Research on multi-beam survey line based on multi-dimensional structure analysis

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Abstract. In this paper, study the optimization problem of multibeam sounding, firstly, simplify the working principle of multibeam sounding, establish the coordinate system with the horizontal plane and the center point of the sea area, and use trigonometry and triangle similarity to establish a model of the coverage width and overlap rate of multibeam sounding. The coverage width, seawater depth and overlap rate are obtained at different line spacing, and the seawater depth is about 64.763m and the coverage width is about 224.345m with an overlap rate of about 10.85% at a line spacing of 200m. Secondly, a coverage width model is established to solve the coverage width at different distances from the center of the survey vessel and at different line direction angles. The mathematical model of coverage width and overlap rate was upgraded from two-dimensional to three-dimensional to establish a coverage width model. The results of the coverage width in each case were obtained, and finally it was found that excluding 0° and 180°, there was a positive correlation between the angle of the survey line direction and the coverage width. Finally, choose 12% coverage as the target value to solve the problem, and establish a model of the shortest survey line, and then according to the data of coverage width, survey spacing and seabed slope, finally solve the problem to get 23 survey lines that meet the conditions, and find the coverage width of 381.05 m, and the spacing of 353.33 m.

Keywords: Multibeam Line Measurement, Trigonometry, Trigonometric Similarity, Coverage Width.

1. Introduction

Multi-beam bathymetry system adopts the same working principle with single-beam bathymetry system, the system consists of multiple angle-fixed orthogonal transducers, the transducer transmits acoustic waves to the underwater, and then through the receiver to get and the direction of the narrow beam perpendicular to the traveling direction of the ship, according to which the detection of underwater terrain data[1] Multi-wavelength bathymetry system operation, breaking through the single-beam measurement in only one bathymetric line bathymetry information in the operation of the limitations, and multi-beam illumination pattern can be changed with the increase in the number of subarrays, for system resource management to provide greater flexibility[2]. The general steps are applying sound velocity profile correction (SVPardier), inputting calibration corrections, using filters to remove outliers, manually rejecting errors, creating a grid model[3]. The mesh model is then combined with the ship's survey track to form a strip bathymetry. This is used to accurately navigate underwater terrain and features[4].

Often it is challenging to perform accurate multibeam tracking without knowledge of the dynamic model. Previously, Seonyong Kim et al. proposed a model-free multibeam tracking algorithm combined with angle estimation based on auxiliary beam pairs in a multimassive environment, which achieves at least a 54% improvement in achievable sum rate over the baseline scheme at a signal-to-noise ratio of =20dB. However, the algorithm model is only applicable to dynamic models, while our coverage width model based on trigonometry, etc., and the shortest line length model can better measure dynamic as well as static models at the same time[5]. The shortest line length model can better measure dynamic as well as static models at the same time. Therefore, we propose that multiple beams can be created by utilizing the symmetry or superposition equations between the target

modes[6]. To establish a model of multibeam bathymetry with coverage width and overlap rate between two adjacent bands when the angle between the seafloor slope and the ground is α. Based on this model, the depth of seawater, the coverage width and the overlap rate are computed when the transducer opening angle θ is 120 degrees, the seafloor slope α is 1.5 degrees, and the center depth of the water is D is 70m. The model of multibeam bathymetry coverage width is established, and the multibeam bathymetry coverage width corresponding to the distance of different measuring vessels and the angle of different measuring line directions is solved when the transducer opening angle θ is 120 degrees, the seafloor slope α is 1.5 degrees, and the center water depth D is 120 m. And the establishment of a 2 km long, 4 km wide rectangular sea area, and is based on the north and south for the long, east and west for the wide, west deep right shallow, water depth 110 m, slope 1.5 degrees, and is in the case of the opening angle 120 degrees to fully cover the sea area to be measured, and the overlapping rate between adjacent strips 10 % ~ 20 % of the shortest line of the indicators. Combined with the use of differential GPS technology methods[7] , mobile edge computing techniques have evolved to address these problems in a distributed manner[8] , the laser intensity distribution is determined by multiple phase differences. Each time the initial phase of a beam is changed, (by delaying the emission method so that each primitive acoustic wave arrives at the same time at the target area at different relative distances[9] it will form a new phase difference with the rest of the beam[10].This allows the model to have a higher measurement accuracy.

2. Materials and Research Methods

2.1. Data sources

In this paper, all the data needed in the three problems we propose to solve are obtained from open source databases in GitHub.

2.2. Research methodology

2.2.1 Multibeam bathymetric model analysis

We use the ground as the horizontal axis and the center of the seabed as the vertical axis, and the wavelength spacing follows the ITU G.692 standard to avoid interference[11]. Then we substitute the coordinates into the spacing d between the two segments of the survey line into, according to the trigonometric function as well as the principle of similarity of triangles, to find out the depth of the seawater at this time, the width of the coverage as well as the overlap rate.

2.2.2 Coverage width model analysis

We first make a plot to restore the plane perpendicular to the trajectory, the beam pattern is still angle-range coupling[12] and the multibeam scanning capability is the beam antenna's[13] So this plane and the horizontal plane is also a vertical relationship, and this plane will intersect the seabed slope in a line, this line is the slope, set the angle of this slope and the ground, and through the β, α can be calculated the angle of the angle of the angle of the angle of the angle of the multibeam bathymetry model we can use the method of multi-beam bathymetry model, and then according to the relevant data to find out the width of the coverage W.

2.2.3 Analysis of the shortest measurement line model

Here we have to find a shortest survey line, and under this sideline requires 100% coverage and overlap rate η in 10%-20%, while the angle β between the slope normal in the horizontal plane and the horizontal plane of the reflection, determines the length of the survey line, and the spacing of the survey line d determines the number of survey lines, as well as determines the extent of the coverage and the overlap rate, on the basis of which we set up a model of the functional relationship of Y = f (β, d), which can be obtained by finding the minimum of the function. Finally, we can get β and d by finding the minimum value of the function.

3. Results and analysis

3.1. Multibeam bathymetric modeling and solving

3.1.1 Derivation of the overlap rate model

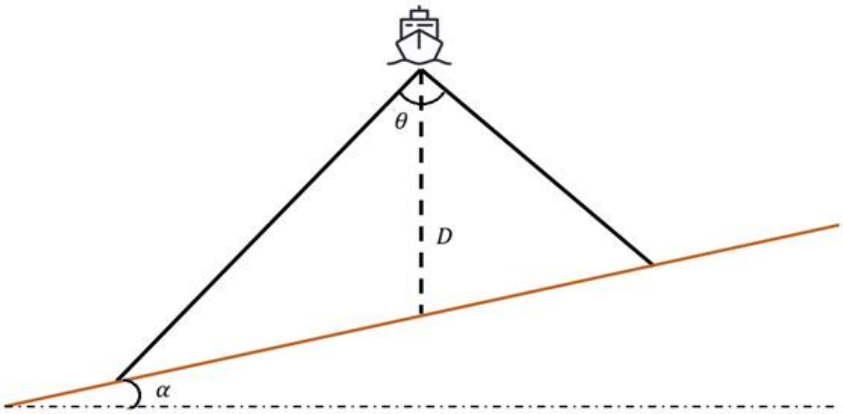


Figure 1. Schematic diagram of bathymetry

The mathematical model of the overlap rate with respect to the coverage width according to the requirements of Figure. 1 is:

$$\eta = 1 - \frac{d}{W} \tag{1}$$

In the above equation η represents the overlap rate, d represents the spacing between two neighboring survey lines, and W is the coverage width of the strip. Now we just need to find out how W relates to the other variables based on the data as well as Figure 1.

Here we might as well set g to be the distance the water slopes downhill in the vertical direction. Then it can be derived:

$$g = D \times \tan(\alpha) \tag{2}$$

By combining Fig. 1 with the basic trigonometric functions and the trigonometric theorem one can derive an expression for W with respect to the remaining variables.

After completing the derivation of the most basic theoretical model, we consider the use of

$$W = 2D\tan\left(\frac{\theta}{2}\right) - 2D\tan(\alpha) \tag{3}$$

functions in MATLAB to calculate the change in water depth due to the change in distance:

$$d = dis\tan ce \times \tan(\alpha) \tag{4}$$

$$\text{D_adjusted} = \text{D} - \text{d} \tag{5}$$

At this point, the theoretical model derivation for multibeam bathymetry is complete, and in the following we use (**D_adjusted**) to perform the solution of the result.

3.1.2 Practical solution of multibeam bathymetry models

In the process of solving the model we write a code based on MATLAB for solving the model and the solving steps of the code solving are shown in Figure. 2:

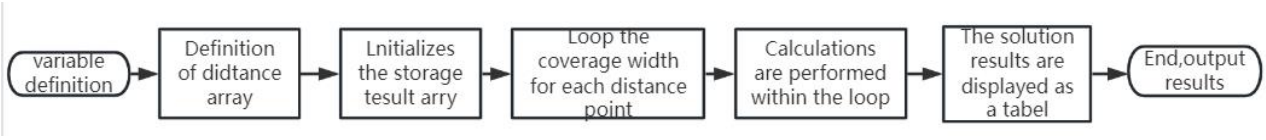


Figure 2. Flowchart of the multibeam bathymetry model solving steps

After that the actual MATLAB operations are performed to solve the results as shown in Table 1:

Table 1. Solution results of the multibeam bathymetry model

Distance of the line from the center/m	-800	-600	-400	-200	0	200	400	600	800
Sea depth/m	90.94	85.71	80.47	75.23	70	64.76	59.52	54.28	49.05
Coverage width/m	315.05	296.91	278.77	260.62	242.48	224.34	206.20	188.06	169.91
Overlap with previous line/%	0	32.64	28.25	23.26	17.52	10.85	3.00	-6.34	-17.70

At this point, the multibeam bathymetric model solution is complete. Observing the table, we will find that the depth of the sea water, the coverage width, and the overlap rate with the previous line all decrease with the increase of the distance of the line from the center point.

It is important to emphasize here that it is because of the omission of the survey line that the overlap rate is negative.

3.2. Coverage width modeling and solution

3.2.1 Theoretical derivation of the coverage width model

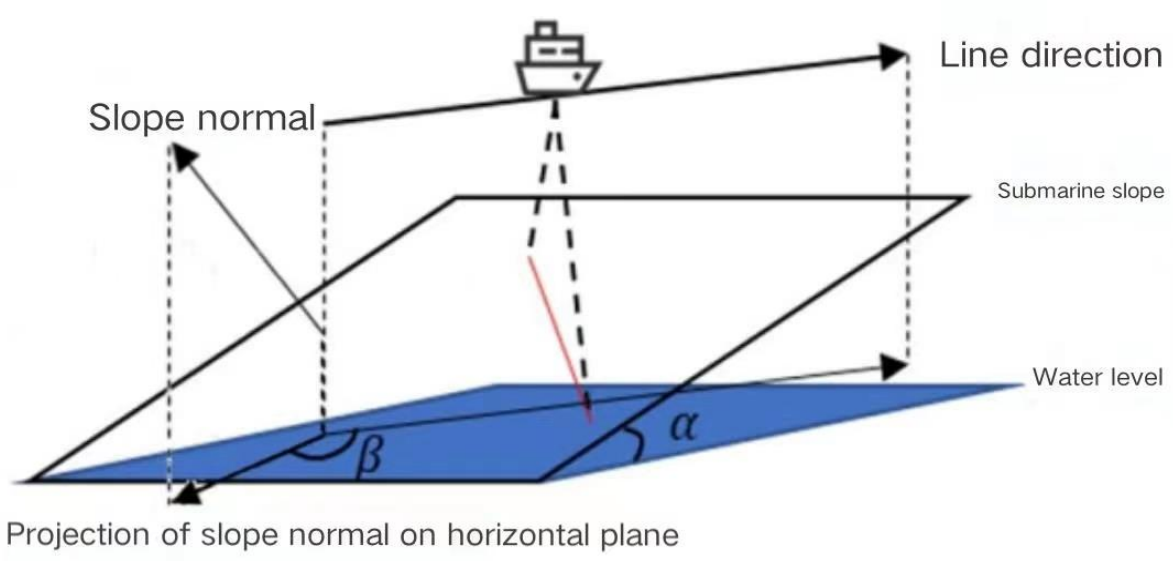


Figure 3. Schematic representation of the coverage width model

Comparing the multibeam bathymetry model with the coverage width model, it is not difficult to find that the coverage width model is only based on the multibeam bathymetry model to transform the two-dimensional model to a three-dimensional model, so we also consider layer-by-layer progression in the derivation of the theoretical model.

First of all, we start with model derivation of the coverage function without slope and pinch angle participation, i.e., the most basic multibeam coverage function as in Figure. 3, with the following equations:

$$W_1 = 2D\tan\left(\frac{\theta}{2}\right) \tag{6}$$

In the above equation, W_1 denotes the initial coverage width, D denotes the depth of seawater, and θ denotes the transducer opening angle.

Then we start to consider the effect of the slope α on D. One thing we need to pay special attention to here is that because of the presence of the slope α the depth of the sea water changes with it, whether it is from the top or from the bottom, and the formula obtained here is as follows:

$$W_1\ D_1 = D + F \times \tan(f(\alpha)) \tag{7}$$

Here, D_1 denotes the depth of the sea water when considering the presence of a slope, F denotes the distance from the center point to the survey line, α denotes the slope, and $f(\alpha)$ denotes the conversion of the unit system of α to radians.

After obtaining the new seawater depth of D_1, we can then derive and calculate the new coverage width, which is affected by both slope and angle, according to the following formula:

$$W = 2D_1 \tan(\frac{\theta}{2}) + 2D_1 \tan(\frac{\theta}{2}) \cos(\beta) \tag{8}$$

At this point, the derivation of the theoretical model for the coverage width is completed, and the subsequent results will be solved based on MATLAB in the following.

3.2.2 Solving the coverage width model

In the process of solving the model we write a code based on MATLAB for solving the model and the solving steps of the code solving are shown in Figure. 4:

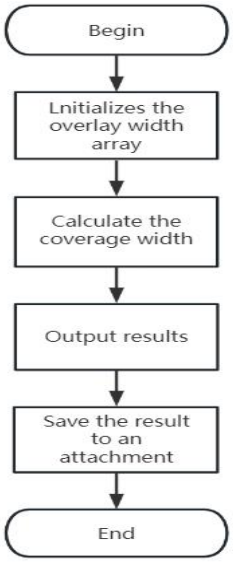


Figure 4. Flowchart of the solution steps for the coverage width model

After that the actual MATLAB operations are performed to solve the results, here we show the solution results as:

Observing Table 2, we can find that the coverage width increases with the increase of the distance of the measuring vessel from the center of the sea. And clip angle except 0 ° and 180 ° other angles under the coverage width and the direction of the clip angle also has a certain relationship. Observing the table in the text, we can find that the distance between the survey vessel and the center of the sea area and the coverage width of the line show a positive correlation.

This concludes the solution of the coverage width model.

Table 2. Results of the coverage width model

Coverage width/m		Distance/nautical mile from the center of the sea by the survey vessel							
		0	0.3	0.6	0.9	1.2	1.5	1.8	2.1
Measuring line direction angle /°	0	415.692	516.489	617.287	718.085	818.883	919.680	1020.47	1121.27
	45	415.692	501.728	587.764	673.800	759.837	845.873	931.909	1017.94
	90	415.692	466.091	516.489	566.888	617.287	667.686	718.085	768.484
	135	415.692	430.453	445.215	459.976	474.738	489.499	504.261	519.022
	180	415.692	415.692	415.692	415.692	415.692	415.692	415.692	415.692
	225	415.692	430.453	445.215	459.976	474.738	489.499	504.261	519.022
	270	415.692	466.091	516.489	566.888	617.287	667.686	718.085	768.484
	315	415.692	501.728	587.764	673.800	759.837	845.873	931.909	1017.94

3.3. Shortest survey line modeling and solution

3.3.1 Determination of survey line design options

① Determine the steps of the design

(1) The spacing of survey lines is determined using the following formula:

$$W_1\ d = W \times (1-\eta) \tag{9}$$

In the above equation, d indicates the distance of the measurement line, and η indicates the overlap rate.

(2) Coverage width is determined using the following formula:

$$W = 2D \times \tan(\frac{\theta}{2}) \tag{10}$$

In the above equation, D denotes the depth and θ denotes the transducer opening angle.

(3) The number of survey lines is determined using the following formula:

$$noml = ceil\ （saw/d） \tag{11}$$

In the above equation, noml is number of measuring lines, saw issea area width, d represents the distance between the survey lines. $ceil$ is represented as a function that takes integers upwards in MATLAB. The important thing to note here is that after determining the number, we need to make sure that these lines are evenly distributed within the sea area to cover the entire sea area.

(4) Determination of the depth of the points of the survey line

After determining the basic scheme of the survey line design, before entering into MATLAB to carry out the calculation, we also need to carry out some preparation and processing of data before the calculation.

② Selection of theoretical and prevalent values:

According to the question, as long as the overlap rate between two neighboring strips is within the range of 10%-20%, the data integrity as well as the convenience of measurement can be ensured. In order to solve the problem of the survey line design scheme, here we choose an overlap rate of 12% as our target value to facilitate the calculation.

In addition, according to the question we can also lock the values of several other variables: the depth of the sea water is 110m, the transducer opening angle is 120°, and the slope is 1.5°. After all the basic data are locked, the calculations begin. At the same time we consider placing the survey line in the east-west direction to achieve the minimum sideline length.

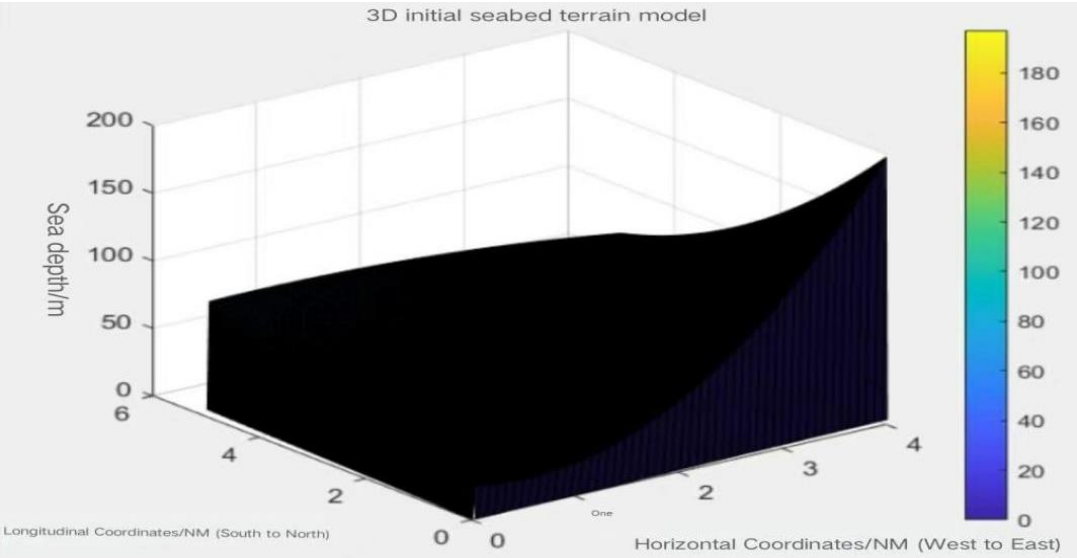


Figure 5. 3D initial seabed model

Here, by looking at the initial model of the seabed structure as in Figure 5, we will first calculate the spacing of the survey lines and the width of the coverage, because only after these two data can we determine their location and number. It is important to note that in addition to these factors, the slope will also affect the depth of each point of the survey line, so the slope will also be taken into account in the calculation process:

$$D_1 = D - a \times \tan(\alpha) \tag{12}$$

In the above equation, D_1 represents the adjusted depth, and a represents the distance from the center point of the line of measurement required by the equation.

3.3.2 Shortest Measuring Line Model Solution

The shortest survey line model is still solved by us through MATLAB, and the predetermined values and formulas listed above are brought into MATLAB and run.

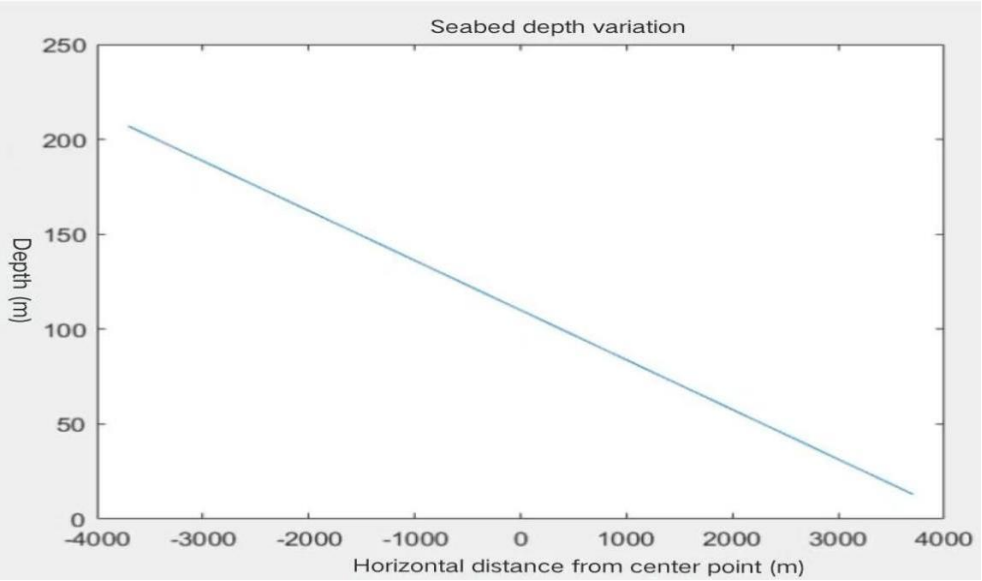


Figure 6. Plot of changes in seafloor depth

By observing the seafloor depth change in Figure 6, we can clearly see that the depth is subject to the law of the change of the horizontal distance from the line of measurement to the center point, and the actual results are shown in Table 3:

Table 3. Solution results of the shortest line model

	Coverage width (m)	Line spacing (m)	Number of lines measured (units)
amount	381.05	353.33	23

Looking at the data in the table we can visualize that the coverage width is 381.05m, the distance between survey lines is 323.89m, and the number of sidings is 23.

At this point, we have derived the coverage width and sideline spacing based on the data of the defined variables, and we have derived the number of lines needed to achieve such coverage widths and sideline spacing.[14] The actual solution process of the shortest line model has been completed, but in order to facilitate the understanding of the results, we have carried out data visualization to increase the visibility of the results.

3.3.3 Visualization of the model solution

After solving we already know the coverage width and the distance between the lines, and as the number of interfering beams increases, the influence of the phase difference on the beam interference effect gradually increases[15] So we can visualize all the lines based on MATLAB:

After running it through MATLAB it is possible to visualize the distribution of the measurement lines as in Figure 7:

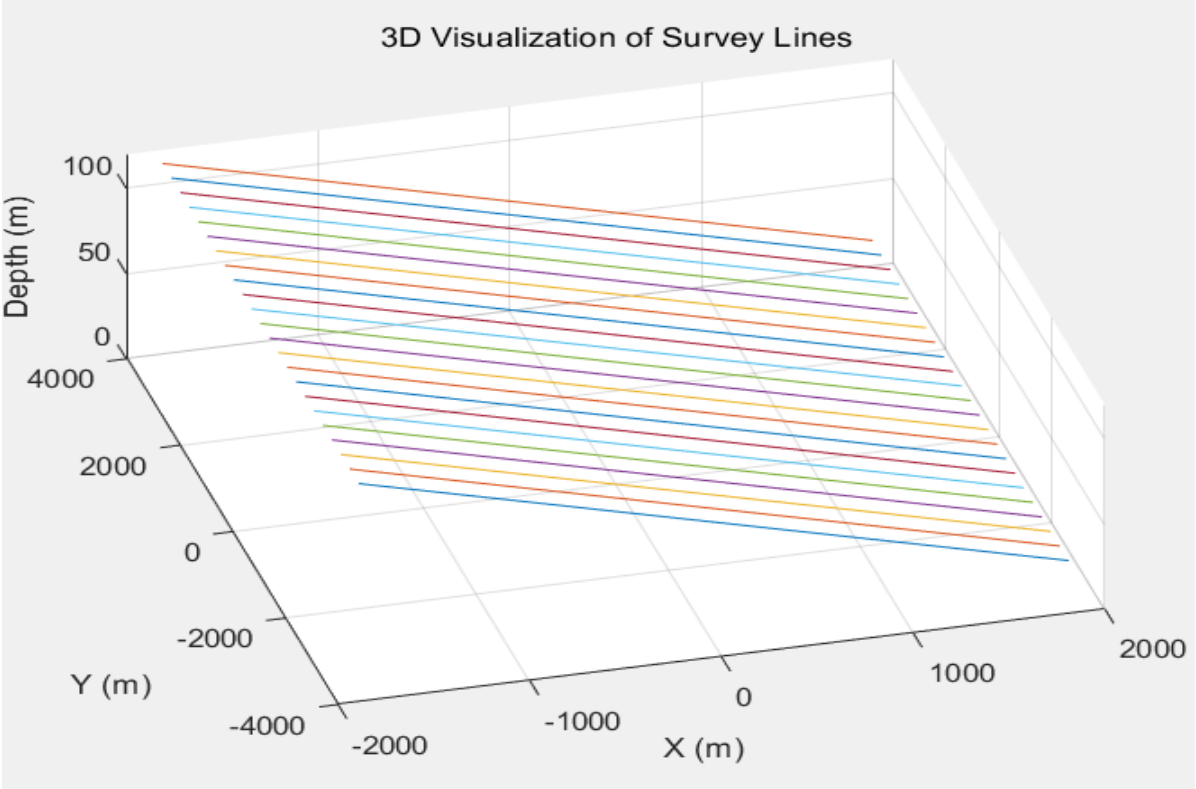


Figure 7. Distribution of survey lines

This concludes all the solution processes for the shortest survey line model. where the distance between Base Stations (BSs) and User Equipment (UEs) is not negligible compared to the distance between BSs and UEs, is not a good idea[11],The distance between base stations (BSs) and user equipment (UEs) is not negligible. which is therefore suitable for small-sized platforms such as CubeSats/small satellites[10].

4. Conclusion

This paper establishes a coverage width and overlap rate model, a coverage width model, a shortest line group design model, and a shortest line optimal solution model to solve the problems of missed measurements and high overlap rate, so as to improve the utilization of resources and time. By adding and changing a few coefficients, it is possible to directly extend the two-dimensional model in the multibeam bathymetry model to the three-dimensional model of the coverage width model, The application of this method to the sea floor is very difficult. Its application to scenarios with high seafloor relief.

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