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The Optimal Search Scheme for a Crashed Plane Research

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Abstract: *It is very important for the rescue workers to predict the fallen position of the crashed plane accurately and provide the search way reasonably. First the prediction model of fallen location and the drift model after the plane crashes need to be established. Then three kinds of model are put forward; they are used for searching the wreckage of plane. Finally, in order to display the provided methods and models visually, the related experimental results are provided. The models are needed to be simplified and supposed to get the results.*

Keywords: *Crashed Plane; Search; Model*

1. Introduction

1.1. Restatement Problem

In comparison with other traffic accident, the probability of aviation accident is very low, both domestically and internationally. But once it happened, the cost will be very heavy including human, weakness and financial resources. Back in 2014, many aviation accidents happened in the world. On January 7th, the US helicopter HH – 60 crashed; On February 16th, the Nepal airlines flight 183 crashed; On March 8th, the Malaysian flight MH370 went missing; On July 17th, the Malaysian flight MH17 was shot down and On July 23rd, a flight of Taiwan's TransAsia Airways was forced to down. So in order to maximize the losses to a minimum, it is necessary to build a generic mathematical model that could assist "searchers" in planning a useful search for a lost plane feared to have crashed in open water.

In this paper we attempt to build a wrecked airplanes search pattern, using the theory of linear programming. In addition, we consider the maximum of search efficiency and the minimum of search cost as the objects in the model, and the distribution of multiplex search aircrafts is regarded as decision variables of the model. Meanwhile, we look upon the sea surface area which there is specific distance from final missing place to as condition of constraint.

1.2. Previous Work

Modeling of searching wrecked airplanes is by no means a new problem, and many mathematical models have previously been used to help search the missing airplanes. Literature[1,2] has studied the common working methods and attention points for search and rescue under harsh meteorological sea conditions for rescuers ;

Literature [3,4] gave the method to select the ship to implement rescue when there are many rescue ships available by using modern decision theory and fuzzy mathematics evaluation method. literature [5,6] has researched the calculation of sea distress target with wind, and flow drift and the determination of the search area; Literature [7,8] has researched the search scope calculation and the optimal search mode problem when the helicopter has been involved in the rescue; has researched sea stereo search global optimization model and the simulation research problem; Literature [9] used probability theory to do their study by modeling in maritime search rescue operations reliability.

Literature [10] has studied how to use maritime satellite positioning and search for lost aircraft by using the maritime satellite terminal positioning technology based on time delay and Doppler frequency shift.

2. METHODS

2.1. Model Assumption

- We get information when plane lose contact, we know speed of plane $\vec{V}_P$, speed of wind $\vec{V}_w$, angle of two speed, time.
- Regardless of the air resistance.
- Few variables fitted to the normal distribution, with the mean at exception $(\mu = \mu_0)$ and variance $\sigma^2 = 0.05\mu$.
- Probability of down when lose contact is 0.5, then probability of down are geometric progression.
- Wreckage will move at the speed of wind and current under the action of wind and water.
- We know the speed of current $\vec{V}_c$.
- We know the speed of wind $\vec{V}_w$.
- Wreckage drifting on the surface of ocean produce so few error we can ignore.
- The closer the distance between plane and datum point is, the higher search efficiency is.

2.2. The Model

The thesis divided the whole model into three-step model. They are the Falling Model, Drifting Model and the Best Search Scheme Model.

2.2.1. Step 1. The Falling Model

Falling Model I Falling Time Model

With the lost contact moment starting point for the timing, the probability that plane crashes: the first is that plane crashes at the lost moment

when $t = 0 \quad P = \frac{1}{2}$

when $t \succ 0 \quad P = \left(\frac{1}{2}\right)^{(t+1)}$

The loss of communication for the most plane is divided into the following two types: the first is communication lost, leading to the plane can't call on the ground, or the ground is unable to call to the plane.

In order to simulation conveniently, to suppose that plane flies in the original flight path.

According to the supposition, the location change models after the aircraft losing track but not falling can be given:

$$P_1 = f_1\left(t, \overrightarrow{v_0, P_0}\right) \tag{2.1}$$

P_1 for the variable of the plane position in time t, people often use latitude and longitude and the distance from the center of the Earth to represent this position on earth. $\vec{V}_0$ for aircraft flight velocity and direction of lost time. P_0 for a constant of aircraft position at the lost time.

Falling Model I Falling Location Model

In the process of plane falling, we only consider the effect of gravity and wind. The figure 2 is the force analysis of plane on the vertical direction and the figure 3 is the speed of plane in a horizontal direction, we can conclude:

The descent time of plane 2.2 and the aircraft's position after crash relative to its offset of projection in horizontal plane before it crashes 2.3.

$$t_d = \sqrt{\frac{2\times H}{g}} \tag{2.2}$$

$$O = \sqrt{\left[\left(v_p + v_w \times \cos\alpha\right)\times t_d\right]^2 + \left(v_w \times \sin\alpha \times t_d\right)^2} \tag{2.3}$$

We get the airliner crash location model:

$$P_2 = f_2\left(t + \mathrm{V}t_1, P_1\right) \tag{2.4}$$

P_2 for a location description variable of the crashed airliner.

2.2.2. Step 2. Drifting Model

Target drift speed is the sum of a vector that includes the current speed around the target and the speed that target is relative to the seawater around.

$$\vec{V}_{drift} = \vec{V}_{current} + \vec{V}_{relarive} \tag{2.5}$$

Among them, $\vec{V}_{current}$ for the current speed around the target. $\vec{V}_{relarive}$ for the speed that target is relative to the seawater around. $\vec{V}_{current}$ consists of surface currents and waves stokes drift. The surface currents include ekman drift, baroclinic movement, tide and inertia flow, etc. $\vec{V}_{relarive}$ embodies the influence of the wind and the waves on the drift speed. When the length of search target is less than the wave length, the influence of the wave can be ignored. While $\vec{V}_{relarive}$ is mainly affected by the wind, $\vec{V}_{current}$ is mainly affected by the surface currents. When the target length is comparable with the wavelength (more than 50 m, bigger ship), at this time, the influence of wave can't be ignored, we need to build a complex analytic model to solve. This paper only studies the drift of general search target whose length is smaller relative to the wavelength. C for the velocity vector of surface current, L for the wind-induced drift velocity vector of the target, at this time target drift velocity vector V can be represented as:

$$\vec{V} = \vec{C} + \vec{L} \tag{2.6}$$

The target drift model can be expressed as:

$$X(t) - X(0)\int_0^t V(t')dt'\int_0^t \left[C(t') + L(t')\right]dt' \tag{2.7}$$

$X(t)$ for the location of the object at time.

Our model for the above model is simplified, only consider the influence of ocean currents and wind on drift:

$$\overrightarrow{V_{drift}} = \overrightarrow{V_{current}} + \overrightarrow{V_{wind}} \tag{2.8}$$

α, β are representing the angle of the ocean currents, wind and initial position point as Figure 1.

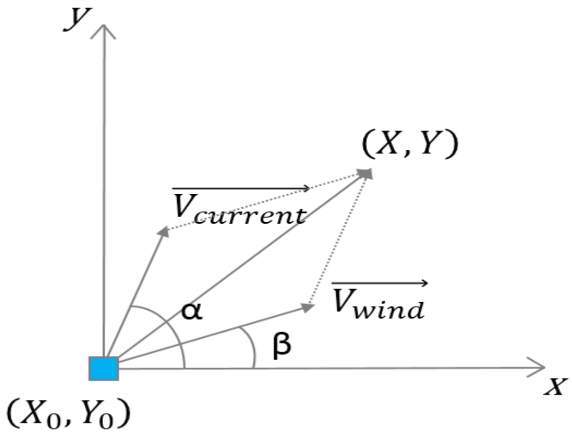

Figure1. *Velocity of Drifting*

Suppose the plane's initial position of falling into water after crashing is (X0,Y0),the position after time t is

$$X = X_0 + \left|\overrightarrow{V_{current}}\right| \times t \times \cos\alpha + \left|\overrightarrow{V_{wind}}\right| \times t \times \cos\beta \tag{2.9}$$

$$X = X_0 + \left|\overrightarrow{V_{current}}\right| \times t \times \sin\alpha + \left|\overrightarrow{V_{wind}}\right| \times t \times \sin\beta \tag{2.10}$$

So the final position is (X, Y).

We input the coordinates of the initial position and the changes of ocean currents and wind speed and direction through the drift model. Then we can get position of floater at moment t.

2.2.3. Step 3 The Best Search Scheme Model

After we have determined the possible distribution area and probability distribution of the plane wreckage, the next task is how to determine the search solutions. Because the search tool is plane, and the electronic devices and sensors are used to search, plane can search a rectangular area, at the same time, considering the recognition efficiency of electronic devices and sensors, we assume that the closer the distance between plane and datum point is, the higher search efficiency is.

Search Scheme I

We put forward the first effective search plan, as follows:

The first step: Find the current basic point and regard the basic point as center, the possibly falling area is divided into square area that the side length depends on the longest horizontal distance. The plane search Start at a certain point, every point of intersection for straight line are set to the key nodes for search, as shown in the Figure 2.

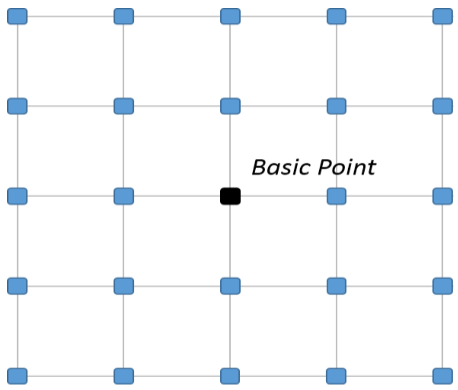

Figure2. *Basic Point and other Nodes*

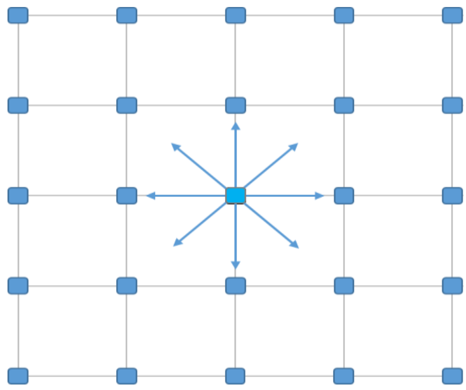

Figure3. *Which is Next Node*

The Second Step: The plane rushed to point to search, the falling probability of wreckage for the area need to be dynamically adjusted, including the decrease of all nodes' probability density after search and the change of nodes' probability density after drifting. The searched regional information needed to be recorded well. As shown in the Figure 3.

The Third Step: Choose the next neighboring search node randomly, the neighboring nodes includes eight direction nodes at most, and there exists certain differences in horizontal and inclined direction, as shown. The falling probability of wreckage for the area need to be dynamically adjusted after search and the searched regional information needed to be recorded well. As shown in the Figure 4.

The Fourth Step: To compare the search distance with the pre-determined maximum search distance, the plane needs to stop search if it exceeds the maximum search range, or repeat the third step.

It is not difficult to find that the above effective search scheme is not optimized. In order to improve the search efficiency, we need to make many simulation experiments, and then select the optimal search. The more experiments we make, the greater likelihood of optimal search scheme we can get.

Search Scheme II

Because of the first round of search, all of the probability density of each node are made relevant adjustments, and the wreckages exist present floating in the process of joining together the two round searches, so a new basic point must be determined in the search process of next round. The basic point can be defined the node with the biggest sum of the probability density in the second and the subsequent rounds, after this, the round search can be proceed like the first round search.

The search scheme 1 have developed the continuous search in the possible falling area, it is more suitable for searching more certain areas. Following, more general search will be introduced.

The First Step: The search area and its probability density need to be determined, the search radius and other parameters also needed to be determined.

The Second Step: Look for the best positions as search center on first point and the radiuses is the search radius of search equipment and expand the corresponding search, then falling probability density of the wreckage should be adjusted in that area.

The Third Step: Calculate that whether the plane could do the next round search, if not, the algorithm is finished, if can, return to the second step.

Search Scheme III

If it can search the wreckage fast, and the falling area will not spread quickly in a short time, aircraft search queries can be transferred into site selection problems and delivery problems in logistics. Specific search programs are as follows:

The First Step: To determine the nodes and distance that the plane can search;

The Second Step: Use MCLP coverage model to calculate the best P site locations. The specific model and Figure 5 are as follows:

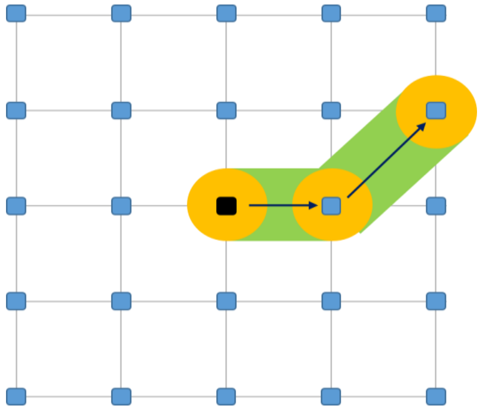

Figure4. *Route of Searching*

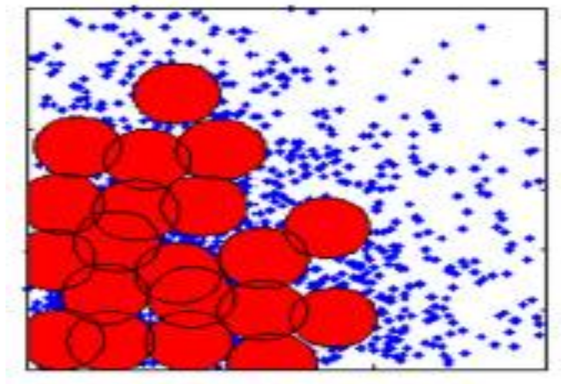

Figure5. *Distribution of Nodes*

The formulation of the MCLP is

$$Maximize \quad z = \sum_{i \in I} w_i y_i$$

Subject to:

$$y_i \le \sum_{j \in N(i)} x_j \quad for\ \ all\ \ i \in I$$

$$\sum_{j \in J} x_j = P$$

$$x_j \in \{0,1\} \quad for\ all\ \ j \in J$$

$$y_i \in \{0,1\} \quad for\ all\ i \in I$$

The Third Step: Obtain a feasible flight plan based on the adjacent search principle and use the principle of one by one revision of two sides to optimize the plan step by step.

The Fourth Step: To determine whether the flight distance of optimal search path is lower than the upper limit set in advance. If it is lower than the upper limit set in advance, then increase P values; if it is higher, then reduce the P values.

The Firth Step: To find the ideal P values and flight routes and launches the corresponding search, then adjust the probability density of every area after search.

The Sixth Step: To determine whether it is necessary to continue the next round search, if need, then turn to the second step, otherwise end.

3. Results

3.1. Falling Model Results

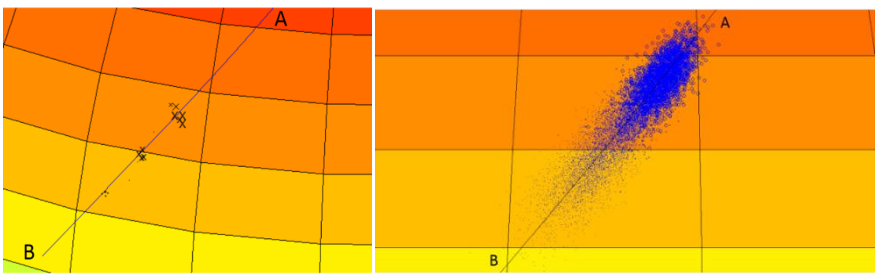

Figure6. *The Fall Point Probability Distribution and Location Distribution*

When the latitude and longitude of AB two points, the plane lost time t, as well as the total flight time t are known, can be drawn according to the hypothesis and model (Figure 6).

3.2. Drifting Model Results

Graph was displayed for this process (Figure 7). So, we can simulate the position of the aircraft in the water according to that situation to provide initial point about the situation of wreckage floating.

3.3. The Best Search Scheme Model Results

Search Scheme I

By the prediction model of reservoir location, the experimental data needs to be set up: the plane flies from point A (115ºE,40ºN)to point B(90ºE,10ºN), total flight

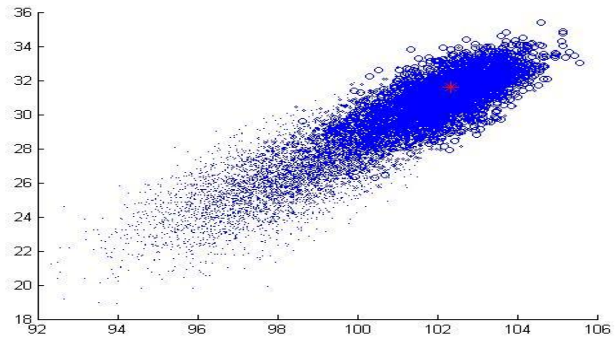

Figure7. *The Point Location Distribution after Drifting*

time is 12 hours. The plane takes off at 6 hours then lost connection. The aircraft is at the rate of 260 m/s, when the wind speed is 10 m/s, the angle of wind speed and their craft speed is 90 degrees when the plane loses connection. At this time, the flying height is 10000 m. After the plane lost, the plane's airline searches the plane immediately. Using the prediction model, the figure can be got (See Figure 8).

The red asterisk in the figure represents the basis position of the crashed plane. the blue areas is the possible falling position, the greater the density is, the greater the falling possibility is. And, airlines search the plane timely, so the spread area of the wreckage is smaller. The figure could be got by the first kind of route search model. Results in the figure are acquired by many randomized trials, so it has certain credibility.

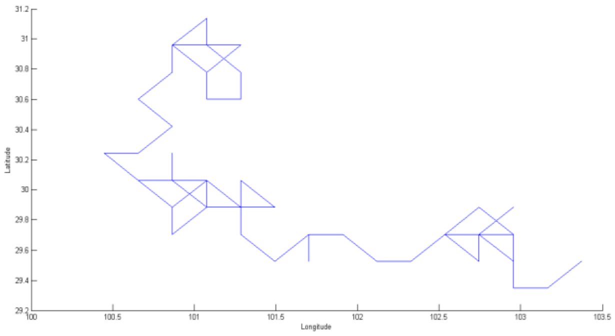

Figure8. *Search Line*

Search Scheme II

The x-axis and y-axis of the No. 2 search model need to be bisected basing on the range of known position and corresponding probability, similar to the future, the same as the picture, each node corresponds to the search radius, it include many points, the sum of the probability of all the points can be got. The largest point of the sum of the probability is selected to be searched.

```
>> searchpoint

jdj =

     3


jdw =

     6


pp =

         0         0         0         0         0         0         0
    1.0551         0    0.5242         0    0.3308    0.9345         0
         0    0.7943         0         0    0.2442    1.9330         0
         0    0.9787         0    1.3749    0.8901         0    0.3554
    0.1197    0.2788         0    0.4077    0.1228    0.9715    0.7668
         0    0.7504         0    0.3662    0.4566    1.0514    0.5239
         0    0.2578    0.9713    0.8843         0         0         0
```

Figure9. *Result of Search Scheme II*

The position matrix of points and corresponding probability are used by the model, those points come from stochastic simulation. The model is applied practically; the corresponding data from the previous model should be used, so the accuracy of model solution could be guaranteed as Figure 9.

The No. 1 node for search is (3,6) by the result of a computer, after t search of this node, it's probability reduced to 10% of the original, later the highest probability need to be looking for continually. The second point is searched until the probability of all the points is very low.

4. Discussion

Strength

- Model of the whole process can be divided into three steps. It is so good to master movement process of each stage that we obtain a more accurate prediction model.
- Model is easy to understand, people can accept them easily.

Weakness

- The linkage between the three models did not reach the perfect effect. If a model is divided into few parts, the output of one is input of another. But the three-step model is not satisfactory.
- The lack of a real data. Model uses the Monte Carle method to simulate randomly. Although model calculate data and produce a result, real data can make our model more close to the real situation.
- Ignore the influence of air resistance. In order to simplify the model of calculation, we did not consider the air resistance. So the model is likely to have an error.

5. Conclusion

- No matter using the Monte Carlo method to simulate experiment and using the optimization algorithm, more time can be won for the search and rescue work.
- The plane crashed accidents happen, airline should take measure immediately, this paper has already mentioned that the sooner the measures are taken, the faster the plane wreckage can be found. So it can reduce the burden for the following work.
- Although the models have good application value, they have some limitations. Because the search problem of crashed plane itself is very complicated, many assumptions are specified when the models are put forward.

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