Route Planning for Surveying Major Roads after Natural Disasters

Fengbin Chen

Department of Electronics and Communication Engineering, North China Electric Power University, Baoding 071000, China

1097040866@qq.com

Keywords: route planning, TSP, SA.

Abstract: After the natural disaster, in addition to the disaster itself, the affected area also faces huge challenges, that is, the collapse of cellular communications, power and transportation networks has brought a lot of inconvenience to the disaster relief work. The surge in demand for medical supplies and the restoration of roads are two aspects that cannot be ignored. The reasonable solution of the above two problems will not only help improve the efficiency of rescue, but also promote the post-disaster reconstruction process. The survey of the main roads in the affected areas is the first step in solving these two problems. In this article, a series of methods have been developed to help plan the route of the survey task. To find the best reconnaissance lines, we learn from the Traveling Salesman Problem (TSP), and then roughly get the shortest flight routes of the drones carrying the aerial photography device based on the graph and network model. Due to the inevitable errors, we have improved them through the Simulated Annealing (SA) algorithm to achieve the purpose of optimization. We selected Puerto Rico as the research object. By collecting information about Puerto Rico's geography, climate, major cities and roads, and using the methods described above, the best route for the survey mission was obtained. Through verification, we conclude that this model can solve relatively optimal route planning.

1. Introduction

The road was blocked after the devastating hurricane. In addition, power and communication disruptions have also led to increased demand for medical supplies in hospitals or temporary medical centers. At the same time, measuring road conditions has become a top priority. In order to effectively solve these problems, the route planning of the survey task is crucial. For the delivery of medical supplies, we hope that the delivery time is as short as possible to facilitate treatment. For road restoration, the investigation scope of drones should be expanded as much as possible.

The order we solve the problem is as follows. First, divide the area. Second, calculate the distance between major cities. Finally, plan the routes for each area separately. In this process, we used the approximate circle algorithm, simulated annealing algorithm, etc. for a reasonable analysis, and taking into account the geographical conditions, communication equipment and other objective conditions, we finally gave a relatively reasonable solution.

2. Assumptions and Symbol Explanation

2.1General Assumptions

To simply the problems, we make the assumptions. The following assumptions are reasonable.

- There are no mechanical losses or accidents with the drones.
- The drone signal is received normally without any interference.
- The drone has sufficient power.
- We think of the earth as a sphere.

2.2 Symbol and Explanation

Symbol	Definition	Units
R	Earth radius(≈6350)	km
x_i	Longitude of location i	unitless
y_i	Latitude of location i	unitless
v_i	Site i	unitless
d	Distance of two sites	km
C	Hamilton circle	unitless
S	Solution space	unitless
π_i	Location coordinates	unitless
$\triangle f$	Path difference	km

3. Finding the best survey route

Before solving, we did some preparations, including the map of Puerto Rico (see Figure 1) [1]and the latitude and longitude of Puerto Rico's important ports(in bule) and major cities (see Table 1)[2].

Figure 1. The map of Puerto Rico

Table 1. The latitude and longitude of Puerto Rico's important ports and major cities

Name	Latitude	Longitude
Aguadilla	18.43	-67.15
Mayaguez	18.20	-67.14
Quebradillas	18.47	-66.94
San Sebastian	18.33	-66.99
San German	18.08	-67.04
Ensenada	17.96	-66.93
Arecibo	18.47	-66.73
Utuado	18.26	-66.70
Manati	18.42	-66.48
Dorado	18.45	-66.27
Bayamon	18.40	-66.16
Orocovis	18.22	-66.40
Santa Isabel	17.97	-66.39
Comerio	18.21	-66.23
Cayey	18.11	-66.16
Guayama	17.98	-66.11
San Juan	18.44	-66.07
Caguas	18.22	-66.03
Loiza	18.43	-65.87

Rio Grande	18.37	-65.84
Maguabo	18.21	-65.73
Humacao	18.15	-65.82
Maunabo	18.00	-65.89
Fajardo	18.33	-65.65
Ponce	18.00	-66.61
Guayama	17.98	-66.11
Yabucoa	18.05	-65.87
Aguadilla	18.43	-67.15
Mayaguez	18.20	-67.14
San Juan	18.44	-66.07
Fajardo	18.33	-65.65
Arecibo	18.47	-66.73

Considering the actual distance, the flight time of the drone, and the geographical factors, we divided the affected area into three areas, with San Juan(including San Juan, Fajardo, Maguab, Humacao, Caguas, Comerio, Orocovis, Manati, Dorado, Bayamon), Mayaquez(including Mayaguez, Arecibo, Utuado, Quebradillas, Aguadilla, San German, Ensenada), and Guayama(including Guayama, Santa Isabel, Cayey, Maunab) as the centers.

3.1 Preliminary Model

3.1.1 TSP in Graph and Network Model

a) Set an original circle:

$C = v_1 v_2 \cdots v_n v_1$

b) For $1 \le i < i+1 < j \le n,$ we build a new Hamilton circle：

$C_{ij} = v_1 v_2 \cdots v_i v_j v_{j-1} v_{j-2} \cdots v_{i+1} v_{j+1} v_{j+2} \cdots v_n v_1$

We get it by canceling $v_i v_{i+1}$ and $v_j v_{j+1}$,and then adding $v_i v_j$ and $v_{i+1} v_{j+1}$ to it. If $w(v_i v_j) + w(v_{i+1} v_{j+1}) < w(v_i v_{i+1}) + w(v_j v_{j+1})$, we replace C with Cij, which is called the improved circle for C.

c) Make changes for Cij until it can’t be improved. We can choose different original circles to repeat changes to get a more accurate outcome.

3.1.2 Calculating the Model

How can we get the distance between the two sites?

We get it by converting the latitude and longitude coordinates into spherical coordinates.

Assume that A is one point, another point is B.

$$A(R\cos x_1 \cos y_1, R\sin x_1 \cos y_1, R\sin y_1)$$

$$B(R\cos x_2 \cos y_2, R\sin x_2 \cos y_2, R\sin y_2)$$

Then we can get the distance between A and B.

$$d = R\arccos\left[\cos(x_1 - x_2)\cos y_1 \cos y_2 + \sin y_1 \sin y_2\right]$$

Using Matlab, inputting the data (see Table 1) into the model, we get the routes. (see Figure 2, Figure 3, Figure 4, Figure 5)

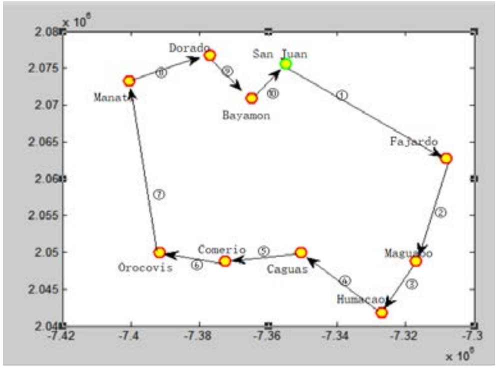

Figure 2. The route in San Juan

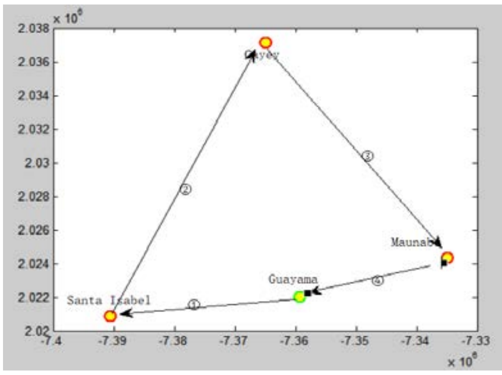

Figure 3. The route in Guayama

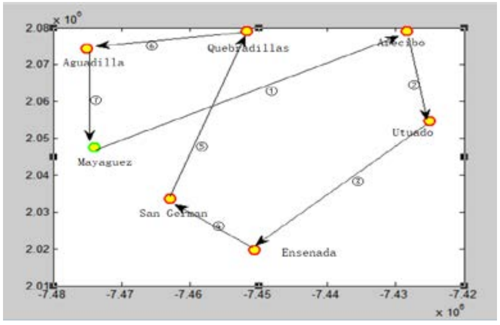

Figure 4. The route in Mayaguez

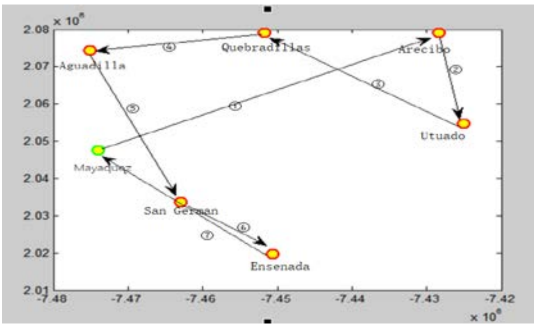

Figure 5. The route in Mayaguez

One of the shortcomings of the solution is that the time complexity is high, and in order to improve the accuracy of the distance calculation, we have improved the model. The analog annealing algorithm capable of processing an objective function with arbitrary degree of nonlinearity, discontinuity, and randomness, and a small programming workload is introduced.

3.2 Modified Model

3.2.1 Simulated Annealing algorithm

Now that we have chosen the concrete ports. For three ports, the application of the SA algorithm is similar.[3] It is merely different in the number of sites drones flying away. We take San Juan as an example to describe the algorithm.

a) The solution space S can be expressed as a circular permutation set of all fixed Starting points and ending points.

$$S=\{(\pi_1,\cdots,\pi_{11})\,|\,\pi_1=1,(\pi_2,\cdots,\pi_{10}) \text{ is the circulating of } \{2,3,\cdots,10\},\pi_{11}=11\}$$

b) The objective function is to detect the path length of all targets. It demands:

$$\min f(\pi_1,\pi_2,\cdots\pi_{11})=\sum_{i=1}^{10} d_{\pi_i\pi_{i+1}}$$

c) Through iteration, we can see the solution:

$$\pi_1\cdots\pi_{u-1}\pi_u\pi_{u+1}\cdots\pi_{v-1}\pi_v\pi_{v+1}\cdots\pi_{w-1}\pi_w\pi_{w+1}\cdots\pi_{11}$$

d) We select serial number u and v and exchange their order to make it reverse. The new path is $\pi_1\cdots\pi_{u-1}\pi_v\pi_{v-1}\cdots\pi_{u+1}\pi_u\pi_{v+1}\cdots\pi_{11}$.

e) The path difference is

$$\triangle f=(d_{\pi_{u-1}\pi_v}+d_{\pi_u\pi_{v+1}})-(d_{\pi_{u-1}\pi_u}+d_{\pi_v\pi_{v+1}})$$

f) The reception principle is that

$$P=\begin{cases} 1, & \triangle f<0, \\ \exp(-\triangle f/T), & \triangle f\geq 0. \end{cases}$$

g) In general, we think of α=0.999 to lower the temperature. Then, we stop it by ordered breaking temperature $e=10^{-30}$.

3.2.2 Calculating the Model

In order to improve the accuracy of distance calculation, we use another distance calculation function to calculate the distance (not described here). Compared with the previous calculation results, according to the map data, we find that the new function results are more accurate. We decided to use this function to calculate the distance. You can see more accurate figures in Figure 6.

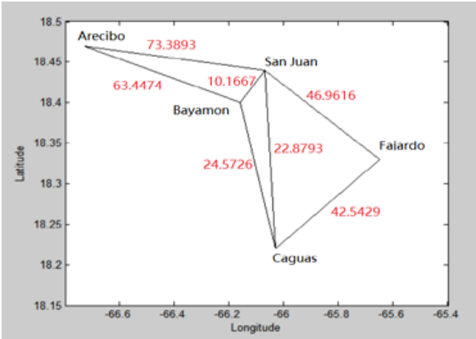

Figure 6. The distance of five cities

Using Matlab, inputting the distance data into the SA model, we get the routes.(see Figure 7, Figure 8). In addition, the route in Mayaguez is the same as that in preliminary model.

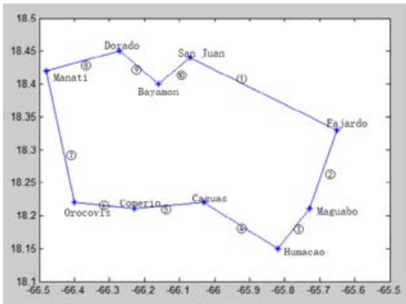

Figure 7. The route in San Juan

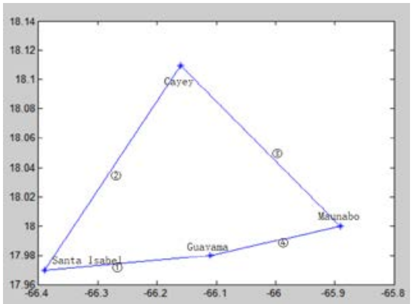

Figure 8. The route in Guayama

4. Solution of Problem and Conclusion

The drone flying routes are below:

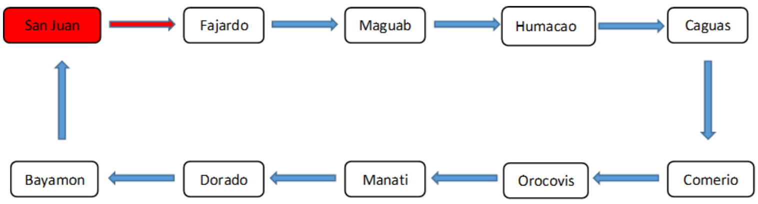

Figure 9. Flying route about San Juan

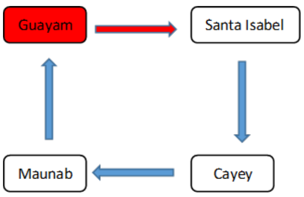

Figure 10.Flying route about Guayama

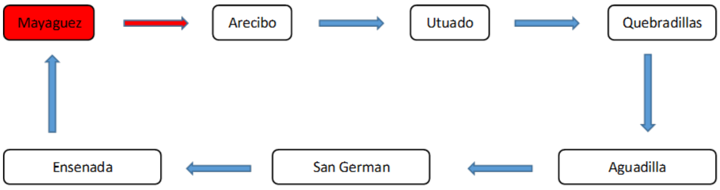

Figure 11. Flying route about Mayaquez

After verification, the above solutions are in line with the actual situation and can better complete the survey tasks.

References

[1] Information on: https://www.earthol.com/.

[2] Information on: http://www.gpsspg.com/maps.htm.

[3] Shoukui Si, Zhaoliang Sun. Mathematical Modeling Algorithms and Applications. National Defense Industry Press, 2015.