Research on multi-beam line measurement based on theoretical derivation and particle swarm optimization model

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Abstract. Starting from the geometric model formed by the multi-beam line measuring device for seabed mapping, this paper makes geometric analysis of the two-dimensional plane and three-dimensional map respectively and establishes the mathematical expressions of the relevant parameters, and calculates the mathematical function relationship of the relevant parameters according to the motion of the surveying ship on the sea level and the distribution of the survey lines. Two and three dimensional models are established to improve the accuracy of surveying submarine depth and the utilization rate of multi-beam line measuring device. By using geometric relation in two-dimensional plane, linear function relation is established and related parameters are solved. Based on the working principle of analyzing the solution method of the full coverage shortest path, a benchmark is established, the measured line is perpendicular to the sea boundary, the parameter values at this time are calculated, the dynamic programming model is established, the local optimal solution is obtained by particle swarm optimization algorithm, and the optimal solution is obtained by cyclic traversal. The minimum number of survey lines N and the minimum total measurement length L are obtained.

Keywords: Sea area survey; multi-beam line measuring device; Particle swarm optimization model.

1. Introduction

Single-beam sounding is a technology that uses the propagation characteristics of sound waves in water to measure the depth of water. The principle is that sound waves propagate uniformly in a straight line in a uniform medium and generate reflections on different interfaces [1-2]. In the relatively flat area of the seabed, multi-beam sounding can measure the full coverage of depth bands, bands, lines and overlapping areas with the survey ship line as the axis and with a certain width. The coverage width of the multi-beam sounding strip W varies with the opening Angle of the transducer θ and the water depth D. If the survey lines are parallel to each other and the seabed topography is flat, the overlap rate between adjacent strips is defined as $\eta = 1 - d / W$, where d is the distance between two adjacent survey lines and W is the coverage width of the strip [3-4]. If $\eta < 0$: indicates a missed test. In order to ensure the convenience of measurement and the integrity of data, the overlap rate between adjacent strips should be 10% to 20%. If the bathymetric data of a single beam survey in a certain sea area is given, the requirements are: (1) the strip scanned along the survey line should cover the whole sea area to be measured as much as possible; (2) The overlap rate between adjacent strips should be controlled below 20% as far as possible; (3) The total length of the measuring line should be as short as possible. Then the model can be used to calculate: (1) the total length of the measured line; (2) The percentage of the missing sea area in the total sea area to be measured; (3) In the overlap area, the overlap rate exceeds 20% of the total length of the part.

2. The establishment of two-dimensional geometric model

2.1. Model analysis

For calculating the seawater depth D, coverage width W and overlap rate η of the given table, as shown in fig 1, the problem can be solved on a two-dimensional plane, and the required parameter values can be calculated by means of mathematical relations such as Angle and side length and the sine theorem.

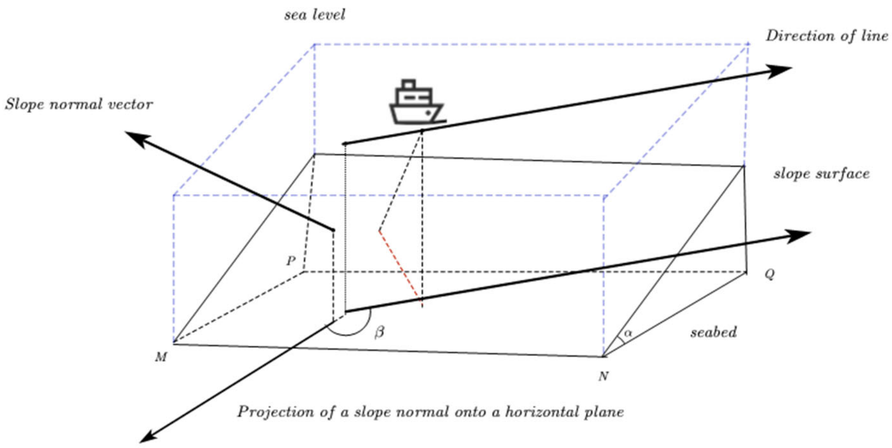

Fig 1. Simulated sea area.

The calculation method is as follows: (1) Calculate the distance d between adjacent ships. In the first step, calculate the ship at the center of the measurement line and set the position to 0 at this time, and the positive direction distance positioning +x, then the negative direction distance is -x. The second step is to calculate the W of the initial central position through mathematical theorems, such as the sine theorem. Through the relation between the two parameters, a function relation covering width W and vertical depth D is abstracted. The third step, according to the mathematical relationship, the use of programming to achieve the functional relationship, the distance between the measured line and the center point x, into the program, you can get the value of other parameters (1) The BP neural network is linked by different node coefficients. When connecting weights and weights are positive, it indicates that the current link is an exciting state. Conversely, if the link coefficient is negative, the link state is a state of suppression.

2.2. The establishment and solution of geometric model

Based on the analysis problem, this paper USES the sine theorem, Angle relationship and geometrical relationship to establish the geometric model of relative purposes, and the two-dimensional geometric model is shown in fig 2.

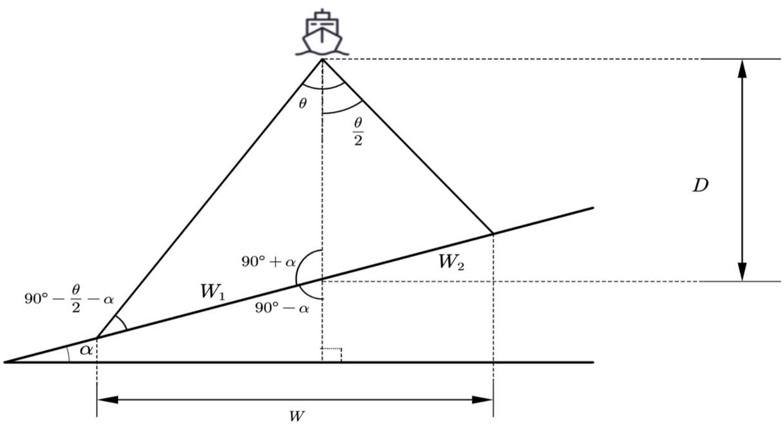

Fig 2. Establishment of geometric model.

First, calculate the coverage width of the survey ship at the center point of the survey line, assuming that the measured data at this position is the depth of the sea D =70m, and at this time θ=120°, α= 1.5°. According to the sine theorem:

$$\begin{cases} W_1 = 70 \cdot \dfrac{\sin 60°}{\sin 31.5°} = 116.023m \\ W_2 = 70 \cdot \dfrac{\sin 60°}{\sin 28.5°} = 127.047m \end{cases} \tag{1}$$

Hencethe formula (1), get

$$W = (W_1 + W_2)\cos a = (116.023 + 127.047)\cos 1.5° = 242.987\ m \tag{2}$$

By calculating the Angle relation, a function covering width W with respect to vertical depth D is deduced, as shown in formula (3):

$$W = D \cdot \left(\frac{\sin \frac{\theta}{2}}{\sin\left(90° + \alpha - \frac{\theta}{2}\right)} + \frac{\sin \frac{\theta}{2}}{\sin\left(90° - \alpha - \frac{\theta}{2}\right)} \right) \tag{3}$$

As can be seen from equation (2), if the value of D is calculated, the value of the coverage width W can be obtained. Therefore, the paper establishes a geometric model about D and the distance x between the measured line and the center point, as shown in figure 3:

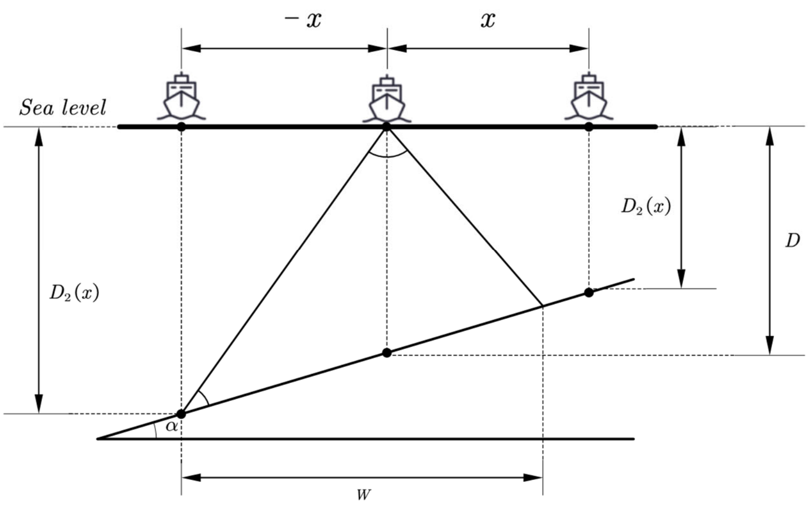

Fig 3. D Geometric model of the distance x from the center point of the measured line.

According to the established geometric model, the relationship between trapezoids in the model can be obtained:

$$D_2(x) = D - x\tan\alpha \tag{4}$$

Since D = 70m, x is the distance between the measurement line and the center point, it is obtained $D_2(x) = 70 - x\tan 1.5°$ .According to formula (2) and (3), it can be obtained:

$$\begin{aligned} W(x) &= (D - x\tan\alpha) \cdot \cos\alpha \left(\frac{\sin \frac{\theta}{2}}{\sin\left(90° + \alpha - \frac{\theta}{2}\right)} + \frac{\sin \frac{\theta}{2}}{\sin\left(90° - \alpha - \frac{\theta}{2}\right)} \right) \\ &= (70 - x\tan 1.5°) \cdot \cos 1.5° \left(\frac{\sin 60°}{\sin 28.5°} + \frac{\sin 60°}{\sin 31.5°} \right) \end{aligned} \tag{5}$$

Calculate the overlap rate with the previous line according to the formula $\eta=1-d/W$. Substitute the given parameters into the expression and enter the corresponding code to calculate the overlap rate with the previous line.

By substituting the expressions W(x) and D(x) obtained into the program and x into the expression, the solution of the parameters can be obtained, and the results are shown in Table 1. According to the existing data, this result is in line with the reality, has a certain reference value, with scientific and usable. Therefore, the two-dimensional model is meaningful for multi-beam measurement, and the measured data conforms to the specification.

Table 1. Results for 2D geometric models.

x	-600	-400	-200	0	200	400	600
D	85.71	80.47	75.24	70	64.76	59.53	54.29
W	297.52	279.35	261.16	242.99	224.81	206.63	188.45
η	36.64	32.77	28.4	17.69	11.03	3.21	-6.12

3. Expansion of 3D geometric models

3.1. Model analysis

On the basis of two-dimensional geometric model, the three-dimensional geometric model is established, and the scientific and practical of the model are strengthened. By means of the line direction and the slope surface of the submarine slope, the three-dimensional geometric model of the Angle of the projection of the surface of the water plane is established, and the various sections of the three-dimensional geometric model are analyzed, and the relationship between the slope and the depth of the water depth is analyzed. The direction of the measuring line can change in the course of the direction of the measurement line, which can be changed in the course of the voyage, and the level d of the sea level changes, and if it moves above the center position, the depth difference of the sea water will be larger. In the same way, the bottom of the water, the depth difference of the water, will be smaller, and the same thing as the Angle of the slope is no longer the Angle of the Angle. Therefore, this paper establishes the mathematical model of the geometric relationship between the two and the distance of the sea, and the model is solved by means of geometric relationship.

3.2. Analysis of experimental results

Firstly, a 3D geometric model is established and the parameter changes are calculated. fig 4 shows a 3D geometric model of simulated sea area.

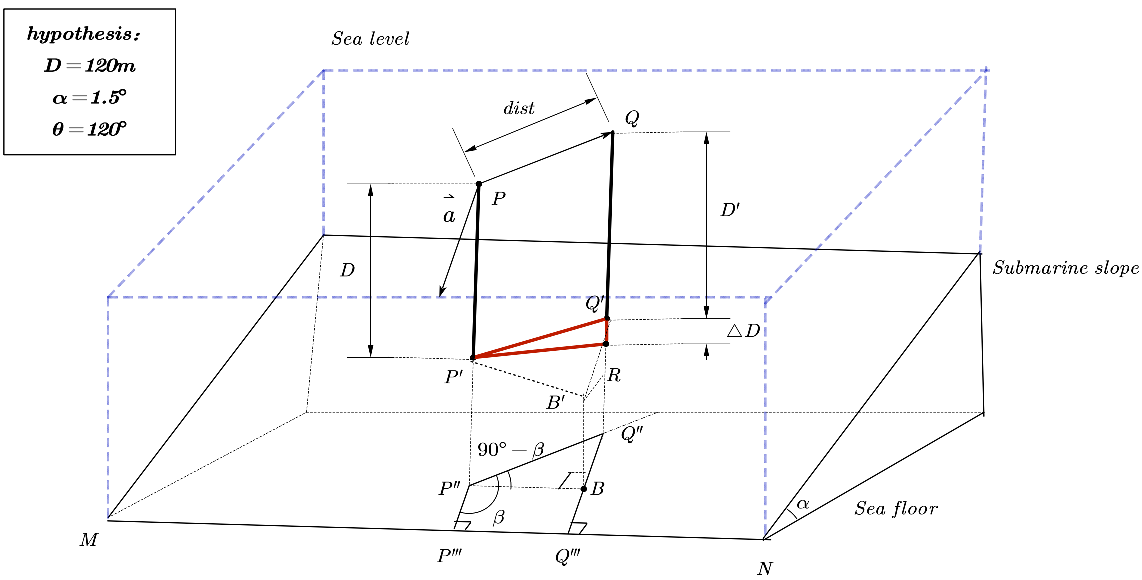

Fig 4. 3D geometric model of simulated sea area.

Point P is set as the position of the surveying ship, and the location of point P is the center point of the sea area. The sea depth is D=120m, the Q point is the distance, the PQ direction is the direction of the measurement line, the position where the Q point is located is the location of the measurement point, and the sea depth is D; However, since the slope is not in the same horizontal plane, the parameter D is changed, so it is necessary to establish ΔD by geometric model. At this time, ΔD is an important parameter for solving the model and needs to be substituted into the formula. Since the Angle of sailing of the survey ship is constantly changing, it is only when the sailing Angle is

$$\theta' = \frac{\pi}{2} \ , \frac{3\pi}{4} \tag{6}$$

If the slope Angle of the section is unchanged, it is necessary to substitute equation (5) into the two-dimensional geometric model to find the mathematical relationship between the slope Angle, the Angle β of the direction of the measurement line and the slope Angle γ at this time. The mathematical geometric model for solving the mathematical relation expression is shown in fig 5.

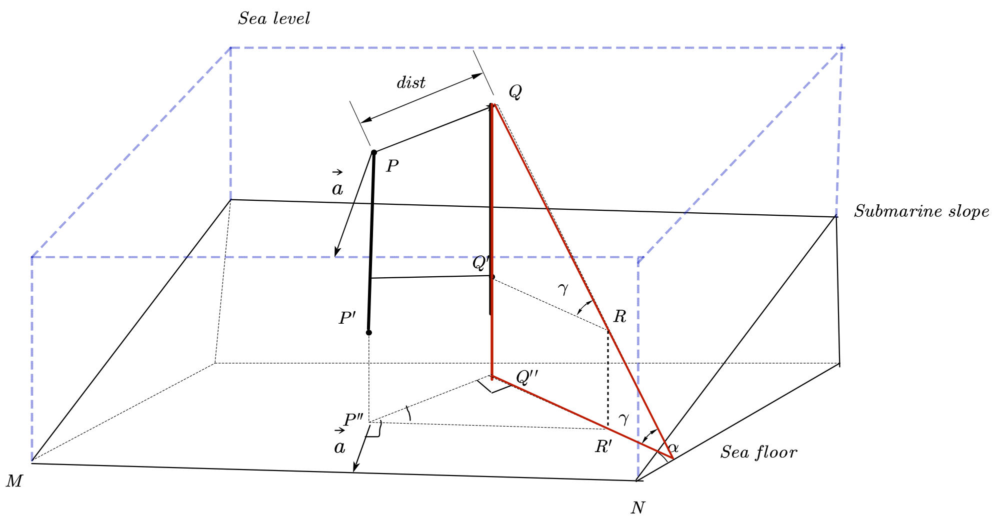

Fig 5. Solving the three-dimensional geometric model of Angle γ.

By obtaining the mathematical expression of y, the parameters are also substituted into the model for solving. Now the effective depth D' of the seabed is solved: calculate the central point P of the sea area, project it on the seabed P", and the initial position of the ship is at P point; Let point Q be the mapping point whose distance from point P is dist, and project it on the seabed Q". PQ direction is the sailing direction of the ship.

Let the projection vector of the normal vector of the slope surface be set as a, then the Angle between the direction of the measurement line and a is B, and. p "and Q" are made to be perpendicular to the sea bottom MN at points P" and Q" respectively, connecting P"P" and Q"Q". then

$$\angle Q''P''P''' = \beta \tag{7}$$

Cross point P" perpendicular to Q"Q" at point B, connect PP' and QQ', PP'= D, QQ'= D', get

$$\begin{cases} \angle Q''P''B = \beta - 90° \\ \varDelta D = D - D' \end{cases} \tag{8}$$

The PQ = P = dist "Q", in the AP "Q" B, Q "B = dist, sin (B - 90 °), < Q 'B' R = a, is in the raising AQ 'B' R, 4 by geometry relationship

$$\begin{cases} Q'R = B'R\tan\alpha = BQ''\tan\alpha \\ \varDelta D = dist \cdot \sin(\beta - 90°) \cdot \tan\alpha \end{cases} \tag{9}$$

The result after simultaneous expression is

$$\begin{cases} Q'R = B'R\tan\alpha = BQ''\tan\alpha \\ \Delta D = dist\cdot\sin(\beta-90°)\cdot\tan\alpha \end{cases} \tag{10}$$

According to the model established in fig 5, the effective slope Angle y is solved, and the projection of R perpendicular to the sea floor is R', which is substituted into the model and in △QQ 'R, get

$$\begin{cases} Q'R = Q''R' = \tan(\beta-90°) \\ QQ' = \tan\gamma\cdot Q'R \\ QQ' = \Delta D \end{cases} \tag{11}$$

So, $\tan\gamma = \cos(\beta-90°)\tan\alpha$, $\gamma = \arctan[\tan\alpha\tan\beta]$.

To sum up, all kinds can be obtained

$$\begin{cases} x = dist\cdot 1852 \\ \gamma = \arctan(\tan\alpha\sin\beta) \\ D' = D-\Delta D = D + x\cos\beta\tan\alpha \\ W(x) = (D' - x\tan\gamma)\cdot\left(\dfrac{\sin 60°}{\sin(30°+\gamma)} + \dfrac{\sin 60°}{\sin(30°-\gamma)}\right)\cdot\cos\gamma \end{cases} \tag{12}$$

The data is filled in table 2.

Table 2. Test result table of 3D geometric model.

Distance(m) / Angle(β)	0	0.3	0.6	0.9	1.2	1.5	1.8	2.1
0°	415.55	465.93	516.31	566.69	617.08	667.46	717.84	768.22
45°	416.05	451.72	487.38	523.05	558.72	594.39	630.06	665.72
90°	416.55	416.55	416.55	416.55	416.55	416.55	416.55	416.55
135°	416.05	380.38	344.71	309.05	273.38	237.71	202.04	166.37
180°	415.55	365.17	314.79	264.4	214.02	163.64	113.26	62.88
225°	416.05	380.38	344.71	309.05	273.38	237.71	202.04	166.37
270°	416.55	416.55	416.55	416.55	416.55	416.55	416.55	416.55
315°	416.05	451.72	487.38	523.05	558.72	594.29	630.06	665.72

3.3. Model checking

The data is tested, that is, when β=90°, the two-dimensional geometric model is substituted. Then D=70m, B=90°. The result of W(x) calculated by Python is shown in Table 3:

Table 3. Python-based verification result table.

x	-800	-600	-400	-200	0	200	400	600	800
W	315.71	297.53	279.35	261.17	242.98	224.81	206.63	188.45	170.27

After testing, the data calculated by the models established by the two are consistent, and the error rate is 0.2%, which is within the error range. Therefore, the three-dimensional geometric model is reliable and scientific.

4. Optimal parameter solving based on particle swarm optimization algorithm

Assume that the rectangular sea area is covered by the shortest path multi-beam measurement with full coverage. Due to the different slope heights, the slope surface is deep in the west and shallow in the east. Based on the functional relationship, a benchmark survey line is first determined with the direction of the survey line being east-west, the constraint relationship is determined, and a dynamic programming model is established [5]. Then, by constantly changing the Angle of the reference measurement line, particle swarm optimization [6-7] is carried out. When the shortest path measurement line is measured, the local optimal solution of full-coverage shortest path multi-beam measurement is obtained [8-10]. According to the principle of multi-beam measurement, when surveying and mapping ship conducts multi-beam measurement, the navigation survey line should be straight line, and the relationship between each survey line is parallel, and the navigation direction should not be changed. It can be obtained by solving the three-dimensional geometric model.

$$\begin{cases} D = 120 + x\cos\beta\sin\alpha \\ \gamma \;=\; \arctan(\tan\alpha\sin\beta) \\ W(x) \;=\; (D - x\tan\gamma)\cdot\left(\dfrac{\sin 60°}{\sin(30° + \gamma)} + \dfrac{\sin 60°}{\sin(30° - \gamma)}\right)\cos\alpha \end{cases} \tag{13}$$

On this basis, a multi-beam mathematical model based on full coverage shortest path is established, and the projection diagram of the rectangular sea area relative to the bottom surface is shown in Fig 6.

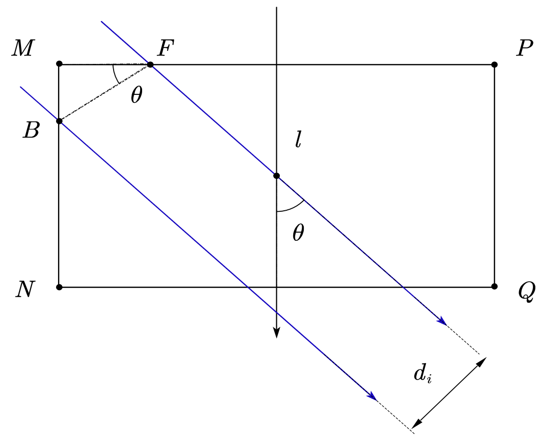

Fig 6. Projection of rectangular sea area.

Let it be a rectangular region MPQN of length PQ and width NQ. The length between two test lines in an adjacent group is d, and the points of intersection between test lines and width MP are B and F. Then according to the geometric relation, the paper get BM = l-d,sinθ, in △FMB

$$d_n = \frac{MB}{\sin\theta} = \frac{l}{2\sin\theta} \tag{14}$$

In order to find the optimal solution, based on the most special case, that is, L is perpendicular to PQ, L⊥PQ, This time needs to meet.

$$\begin{cases} S_{single} \;=\; Wl \\ S_{total} \;=\; nS_{\sin gle} \\ S_{total} \;\geqslant\; S_{total\ sear} \\ 10\% \leqslant \;\eta\; \leqslant\; 20\% \end{cases} \tag{15}$$

According to the constraints, establish the planning model,

$$\min\ M = f(W,\ \eta,\ \beta) \tag{16}$$

$$s.t.\begin{cases} W + d(n-1) \geqslant PQ \\ 10\% \leqslant \eta \leqslant 20\% \\ n,\ d,\ W \geqslant 0 \end{cases} \tag{17}$$

The model is substituted into MATLAB for dynamic programming calculation, and the data on this benchmark is

$$\begin{cases} n = 39 \\ \eta = 38.1847\ \% \\ M = 76.2653\ n\ mile \end{cases} \tag{18}$$

According to the result analysis, although full coverage can be satisfied, the coverage rate obtained does not meet the problem. Therefore, multiple enumeration is carried out for optimization, and the optimal solution of the number of ships n and the coverage rate η is obtained through multiple iterations. The data is obtained by substituting it into the particle swarm optimization model.

$$\begin{cases} n = 6 \\ M = 16.3491\ n\ mile \end{cases} \tag{19}$$

It is proved that the method is scientific and adaptable when the result satisfies the actual situation.

5. Conclusions

For the study of multi-beam line measurement, this paper establishes a two-dimensional geometric model based on theoretical derivation, and uses sine and cosine theorems and geometric relations to establish a two-dimensional geometric model. The special case when the lateral direction is the same as the driving direction can be obtained by using the two-dimensional geometric model. On the basis of the establishment of a two-dimensional geometric model, in order to enhance the adaptability and scientificity of the model, a three-dimensional geometric model is established. A multivariate expression of a nonlinear function is established through the different driving angles of the target on the sea level. By analyzing the special relations in the model, a dynamic programming objective equation is established. Divide the problem into parts. By reducing the dimension of the model. Greatly reduce the amount of computation and improve the running speed of the model. In order to test the real situation, this paper simulated a sea level, through particle swarm optimization algorithm, on the basis of three-dimensional geometric model, layer by layer calculation, exhaustive solution, and finally find the optimal solution of multi-beam measurement, in order to measure all sea areas.

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