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Genetic Algorithm Based Path Planning for Seawater Depth Data Measurement in Real Scenarios

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Abstract. In this paper, firstly, the movement direction of the measuring ship is clarified, and according to the requirements of factors such as the range of overlap rate is controlled at 10% to 20% and the sea area is completely covered, the optimization equation system is derived, and the objective function is derived through the requirements, and the optimal solution can be derived from the two associations as the 34 measuring lines and the total length of 68 nautical miles of the shortest measuring lines. Using genetic algorithm to examine the real scene of seawater depth data measurement path planning, the length of the measurement line and coverage as an assessment index of the algorithm's subsequent optimization of the object of choice. Through the simulation of genetic mutation, crossover and selection operations, the total length of the shortest survey line is 21.5261 nautical miles, the percentage of missed sea area is 1.6%, and the overlap rate is 13.12% after the iterative solution of the genetic algorithm.

Keywords: Multibeam Bathymetric System, Genetic Algorithm, Optimization Equation.

1. Introduction

Multibeam bathymetric system is a popular underwater measurement technology, which is different from four-beam bathymetric system and single-beam bathymetric system, and has a higher efficiency of bathymetric measurement of seabed geomorphology [1-3]. Not only can obtain the depth value and three-dimensional map of multiple seabed measurement points under the complex geomorphological waters, but also through the loading of positioning system, attitude assistance system, computer processing system, etc., to carry out point-to-surface measurements on important waters such as harbor pools, berths, anchorages, navigation channels, etc., which is a kind of bathymetry system that is more widely used at present [4].

2. Model building

2.1. Derivation and calculation

When the line deviation is $\beta \neq 90°$, the sonobuoy sweeps over the slope in the form of a trapezoid, a triangle, or a patchwork of the two, which results in the sonobuoy sweeping over an area that will always have a missing portion of the edge. If a line is specifically designed to fill in this area, the total length of the line will be greatly increased. The line at β=90° will be used for subsequent calculations.

The water depth of 110m is obtained through the center of the sea:

$$D_{Eastern\ Boundary} = D_{Maritime\ Center} + y \cdot tan\ \alpha \quad (1)$$

At this point y=-2 nautical miles, $D_{Maritime\ Center}$ =110m. It can be calculated that $D_{Eastern\ Boundary}$=13m. The line passing through the center of the sea at β = 90° is the x-axis and the northern boundary is the y-axis (the coordinates in the chart are in nautical miles), see Figure 1:

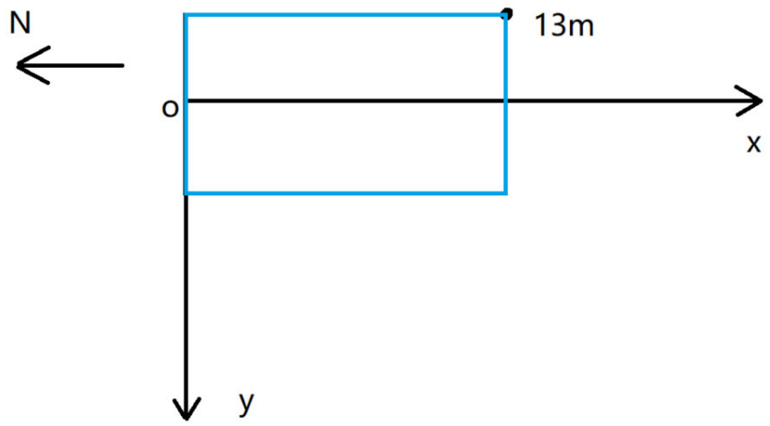

Figure 1. Coordinate system plot with the survey line passing through the center of the sea area at β = 90° as x-axis and the northern boundary as y-axis

It is necessary to find the sum of the shortest survey line, the spacing of the survey line at this time is set to d. Establish a new coordinate system (the coordinates in the chart are in nautical miles), such as Figure 2:

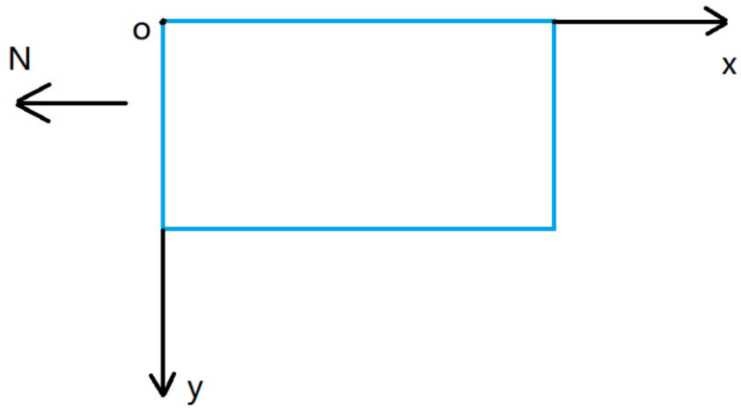

Figure 2. Plot of the coordinate system with the eastern border as the x-axis and the northern border as the y-axis

If complete coverage is required, it is permissible to cover too much area, but not too little. The width of coverage for the first survey line near the upper slope K_1 can be obtained after calculation:

$$K_1 = \frac{D_1 \tan\frac{\theta}{2}}{1+\tan\frac{\theta}{2}\tan\alpha} \tag{2}$$

Let the vertical coordinate of the first survey line be y, then:

$$D_1 = 13 + 1852 \cdot y \cdot \tan\alpha \tag{3}$$

Considering that the width of coverage is allowed to be too large and that the units in the coordinate system are nautical miles need to be harmonized, the relationship can be shown.

$$\frac{\frac{D_1 \tan\frac{\theta}{2}}{1+\tan\frac{\theta}{2}\tan\alpha}}{1852} \geq y \tag{4}$$

After calculating

$$0 \leq y \leq \frac{13\sqrt{3}}{1852} \tag{5}$$

In turn, it was pushed:

$$13 \leq D_1 \leq 13+13\sqrt{3}\tan\alpha \tag{6}$$

Since the overlap is between 10 and 20%, the relationship can be listed:

$$0.1 \leq \eta = 1-\frac{d}{W} \leq 0.2 \tag{7}$$

Correct for averaging the coverage width in this equation.

$$\overline{W} = \frac{W_i+W_{i+1}}{2} \tag{8}$$

It can be calculated that

$$W_i = \frac{2D_i \tan\frac{\theta}{2}}{1-\left(\tan\frac{\theta}{2}\right)^2 (\tan\alpha)^2} \tag{9}$$

Therefore Equation (5) can be expressed:

$$0.1 \leq \frac{d-d\left(\tan\frac{\theta}{2}\right)^2 (\tan\alpha)^2}{D_i \tan\frac{\theta}{2}+D_{i+1}\tan\frac{\theta}{2}} \leq 0.2 \tag{10}$$

It is obtained from the depth relation:

$$D_{i+1} = D_i + d \cdot \tan\alpha \tag{11}$$

Suppose, there are a total of n measured lines, which in turn leads to the last measured line D_n:

$$D_n = 13 + (1852y + (n-1)d)\tan\alpha \tag{12}$$

Calculations show that the last survey line near the downslope covers the width K_2.

$$K_2 = \frac{D_n \tan\frac{\theta}{2}}{1-\tan\frac{\theta}{2}\tan\alpha} \tag{13}$$

In the same way as Equation (3), complete coverage allows the coverage width to be too large, so the relationship can be listed:

$$\frac{D_n \tan\frac{\theta}{2}}{1-\tan\frac{\theta}{2}\tan\alpha} \geq 4-\frac{y+(n-1)d}{1852} \tag{14}$$

The total length of the shortest survey line needs to be found, so the objective function can be listed:

$$min\ 2n \tag{15}$$

Combining the above constraints with the objective function yields:

$$min\ 2n \quad s.t. \begin{cases} 0.1 \leq 1-\frac{d-d(\tan\alpha)^2\left(\tan\frac{\theta}{2}\right)^2}{D_i\tan\frac{\theta}{2}+D_{i+1}\tan\frac{\theta}{2}} \leq 0.2 \\ D_{i+1} = D_i + d\tan\alpha \\ 13 \leq D_1 \leq 13+13\sqrt{3}\tan\alpha \\ D_n = 13+(1852y+(n-1)d)\tan\alpha \\ 0 \leq y \leq \frac{13\sqrt{3}}{1852} \\ \frac{\frac{D_n\tan\frac{\theta}{2}}{1-\tan\frac{\theta}{2}\tan\alpha}}{1852} \geq 4-\frac{y+(n-1)d}{1852} \end{cases} \tag{16}$$

2.2. Solving the model

Solving the above model yields: n=34,2n=68, η=0.16. So the minimum value of the total survey line length is 68 nautical miles. There are 34 survey lines in this group.

3. Measurement of seawater depth data based on genetic algorithm

3.1. Application of Genetic Algorithms

Define the direction and spacing of the survey lines to meet the requirements. Typically, you can select the layout of the survey lines in both horizontal and vertical directions. Calculate the coverage width (W) of each line, using the coverage width formula.

3.1.1. Fitness values

The fitness value is used to assess the quality of each stylus layout, i.e., the performance of the stylus according to the design requirements [5]. In this problem, the fitness value should be based on the following factors:

Total survey line length: the shorter the total survey line length, the higher the fitness [6].

Percentage of missed sea area to total sea area to be measured: the lower the percentage of missed measurements, the higher the fitness [7].

Total length of portions of overlapping areas exceeding 20%: the fewer the overlapping portions exceeding 20%, the higher the degree of adaptation [8].

Combining these factors, the fitness value can be defined as a comprehensive assessment, e.g. a lower fitness value indicates better performance.

3.1.2. Parent Individuals

Parent individuals are a set of measured line layouts that are used to reproduce new individuals in each generation of the genetic algorithm [9]. These individuals are usually selected based on fitness values. Individuals with higher fitness values are more likely to be parent individuals.

3.1.3. Crossover Operation

The crossover operation is used to generate new line-of-survey layouts by cross-combining parts of two parent individuals to generate child individuals.

In this problem, the crossover operation should ensure that the offspring survey line layout satisfies the requirement of no more than 20% overlap [10]. Specific crossover strategies can be designed to maintain this condition.

3.1.4. Mutation operations

Variation operations are used to introduce randomness and help explore the search space. In this problem, the mutation operation can randomize the position of some survey lines to try to improve performance.

Initial Population: The initial population is the starting point of the genetic algorithm and consists of a set of initial survey line layouts. These initial layouts can be randomly generated, but should conform to the dimensions and requirements of the sea area.

3.2. Results obtained from genetic algorithm calculations

After 2000 iterations using the genetic algorithm, the evaluation metrics were filtered through to arrive at: total survey line length = 21.5261, overlap rate = 13.12%, and unmeasured area of 1.6% of the total area.

4. Conclusions

In this paper, first of all, the direction of movement of the survey ship is clearly defined, when the measurement line deviation angle is not 90°, the sonar sweeps through the slope for the trapezoidal, triangular, or both of the splicing graphics, which will make the sonar swept through the area there is always a corner of the area of the omitted part. If a measurement line is specifically designed to fill in the total length of the measurement line will be greatly improved, so through the calculation of different directions of the route and the literature to assist, the coverage width of the lowest rate of waste of a route direction, i.e., for the north-south direction. Then, according to the requirements of controlling the overlap rate in the range of 10% to 20% and completely covering the sea area, a set of optimization equations is derived, and the objective function is derived through the requirements, and the optimal solution can be derived from the association of the two as the 34 survey lines, with a total length of 68 nautical miles as the shortest total length of the survey lines. Genetic algorithm is used to examine the path planning of seawater depth data measurement in real scenarios, and the length and coverage of the survey line are selected as the evaluation indexes for the subsequent optimization of the algorithm to select the objects. By simulating genetic mutation, crossover and selection operations, the total length of the shortest survey line is 21.5261 nautical miles, the percentage of missed sea area is 1.6%, and the overlap rate is 13.12% after the iterative solution of the genetic algorithm.

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