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Optimisation of Multibeam Sonar Measurement Design Based on 0-1 Planning and Optimised Particle Swarm Algorithms

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Abstract: *In this study, a 3D seabed terrain model is constructed based on single-beam survey data through interpolation preprocessing to optimize the design of multibeam bathymetric survey lines. The constrained 0-1 planning model is solved by the 2D particle swarm optimization algorithm to achieve the optimal survey line combination design. The results show that the total length of the optimally designed survey line is 265 nautical miles, the proportion of missed sea area is 2.39%, and the overlap rate of more than 20% in the overlapping area is 0 m2. This study provides an efficient and comprehensive survey solution for ocean depth detection and demonstrates the potential application of multibeam bathymetry in ocean topography research.*

Keywords: *Interpolated Preprocessing, 0-1 Planning Models, 2D Optimized Particle Swarm Algorithm*

1. Introduction

The aim of this study is to investigate the use of multibeam bathymetry to improve the measurement of ocean topography. The multibeam measurement system has the characteristics of efficient and comprehensive measurement, which is crucial for ocean depth detection [1,2]. In this paper, based on the analysis of single-beam measurement data in a certain sea area, we establish a three-dimensional seabed topography model through interpolation preprocessing in order to optimize the design of multibeam bathymetric survey lines. We introduce a 0-1 planning model combined with a penalty function with constraints and use a 2D particle swarm optimization algorithm to solve iteratively to derive the optimal survey line combination. The results show that the total length of the optimally designed survey line is 265 nautical miles, the proportion of missed sea area is 2.39%, and in the overlapping area, the total area of more than 20% part is 0 m2. Through this study, we show how to effectively use multibeam bathymetry to improve the efficiency and accuracy of marine topographic data acquisition, which provides an important reference for marine survey research and resource environment development.

2. Data analysis

Firstly, the data are visualized and analyzed, and the visualization model is established by using the horizontal coordinates as the X -axis of the coordinate system, the vertical coordinates as the Y -axis, and the seawater depth as the Z -axis.

Considering that the data are discrete, the Griddata function in MATLAB software can be used to perform cubic spline interpolation on the discrete data, which makes the curve of the data visualization model smoother, and the results more accurate and more convincing, and at the same time, for the different values, we choose the colors to represent from light to dark, i.e., the lighter colored area represents the shallower depth, and the darker colored area represents the deeper depth. We get the visualization as follows.

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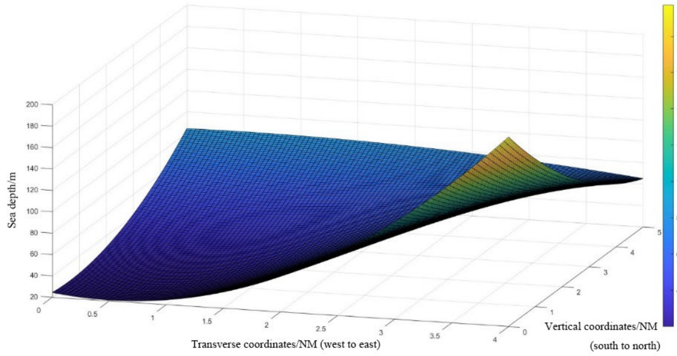

Figure 1: Three-dimensional seabed topography (west to east)

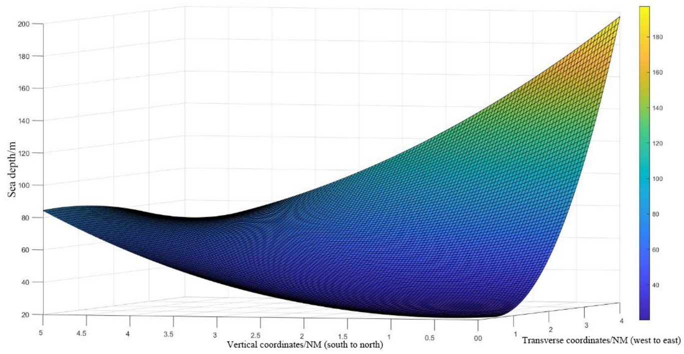

Figure 2: Three-dimensional seabed topography (south to north)

By analyzing Figure 1 and Figure 2 and the data, it can be seen that the data set presents an area 5 nautical miles in length from north to south and 4 nautical miles in width from east to west, while the seafloor topography of the sea area to be measured is higher in the north-west and south-east directions and lower in the north-east and south-west directions. Using these characteristics, it is possible to divide and solve it.

Firstly, the visualization plane of this data is segmented and processed.

Through the above analysis has been interpolated to the original data, so that its surface is smoother, when its surface is smoother, you can divide the smooth surface processing, making the model processing easier, the schematic diagram is as follows:

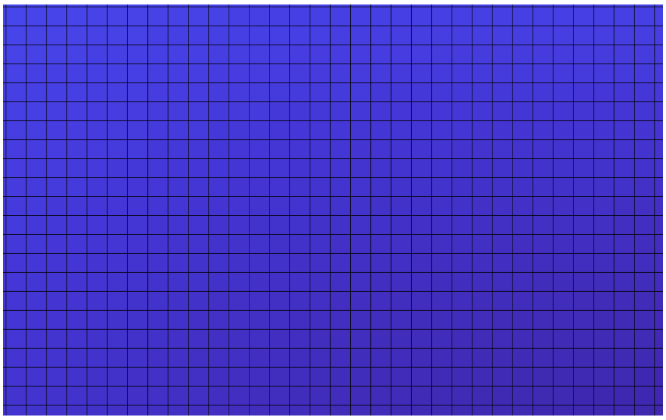

Figure 3: Schematic diagram after segmentation process

From Figure 3, it can be regarded as a superposition effect composed of numerous smooth sloped surfaces, taking a small area of which the interval is 0.1 nautical miles, then it is the plane formed by the integration of the 15 original monitoring points, in which the specific alternative value should be the average value of the integration, and then the integration of all the planes, to obtain the best solution.

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3. 0-1 planning modelling

Set the 0-1 variable, meet:

$$T_i = \begin{cases} h_i \dfrac{1}{X}\sum_{1}^{15} W_i \text{(When a boat passes by)} \\ y_i \dfrac{1}{X}\sum_{1}^{15} W_i \text{(When no boat passes by)} \end{cases} \tag{1}$$

Where T_i denotes the average displacement length of the ship detection in all grids.

In the following, we establish the relevant optimization model.

Objective function,

$$Min\sum_{1}^{n} T_i \tag{2}$$

Constraints:

(1) Minimize the total length of the survey line T.

(2) Overlap rate of 20% or less

(3) Minimize the area of missed measurement sea area M.

In this case, the objective function requires solving for the minimum detection cost, while the constraints are for its overlap rate and the magnitude of the number of missed systems and whether it is a full coverage problem.

4. Model solving

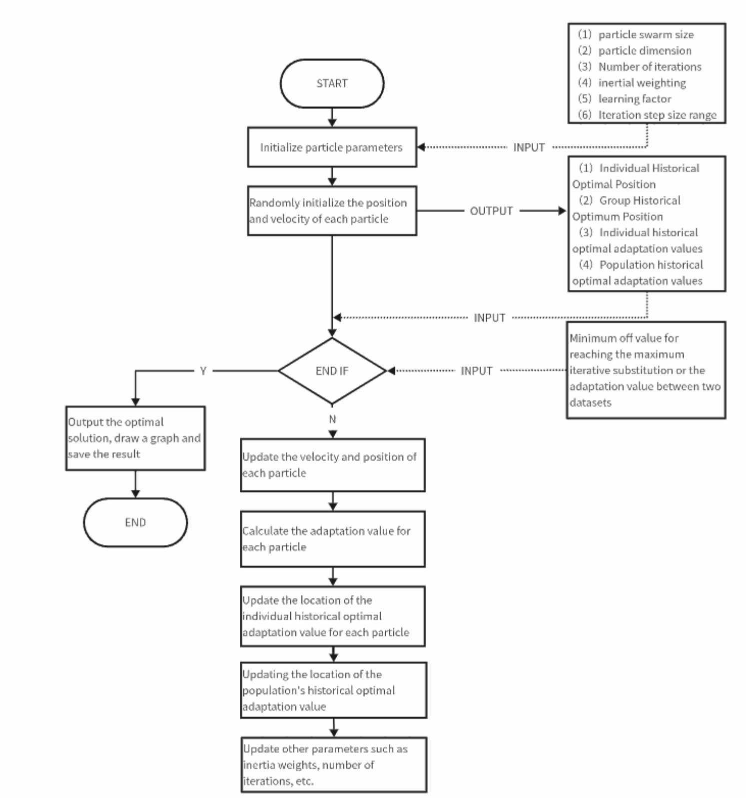

Figure 4: Schematic diagram of particle swarm

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Considering that in the classical particle swarm algorithm, the range of the particle swarm can only fall on one-dimensional coordinate axes and there is no restriction on the independent variables [3], while the range of the sea level change is in a larger two-dimensional coordinate system. Therefore, we introduce a two-dimensional particle swarm optimization algorithm to solve the planning path [4], i.e., the two-dimensional particle swarm optimization algorithm is to add constraints on the variables to the penalty function.

The classical particle swarm schematic is shown in Figure 4.

And the algorithm works as follows [5].

$$L^{k+1}{}_{i} = wL^{k}{}_{i} + c_1 r^{k}{}_{j}(P^{k}{}_{i} - X^{k}{}_{i}) + c_2 r^{k}{}_{j1}(P^{k}{}_{g} - X^{k}{}_{i}) \tag{3}$$

$$X^{k+1}{}_{i} = X^{k}{}_{i} + V^{k}{}_{i} \tag{4}$$

In order to solve the situation that the classical particle swarm algorithm is not applicable in 2D coordinate system, we introduce the 2D particle swarm optimization algorithm:

$$P^{t}{}_{i} = b_1 * P^{t-1}{}_{i} + b_2 * P^{t}{}_{i,best} + b_3 * P^{t}{}_{all,best} \tag{5}$$

Introduction of constraint penalty function in 2D particle swarm optimization algorithm

In order to solve the planning function quickly using the two-dimensional particle swarm algorithm, the fluctuation range of the particles introduces a penalty function to limit the values. At the same time, using the Lagrange multiplier method to add a constrained penalty term to the objective function, then the objective function can be changed into,

$$F(x) = f(x) + h(k)H(x) \tag{6}$$

$$h(k) = \sqrt{k} or k\sqrt{k}, H(x) = \sum_{i=1}^{m} \theta(q_i(x)) q_i(x_i)^{\gamma(q_i(x))} \tag{7}$$

Where, $f(x)$: the original objective function; $h(x)$: dynamically updated penalty coefficients, related to the number of iterations; $H(x)$: constraint penalty term; $q_i(x)$: relative constraint penalty function; $\theta(q_i(x))$: is the segment assignment function; $\gamma(q_i(x))$ is the penalty index.

The objective planning function and the values of X and Y from 0 to 2500 are substituted into the particle swarm to initialize the input correlation coefficients, as shown in Table 1.

Table 1: Description of correlation coefficients

Input coefficient	Description
$n = 400$	Number of particles
$narvs = s$	Number of variables
c_1	Individual learning factor per particle
c_2	Social learning factor per particle
$w = 0.9$	Inertia weights
$k = 400$	Number of iterations
$v_{\max} = 1.2$	Maximum particle velocity
$x_4 = 0$	Lower bound
$x_{-bb} = 2500$	Upper bound

Then the particle swarm iteration is performed, and the iteration effect is as follows:

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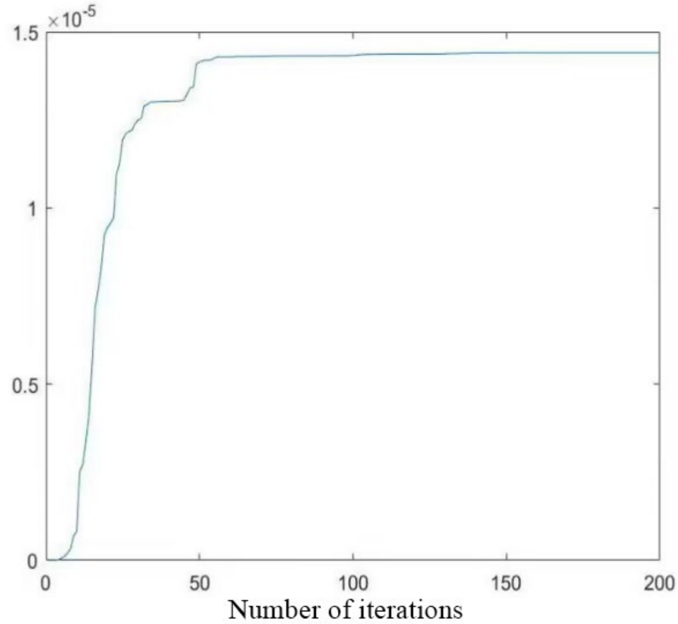

Figure 5: Iteration effect

As can be seen from the iteration effect diagram in Figure 5, when the number of iterations is run to about 100 times, the value of the objective function has basically ceased to change, indicating that at this point in time the amount of computation has basically played out the performance of the particle swarm algorithm, and the figure shows that the convergence speed of PSO is relatively fast, and there is no stepwise convergence, which proves the validity of the algorithm, and the accuracy of the algorithm.

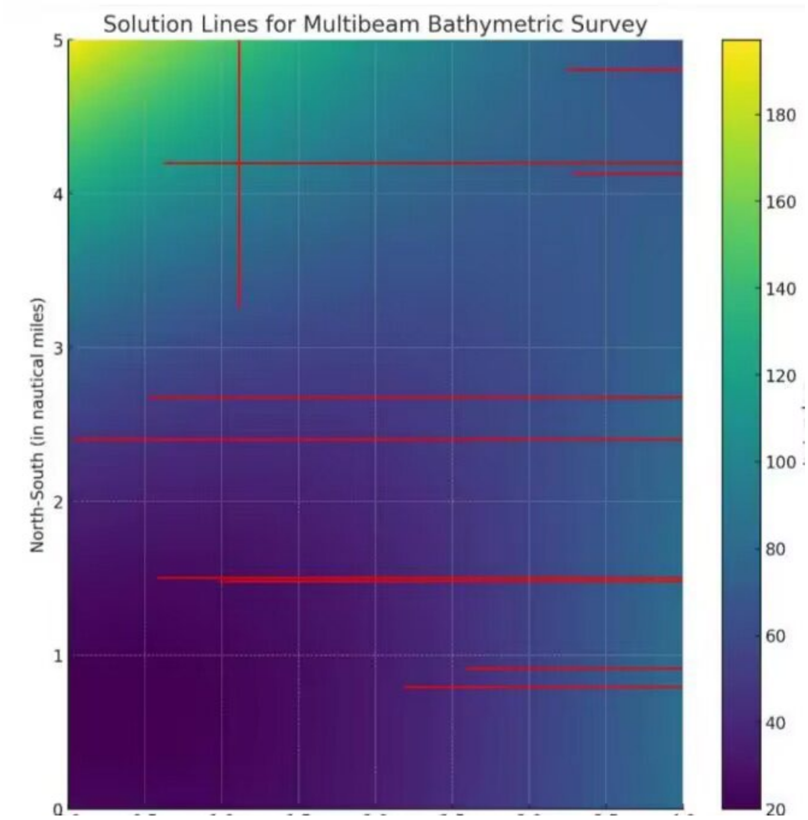

Figure 6: Multibeam bathymetric survey solution line diagrams

According to the solution diagram in Figure 6, the coordinates of the best points obtained are shown in Table 2

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Table 2: The best points

Coordinate	Direction
(0.99050,1 .48074)	‘E’
(0.52719, 2.67487)	‘E’
(2. 18654, 0.79330)	‘E’
(1.11218, 3.267029)	‘N’
(0.62994, 4. 19862)	‘E’
(3.24535, 4.80634)	‘E’
(0.04291, 2.40409)	‘E’
(2.59130, 0.91373)	‘E’
(3.28960, 4.13137)	‘E’
(0.58603, 1.50487)	‘E’

From the coordinates of the best point obtained, it is possible to calculate:

(1) The total length of the survey line is 265 nautical miles.

(2) The percentage of the omitted sea area to the total sea area to be measured is 2.39 per cent.

(3) The total area of the part of the overlapping area with an overlap of more than 20 per cent is 0 square meters.

5. Conclusions

Through this study, we have successfully demonstrated a method to optimize the design of multibeam bathymetric survey lines using interpolation preprocessing, 0-1 planning model and 2D particle swarm optimization algorithm. We transformed the discrete single-beam measurement data into a 3D seabed topographic model and designed the optimal survey line combination, which, on the premise of ensuring that the total survey line length is as short as possible, achieved that the survey line strips cover the sea area to be surveyed as much as possible, controlled the area of the side-leakage sea area, and optimized the data repetition rate of the overlapping area. The optimal design of the survey line length is 265 nautical miles, the percentage of missed sea area is 2.39%, and the overlap rate of more than 20% area in the overlap area is 0 m2. These results show that our proposed method can effectively improve the efficiency and accuracy of marine topographic data acquisition, which provides an important reference for marine survey research and resource environment development.

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