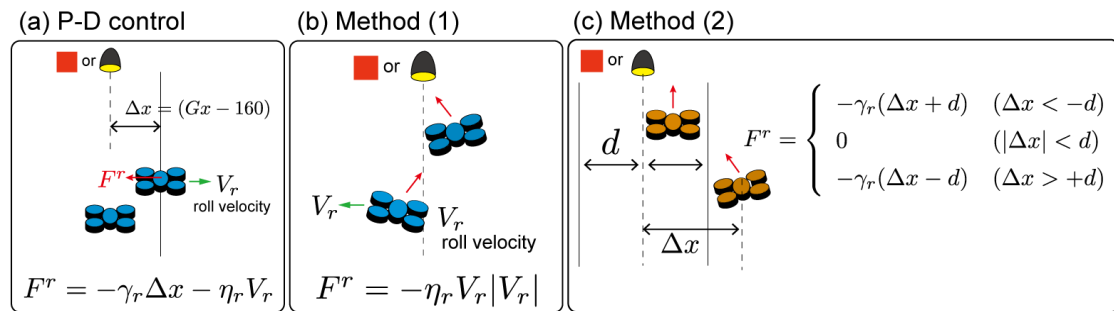Next control strategy was represented as below control equations:

$$F^r = -\eta_r V_r |V_r| \tag{3}$$

The parameters η_r was determined same with the above P control method, and the control command of pitch direction was also same with Eq.2. It is second control strategy denoted as Method (1).

Last control strategy was represented as below control equations:

$$F^r = \begin{cases} -\gamma_r(\Delta x + d) & (\Delta x < -d) \\ 0 & (|\Delta x| < d) \\ -\gamma_r(\Delta x - d) & (\Delta x > +d) \end{cases} \tag{4}$$

γ_r was determined same with the P-D control, and d was determined by the 1/4 distance of the aisle. It is thrid control strategy denoted as Method (2).
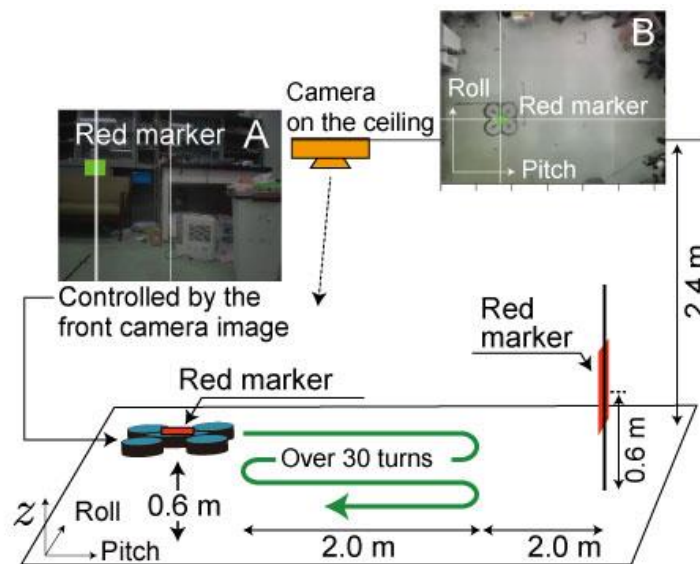
Figure 3. Three control strategy using simple PD control, a proposed control method using 2nd order velocity factor, and a control method using boundary condition of both sides.

4. Experiment

Experiment 1 performs over 50 m distance autonomous back and forth control stability by using the red marker (Fig. 4).The drone was controlled by the red marker's position on the front camera image (A of Fig. 4), and it was moved back and forth within 2.0 m about 30 turns by changing the control parameter of pitch direction γ_p (Ep.2) positive or negative. The position of the drone was measured by the camera attached on the ceil (B of Fig. 4), and the x and y position were continuously measuring by the image. Axis x and y correspond to the roll and pitch direction of the drone respectively. In this situation, three control methods (P-D control, Method (1), Method (2)) were performed.

Experiment 2 performs the long distance autonomous control stability of the corridor surrounded by wall. Width of the corridor was 2.0 m, and the search light was positioned 35 m distance from the start point. The drone was controlled by the search light position on the front camera image (IR75 InfraRed filter was attached on the camera), and it was moved back and forth within 15 m by changing γ_p parameter. The position of the drone was calculated by the search light's center of the gravity and area of the image. In this situation, three control methods (P-D control, Method (1), Method (2)) were performed.

Figure 4. Experimental setup of over 50 m distance autonomous go and back control experiment by using red marker in 6×6 m room.
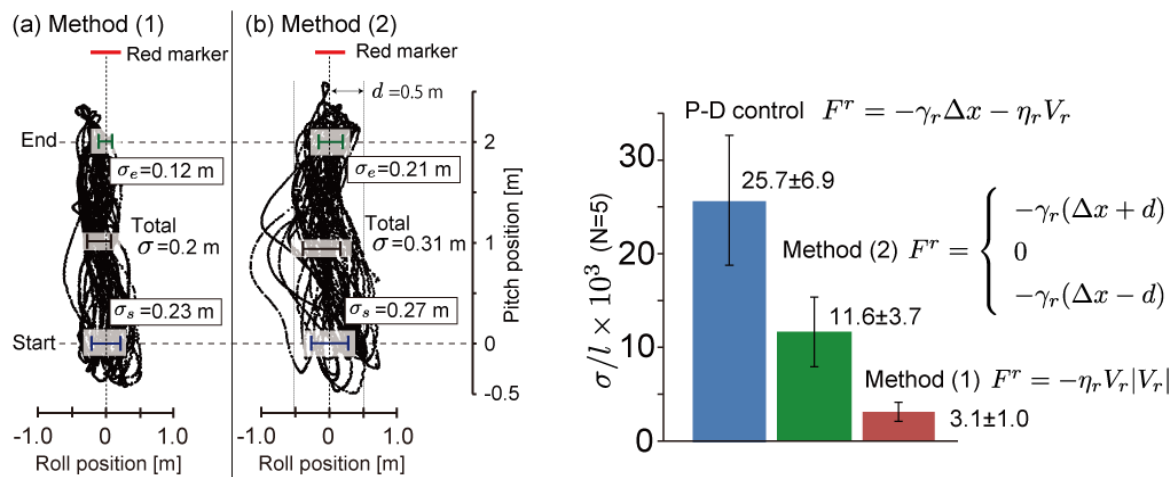
5. Result

Figure 5 left represents the result of roll and pitch position transition over 30 turns within 2.0 m distance. The trajectory of Method (1) and Method (2) were shown in Fig. 5a and Fig. 5b respectively. In the Method (1) result, a total length of the trajectory was measured about 60 m, and the standard deviation

(S.D.) of the roll movement was σ=0.2 m. Values of the σ at the point of start position and end position were calculated as σ_s=0.23 m and σ_e=0.12 m respectively, and it represents that if the drone's position is close to the red marker, the position control performance becomes to increase.
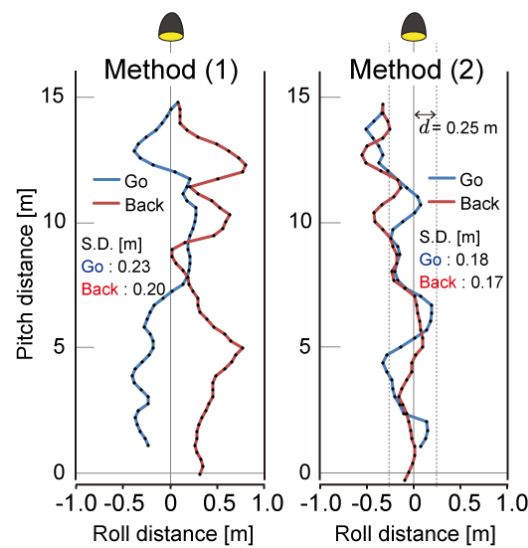
In the Method (2), the boundary condition limitation d was fixed to 0.5 m. The total σ equals to 0.31 m, and it was 1.55 (=0.31/0.2) times larger than the Method (1). Values of the σ at the point of start position and end position depended on the distance from the red marker, and it was same feature of the Method (1).

In Fig. 5 right, the σ divided by the total flight distance (it was denoted as σ/l) were compared in the three control methods. The graph and the error bar (S.D.) shows the result of five time experiments (N=5) of the three control methods. Optimized P-D control (denoted as P control) got worst value ($\sigma/l \times 10^3 = 25.7 \pm 6.9$) comparing to the remaining two methods, and the Method (1) took best value ($\sigma/l \times 10^3 = 3.1 \pm 1.0$) in three methods. Though the control method of the Method (2) ($\sigma/l \times 10^3 = 11.6 \pm 3.7$) is simple, the control performance was good comparing to the P-D control. Since the Method (2) is just controlling the drone when the boundary condition d is exceeded, the battery or energy performance would be good and it would be difficult for the control to become unstable. On the other hand, the Method (1) have been studied and analyzed in our previous studies [2], and it could realize a good performance in a specific condition. However, by the reason that the controller design is complex (2nd order term is used) and the real time control is indispensable, the battery or energy performance would be bad, and it would be easy to become the control unstable.

Figure 5. Result of experiment 1 roll and pitch position transition over 30 turns within 2.0 m distance. The controller Method (1) and Method (2) are compared.

Experiment 2 performs the control to go and back 15 m distance corridor (width 2 m) surrounded by wall (Fig. 6). The blue / red mean the going and returning trajectories. The boundary condition d set as 0.25 m in the Method (2). The S.D. of the go / back area in the Method (1) took 0.23 / 0.20 respectively. On the other hand, the S.D. of the go / back in the Method (2) took 0.18 / 0.17 respectively, and this value is smaller than the Method (1). This means that the Method (1)'s non linear instability would be appeared in the long range control condition, and at least in the 15 m range control, simple controller design Method (2) is useful.

Figure 6. Result of the experiment 2 roll and pitch position transition one turn 15 m distance. The controller Method (1) and Method (2) are compared.

6. Conclusion

In this paper, 50 m-range autonomous 4 rotor helicopter movement control method by using single search light was proposed and the autonomous flight test evaluation was performed. In order to realize over 50 m long distance flight of the drone under unstable GPS signal situations such as under the bridge or inside tunnels for the periodic inspection, the correct self position measurement and the controller design are indispensable for stable control. In the 50 m distance long flight control experiment of the room, a proposed control method using 2nd order velocity factor (Method (1)) and a control method using boundary condition of both sides (Method (2)) represented good performance comparing with the optimized P-D control. Especially in the small room condition, the Method (1) took most good performance. On the contrary, more practical situation, 2 m width 15 m range corridor surrounded by wall long distance flight control showed a good performance in the case of Method (2). It represents that the controller design depends on the flight situation, and there would be effective method even by a simple controller. Our results would be useful to design an autonomous drone controller in the situation that there is no skilled the drone control operator and the flight by visual confirmation of man are hard conditions.

References

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