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Analysis of Importance of Search Altitude Control for Rapid Target Detection of Drones

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Abstract

Rapidity and accuracy are important considerations when a drone is employed in a wide surveillance area to detect a target. They are more important when the scope of application is a search and rescue operation or the monitoring of natural disasters, which may require prompt warnings and response. During the actual operation of a drone, rapidity and accuracy are associated with the change in the altitude of the drone. The aim of this study is to analyze the characteristics of drones at varying altitudes and prove that altitude is a relevant factor in the performance of drones. Herein, the characteristics of the drone at varying altitudes were analyzed through several search simulations. The results suggest that a high-altitude drone is relatively advantageous compared to a low-altitude drone in a probability-based target search, and that the search altitude is also a very important and fundamental factor in target search by drones.

Index Terms: Altitude change, Drone altitude control, Drone search, Target detection, Unmanned aerial vehicles

I. INTRODUCTION

The rapid deployment of drones is required in many applications, such as effective search-and-rescue operations, monitoring of military facilities for the deployment of weapons during wartime, and monitoring of natural disasters (such as propagation of forest fires). A drone may be hindered by a variety of external disturbances during its attempt to track the location of a target, and hence may spend considerable time searching for it. Therefore, an effective technique by which the drone locks the position of a target in a wide navigation area is essential [1].

The quality of the information that a drone acquires when executing a mission varies in accordance with altitude. At a high altitude, the drone can hover over a wider range, but the quality (accuracy) of the acquired data declines. On the contrary, at a low altitude, a drone can obtain higher-quality data by searching a narrower range. Moreover, the quality of the acquired imagery is subject to the resolution of the onboard drone camera, and it is therefore necessary to determine the optimum altitude of operation in consideration of such characteristics [2].

During the actual operation of a drone, its accuracy and rapidity are related to the change in its altitude. The scope of this research was to improve the accuracy and rapidity of the drone in target acquisition. The operational characteristics of drones were analyzed at varying altitudes. A method for detecting a target more rapidly is suggested.

This paper is organized as follows: Section II discusses the existing altitude control strategies. In Section III, we investigate the problem of the search altitude and search area that should be considered for the target search by drones. In Section IV, we analyze the importance of search altitude control in target detection by drones through various simulations. Section V concludes this paper.

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II. EXISTING ALTITUDE CONTROL STRATEGIES

In this section, we review and analyze existing research related to the search altitude control strategies for a drone's target search.

Table 1 presents a summary of research performed on the altitude control of drones so far. Chung and Burdick [3] defined a navigation problem and proposed a navigation model based on probabilistic methods. This model is significant as a starting point to tackle accuracy issues with regard to altitude. The study of Waharte et al. [4] was an early one that presented a cooperation method between a high-altitude drone and a low-altitude drone. However, this study did not present specific navigation algorithms and mainly focused on the comparison between cooperation and noncooperation of the two drones at different altitudes. Symington et al. [5] delved into the experimental determination of the values of α and β of the probability update function for a probabilistic search, where α is the probability of false alarms, and β is the probability of missed detection. Kim et al. [6] compared the navigation performance of two drones with varying altitudes using the partially observable Markov decision process (POMDP) method. Waharte and Trigoni [7] introduced algorithms related to the altitude of drones as described above, simulated their performance in a specific experimental environment, and presented a comparative analysis of the results.

Another paper [8] based on probabilistic acquisition methods reported the change in the maximum probability of the search success of drones with varying altitude. Ha [9] presented an improved idea of the hierarchical POMDP algorithm.

Tisdale et al. [10] proposed a method to search the exact target position by the convergence of search information of a large number of unmanned aircraft. In this study, altitude is assumed to be an independent factor.

Hayajneh et al. [11] proposed that an optimal drone height exists that ensures the best communication performance between unmanned aerial vehicles and all mobile users in the drone's entire coverage area.

Mozaffari et al. [12] derived the optimal altitude of a low-altitude drone that leads to minimum ground coverage and minimum required transmit power for a small single drone.

Hayajneh et al. [13] investigated the impact of a drone's altitude to enhance communication performance in drone-powered small cellular networks for resilient smart cities.

Table 1. Studies related to altitude control strategies

Ref.	Subject	Weakness
[3]	Definition of the drone's target-detection problem	No altitude control strategy
[4]	Cooperation between multiple altitude drones	No altitude control strategy
[5]	Experimental determination of α and β coefficients for use with the probability update function	No specific search algorithm and no collaboration between drones
[6]	Consideration of multiple complete cell observations and unaligned cell observations	No specific search environment
[7]	Analysis of drone target searching algorithms	No unique search algorithm

III. ALTITUDE CONTROL STRATEGY

When examining target detection by means of a drone, two factors need to be considered. The first consideration is the division of the altitude (height) of navigation, i.e., dividing the altitude of detection into several different levels, and it is also dependent on the number of drones participating in the detection process. The second consideration is the partitioning of the navigation area, i.e., partitioning a search area into clusters of an optimum size.

A. Altitude Division

Assuming that the search area is in the form of a square, it is proportional to the square of the altitude as shown in Fig. 1. If the altitude of the highest drone is measured as *h* and the search area is *A*, this can be expressed as follows by Eq. (1). It follows that the search area of the lower drones with an altitude of 1/2 *h* is 1/4 A. In [7], there was no mention of specific heights. This was also true for [8], where no specific altitude reference for the UAV could be found, although the search drones were divided into low-altitude and high-altitude drones.

$$\frac{A_3}{A_1} = \frac{\left(\frac{1}{2}h_1\right)^2}{h_1^2} \tag{1}$$

B. Method for Partitioning of the Search Area

The second consideration is partitioning of the search area, a process that depends on the altitude of the highest drones. Depending on the assigned altitude, the first search area of the drone is determined. The first search is performed based on an algorithm, according to which the search area is partitioned and observed by low-altitude drones. When the level of low-altitude drones reaches the assigned limit, the search area is no longer divided, and the search is resumed by the drone assigned to that particular cluster.

When the level of the highest-altitude drone is determined, the calculation of the first search area is performed as follows. The drone's camera has a wide-angle lens having a field of view exceeding 180°. The border of such lenses suffer from distortion, which is a characteristic that does not

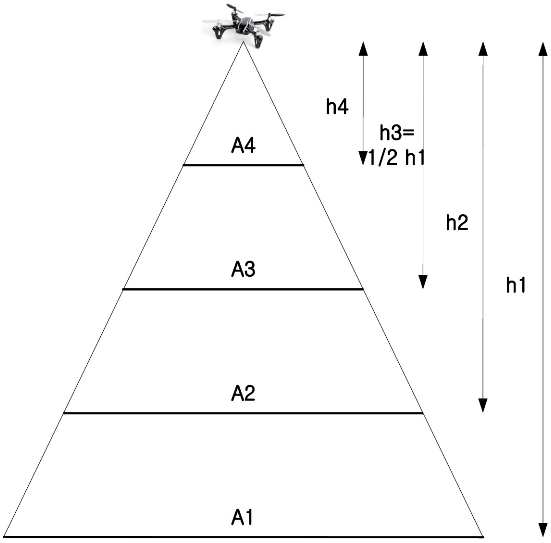

Fig. 1. Search altitude and search area of drones.

allow an easy adjustment to the focus of the image, as compared to a conventional lens. Although the acquired image seems to be wide, for both convenience and accuracy of calculation, the search area should be considered in the form of a rectangle, as shown in Fig. 2.

If the initial circular search area is considered to have a radius *b*, the relationship between radius *b* and altitude *h* can be expressed as Eq. (2). Then, the actual search area "A" may be solved by substituting for *c*, as shown in Eq. (2).

According to this equation, a reduction of 1/2 in the hovering altitude difference between the upper and lower drone reduces the search area of the drone to 1/4. The subsequent increase in the accuracy of detection and the increase in the speed of search was monitored.

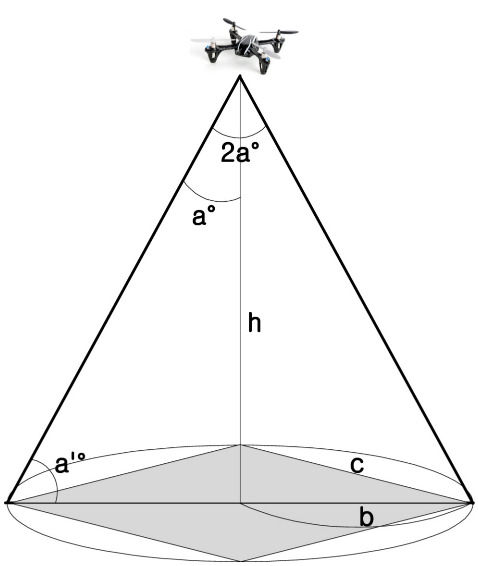

Fig. 2. Relationship between search altitude and search area.

$$b = \frac{h}{\tan a'}$$

$$A = c \times c = (\sqrt{2} \times b)^2 = 2b^2 = 2\left(\frac{h}{\tan a'}\right)^2 \qquad (2)$$

IV. ANALYSIS OF CHARACTERISTICS OF SEARCH ALTITUDE

The behavior of drones with different altitudes was analyzed through several simulations. Table 2 provides the simulation environment. In this simulation, the missed detection probability β of each drone is assumed to be within the range of 0.0 to 0.2 [5]. β is dependent on the altitude of the drone and the resolution of the camera, amongst other factors.

A static single target, which is generated randomly in the search area, is used to compare the characteristics of the drones at different altitudes. The search path of the drones for searching the target is shown in Fig. 3. The high-altitude drone performs a linear search at a 20-m altitude and the low-altitude drone performs a linear search at a 10-m altitude. At this time, each of the drones has unique α and β values.

Fig. 4 compares the search time up to success (finding of the target) at different altitudes. Assuming that the actual missed detection probability β of each altitude is as in Table 2, the high-altitude drone demonstrates a better performance than the low-altitude drones. Fig. 5 compares the search distances up to the success of the search at different altitudes. The search distance is calculated using Eq. (3).

$$Distance = \#\ of\ cells\ moved \times \sqrt{2 \times \left(\frac{1}{\tan a'} \times h\right)^2} \qquad (3)$$

The search time can also be calculated by Eq. (4). Here,

Table 2. Simulation environment

Category	Contents
Simulation tool	MATLAB
Size of search area	8 × 8 units
Number of drones	1 (static)
Number of targets	1 (random)
Average speed of drones	15 km/h (4.1666667 m/s)
Search area	
High-altitude drone	4 × 4 units (altitude: 20 m, β = 0.0-0.2)
Low-altitude drone	2 × 2 units (altitude: 10 m, β = 0.1)
	1 × 1 units (altitude: 5 m, β = 0.0)

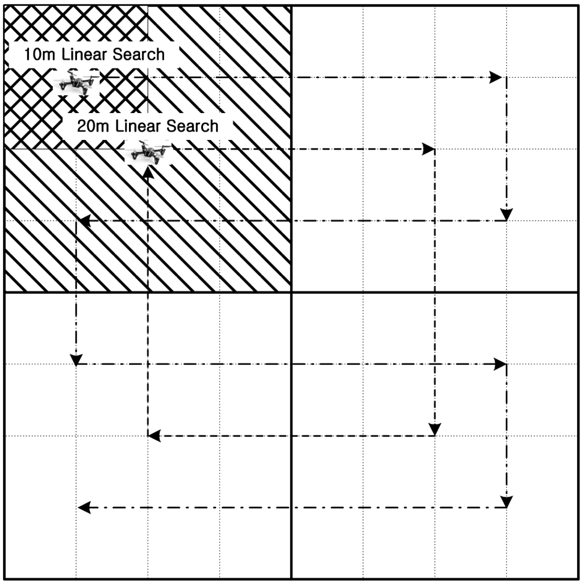

Fig. 3. Search path of the drones for searching the target.

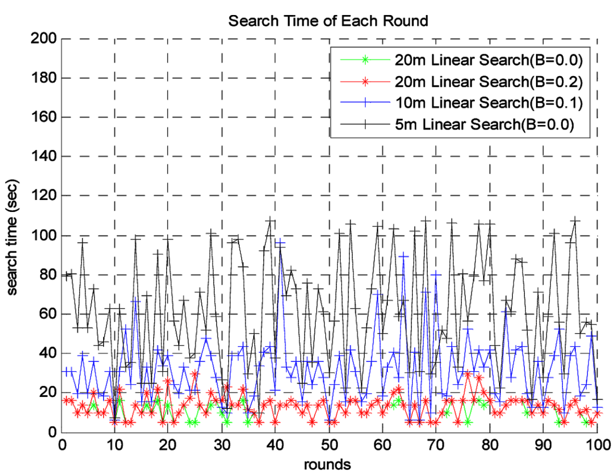

Fig. 4. Comparison of search time of drones with different altitudes.

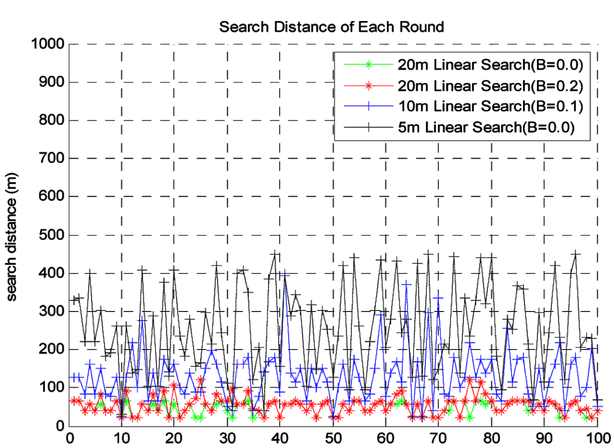

Fig. 5. Comparison of search distance of drones with different altitudes.

we assume that the speed of the drone is 4.1666667 m/s as listed in Table 2.

$$\textit{Search time} = \textit{Speed of drone}/\textit{Distance} \tag{4}$$

The computation of the probability of target existence for each cell uses a cyclic probability update equation [6, 14-16] as in Eq. (5). In this equation, p_{t-1} means the probability of cell at time t-1, α_h is the false alarm probability of altitude h, and β_h is the missed detection probability. Different expressions are applied according to the determination result of the presence of the target of the drone in the current cell. In other words, $d^t = 1$ means that the drone determines that there is a target, and $d^t = 0$ means that the drone determines that there is no target, and different equations are applied.

$$P_t = \begin{cases} \dfrac{(1-\beta_h)P_{t-1}}{(1-\beta_h)P_{t-1} + \alpha_h(1-P_{t-1})}, \text{if } d^t = 1 \\ \dfrac{(\beta_h)P_{t-1}}{(\beta_h)P_{t-1} + (1-\alpha_h)(1-P_{t-1})}, \text{if } d^t = 0 \end{cases} \tag{5}$$

Figs. 6 and 7 show the cumulative search time and distance for the linear search by drones with different altitudes, respectively. As may be interpreted graphically, when the missed detection coefficient (β) is taken into consideration, the performance of the high-altitude drone, which searches a wider area, is higher.

In other words, as the altitude increases, a large performance difference is observed. When different missed detection values are applied at the same altitude (red line and green line, lower two lines), the difference in performance is less than the difference in performance due to altitude. Therefore, we may also deduce that the performance of drones is highly influenced by the hovering altitude.

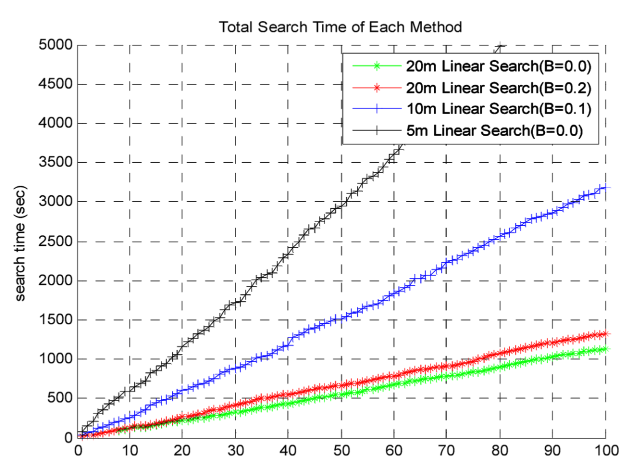

Fig. 6. Total search time of each method.

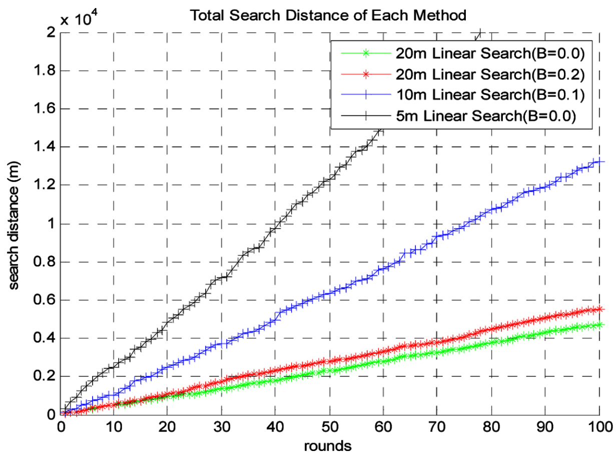

Fig. 7. Total search distance of each method.

V. CONCLUSION

This study focused on analyzing the relationship between the altitude and search area when a drone is employed for target detection. The characteristics of the drone at varying altitudes were analyzed by means of several search simulations. The results of these simulations suggest the following conclusions.

When the characteristics of the drones at different altitudes were compared in the first simulation, the high-altitude drone demonstrated better performance than the low-altitude drones. Therefore, we can conclude that the search performance of high-level drones is relatively good in probability-based target search by drones.

When the cumulative search time and distance for the linear search by drones at different altitudes were compared in the second simulation, as the altitude increased, a large difference in performance was observed. This difference increased more rapidly than the difference in performance according to the missed detection (β). Therefore, we can conclude that the search altitude is also a very important and fundamental factor in probability-based search by drones.

The results also suggest that studying search by cooperation of multiple drones through altitude control is necessary. Further experimental studies on the cooperation of drones by altitude control may be necessary.

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