Research On Optimal Search Efficiency Of Rocket Wreckage Based On UAV

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Abstract: In order to improve the efficiency of UAV search for debris targets in the area of debris. The paper discusses the relationship between the flight altitude, photoelectric turret parameters, searching area and resolution of UAV. Then discusses the characteristics of rocket debris distribution based on historical debris distribution data by building the model of UAV operating area and regularities of debris distribution, this paper calculate the probability of finding the debris targets in one flight with optimal searching method by Monte Carlo calculation method. This method has high practical value for using UAV to search rocket debris.

1. Introduction
The conventional rocket still can't be recycled in a controllable way at this stage. The fuel used in the rocket is a highly toxic substance, resulting in the risk that the rocket debris will cause great harm to people and the environment, thus, it must be recycled in the shortest time. With the development and maturity of UAV technology, the application of UAV searching in the landing area will be one of the important means to improve the search and recovery ability of the existing rocket debris. It conducts air search by UAV with optical detection equipment so as to quickly find and locate the fallen rocket debris and improve the speed and accuracy in searching debris, which simplifies the research and improves the efficiency. There is little analysis on the falling point of rocket debris in the existing literature. Xiao et al. mainly analyzed the random interference term in the falling process of debris[1-2]; Wang et al. studied the distribution rule of the falling point of rocket fairing debris[3]. In this paper, combining with the distribution characteristics of the debris of a certain type of rocket, the author makes a quantitative analysis on detection ability of the UAV, and eventually, determines the optimal single search area and debris detection probability of the UAV.

2. Modeling of the UAV Detection Capability
The detection capability of a UAV is mainly determined by the load it carries. The payload of a search UAV mainly achieved by photoelectric turret, whose optical mechanical system is relatively complex as a whole, but can be abstracted into the imaging optical path of the main optical axis in the general optical system through simplification. The mainstream visible light detector in the photoelectric turret is selected for modeling.

2.1 Basic Assumptions
1) Main indexes of a type of photoelectric turret
Detector: 1/2.8 inch
Pixel size: 2.9 um * 2.9 um
Resolution: 1920 * 1080
Focal length: 4.3 mm (wide angle) – 129 mm (far end)
Field of view: 63.7° (wide angle) - 2.3° (far end)
2) Size of the object being searched
According to publicly available information, the rocket booster is a cylinder with a length of about 10 m and a diameter of 2.25 m. After falling into the ground, the whole body will be impacted, broken or deformed. Assumed a calculation standard with the overhead cross-section of debris as 3.2 m * 1.5 m.

3) Pixel occupied by target recognition
The Johnson’s criteria were adopted in the present study [4].

The definition of “detection”: to find a target in the field of view. The target image must occupy more than 2 pixels in the direction of critical size. The definition of “recognition”: to classify a target such as a tank, a truck, or people. The target image must occupy more than 8 pixels in the direction of critical size. The definition of “identification”: the type or other characteristics of the target can be distinguished, such as distinguishing between enemy and foe. The target image must occupy more than 16 pixels in the direction of critical size.

Based on Johnson’s criteria and empirical value, it is assumed that a 0.2 m resolution of a UAV photoelectric turret to the ground can achieve an effective target recognition.

2.2 Calculation Model
The relationship between camera focal length and UAV flight altitude:

$$h = f \frac{D}{d}$$ (1)

The relationship between camera focal length and field angle:

$$w = \frac{180}{\pi} \arctan \left( \frac{p}{2f} \right)$$ (2)

The ground scanning width of the UAV:

$$L = 2h \tan \left( \frac{w\pi}{360} \right)$$ (3)

The relationship between flight time and operating area of a UAV:

$$S = cvtL$$ (4)

In the above formula: $d$: pixel size of detector; $h$: relative height of a UAV to the ground; $D$: resolution of ground pixel; $w$: field of view of optical system; $P$: size of CMOS detector; $f$: focal length of optical system; $L$: ground scanning width of a UAV; $S$: scanning area size of a UAV; $v$: flying speed during a UAV scanning; $t$: UAV flight time; $C$: the influence coefficient of the deviation of working area caused by partial overlap of images or a turning of a UAV.

2.3 Calculation Results
Under the condition of 0.2m observation accuracy, the relationships between a UAV focal length and flight height, field of view, sweep width, flight time and operating area of a UAV are shown in Figure 1.
3. Historical Distribution of Debris in the Falling Area

During the rocket launching, it is necessary to calculate the final impact point of the debris according to the location and speed of the debris in separation time, but there is usually a deviation of several thousand meters between the calculated landing point of the central plane and the actual point of the debris. The calculation of the deviation between the actual and the calculated drop point aims to summarizing the distribution rule of debris impact points.

According to the statistics of rocket launching points, the author made an in-depth analysis on the movement characteristics of the same type of rocket debris, and considered random interference factors such as propellant flow deviation, thrust deviation and takeoff mass deviation. According to the central limit theorem in probability theory, the sum of variables produced by these random interference factors nearly obeys normal distribution. Though there’s a small number of accumulated data samples, the normal distribution model can be used to approximate the actual distribution of debris impact points by analyzing the characteristics of existing data. In order to better reflect the physical characteristics of the falling process of debris, two hypotheses are put forward here: First, each falling process of debris is independent of each other; Second, the deviation of the falling point of a single debris is independent of each other in the vertical and lateral coordinates.

The normal distribution function is used to fit the lateral deviation data of the debris falling point, as shown in Figure 2.
Figure 2 Data Distribution of Lateral Deviation of Debris Falling Point

The normal distribution function is used to fit the vertical deviation data of the debris falling point, as shown in Figure 3.

Figure 3 Data Distribution of Vertical Deviation of Debris Falling Point

After calculation, the lateral deviation $X$ of the debris falling point approximately obeys $N(11.9, 22.8)$, and the vertical deviation of the debris falling point approximately obeys $N(0.92, 6.4)$.

4. Simulation of Optimal Search Efficiency of the UAV

4.1 Monte Carlo Simulation of Debris Dispersion

The application of Monte Carlo in simulation calculation of debris falling point dispersion is based on the statistical characteristics of the debris falling points in the actual rocket launching process. Firstly, a probability model similar to the problem to be solved is established. Then, the probability model and the problem to be solved are simulated or sampled by using this similarity, to mathematically process the result and transform it into the approximate solution of the problem [5].

The distribution of rocket debris involves both lateral and vertical directions, which can be described by two-dimensional Normal distribution, as shown in formula 5.
Taking the calculated impact point as the aiming point center in the process of rocket launching, the vertical and lateral coordinates of deviation between the actual falling point and the calculated impact point are independent of each other, then the two-dimensional Normal distribution can be simplified to formula 6.

\[
f(x, y) = \left(2\pi\sigma_1\sigma_2\sqrt{1-\rho^2}\right)^{-1} \exp\left[-\frac{1}{2(1-\rho^2)}\left(\frac{(x-\mu_1)^2}{\sigma_1^2} - \frac{2\rho(x-\mu_1)(y-\mu_2)}{\sigma_1\sigma_2} + \frac{(y-\mu_2)^2}{\sigma_2^2}\right)\right]
\]

Then the falling point of debris obeys the two-dimensional Normal distribution with the parameters of \((\mu_1, \mu_2, \sigma_1, \sigma_2)\). \(\mu_1, \mu_2\) are the mean values of the actual falling point in X and Y directions, and \(\sigma_1, \sigma_2\) are the standard deviations. According to the statistics of debris distribution in the falling area, the vertical distribution obeys \(N(11.9, 22.8)\), and the lateral distribution obeys \(N(0.92, 6.4)\). Then the falling point of debris obeys the Normal distribution of \((11.9, 0.92, 22.8, 6.4)\).

When Monte Carlo method is used to calculate the probability, it is necessary to produce the random numbers that obey the Normal distribution. Usually, a group of random numbers with uniform distribution are generated first, and then the random numbers of normal distribution are generated by using the uniform random numbers. Finally, the result of conducting 5000 times of debris impact point simulation is carried out is shown in Figure 4.

![Figure 4 Simulation Diagram of 5000 Debris Falling Points](image)

4.2 Simulation of Optimal Search Area for the UAV

According to the above calculation, a sortie can cover a range of 100km² by adapting the photoelectric turret as the optical load. Owing to the characteristics of autonomous flight and the convenience of operation, the UAV adopts rectangular search mode. Now the optimal area can be obtained by sliding window searching, a more simplified way, which can calculate the number of debris in each sliding window and get the maximum value after analyzing and comparing process so as to figure out the
optimal searching area for UAV as shown in Figure 5.

![Figure 5 Simulation Diagram of Optimal Search Area for the UAV](image)

Figure 5 Simulation Diagram of Optimal Search Area for the UAV

The results are basically consistent after comparing the theoretical vertex (11.9, 0.92) of two-dimensional Normal distribution and the center point of the best search area obtained by Monte Carlo method, which shows that this method is feasible.

According to the simulation results, by conducting research with photoelectric turret, the probability of finding at least one debris in one sortie is 35.6% for a certain type of rocket with four boosters.

5. Conclusion
This paper builds the detection model of the UAV, establishes the relationship between UAV operation time and operation area under a certain type of photoelectric turret. Meanwhile, it analyzes the distribution of debris in the falling area, based on which, determines the optimal search area and search efficiency of UAVs by Monte Carlo method. In this paper, the existing data and equipment are used to analyze the search process and make it optimal, which has great value for guiding the search of debris in the falling area.

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