Research on the Optimization of Multibeam Bathymetric Survey Line Arrangement Based on Multimodal and Clustering Techniques

Jiyang Liu *, Haokun He #, Mingkai Li #

School of Mathematics and Statistics, Shandong University, Weihai, Shandong, China 264209

* Corresponding Author Email: jiyangliu@mail.sdu.edu.cn

#These authors contributed equally.

Abstract. Currently, there is limited research on the survey line arrangement for multibeam bathymetric technology in the marine surveying field. This study aims to propose a more cost-effective and efficient survey line arrangement for multibeam bathymetric technology, providing stronger theoretical and practical support for the relevant field. Assuming an ideal scenario where the seafloor is a flat slope, this study, based on computational geometry, establishes five survey line models. It plans the survey line arrangement reasonably, calculating the number of survey lines, their lengths, overlap rates, and omission rates, achieving multimodal universality of the model. In addition, hypothetical situations are constructed for computational comparisons. Subsequently, a set of real seafloor surface parameters were selected for discussion. The seafloor slope was first clustered and the slope was calculated using the central difference method. The sea area was then gridded, and using clustering techniques and sensitivity tests on the slope, effective clustering of the seafloor was achieved. Finally, comprehensive solutions were sought for each partitioned area, combined with the multimodal survey line model. Therefore, based on multimodal and clustering techniques, this study provides an effective survey line design method for multibeam transducer technology in marine surveying. The proposed line arrangement model and computational scheme provide strong theoretical and practical guidance for further applications of marine depth measurement technology.

Keywords: Multibeam bathymetry, Computational geometry, Cluster partitioning, Sensitivity analysis, Optimization problem.

1. Introduction

Bathymetric technology plays a significant role in marine surveys, seabed topography research, and marine engineering. Both single-beam bathymetry and multibeam bathymetry, as two commonly used bathymetric methods, utilize the principle of sound wave propagation to measure water depth. While single-beam bathymetry has advantages in continuous measurement, it has certain limitations in the continuity and completeness of data acquisition. To overcome the limitations of single-beam bathymetry, the multibeam bathymetric system was developed, which can achieve efficient and accurate measurements of the seafloor by simultaneously emitting multiple beams and receiving reflected signals. However, determining the appropriate survey line arrangement for multibeam bathymetry is a key issue, and solving it is vital for improving marine mapping efficiency.

This paper aims to explore the key technical challenges in determining the appropriate survey line arrangement for multibeam bathymetric systems and proposes corresponding solutions. Given the complex and varied characteristics of the seabed topography, this research aims to introduce a flexible and feasible survey line arrangement to ensure the completeness and accuracy of marine topographic measurement data while improving efficiency. By analyzing the measurement requirements under different seabed topographic conditions and existing survey line design strategies, this study aims to provide a comprehensive survey line interval determination scheme to enhance the application effect of multibeam bathymetry in marine surveys. Through the progress of this research, we hope to provide a more comprehensive, efficient, and accurate technical support for the marine topographic measurement field, promote continuous innovation and development of bathymetric technology, and further expand its application prospects in marine science research and engineering applications.

2. Research Methods

2.1. Definition of Indicator Parameters

In the work of multibeam bathymetry, there are various common technical parameters. The definitions for coverage width, survey line spacing, and overlap rate are as follows: The coverage width W of the multibeam bathymetric strip varies with the opening angle θ of the transducer and water depth D. If the survey lines are parallel to each other and the seabed is flat, then the overlap rate between adjacent strips is defined as $\eta = 1 - \frac{d}{W}$, where d is the spacing between two adjacent survey lines, and W is the coverage width of the strip. If $\eta < 0$, it indicates missing measurements.

To ensure the convenience of measurement and the completeness of the data, there should be an overlap rate of $10\%\sim20\%$ between adjacent strips [1]. As shown in Figure 1.

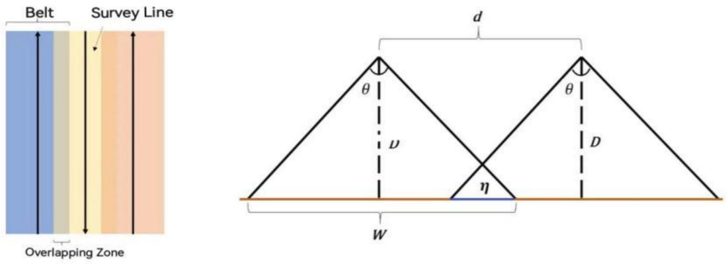


Figure 1. Indicator parameter diagram

2.2. Ideal Wiring Model Construction Approach

2.2.1 Background Construction

Assume the opening angle of the multibeam transducer is 120°, with a slope of 1.5°, and the seawater depth at the center of the sea area is 110 m. The sea area is defined as being 2 nautical miles long from north to south and 4 nautical miles wide from east to west, with the western part being deeper than the eastern part. Design a set of survey lines with the shortest total length to completely cover the entire area to be surveyed, and the overlap rate between adjacent strips should be between 10% and 20% [2].

2.2.2 Problem Analysis

In response to the requirements, the aim of this research is to construct five wiring models, namely five different wiring schemes to cover all possible scenarios. The five wiring strategies are: using diagonal parallel survey lines, using east-west directional parallel survey lines, using north-south directional parallel survey lines, using directionally perpendicular parallel survey lines in different areas, and using non-parallel survey lines.

2.3. Practical Wiring Model Application Approach

2.3.1 Background Construction

Based on the provided single-beam bathymetric data of the actual sea area, we will conduct a multibeam bathymetric survey of this sea area again. For this, design a wiring plan that requires: (1) covering the entire area to be surveyed as much as possible; (2) controlling the overlap rate of adjacent strips to below 20%; (3) ensuring the shortest total length of the survey lines. After completing the wiring plan design, calculate the following indicators: (1) total length of the survey lines; (2) percentage of the unmeasured sea area in relation to the total area to be surveyed; (3) in overlapping areas, the total length where the overlap rate exceeds 20% [3].

2.3.2 Problem Analysis

Based on the seabed depth data, the seabed is a curved surface, making the problem more complex. Hence, this study decided to transform the curved surface problem into a planar one for discussion. Firstly, this research will grid the sea area based on single-beam bathymetric data and conduct a slope sensitivity analysis simultaneously. According to the slope sensitivity analysis and slope clustering, the seabed area will be divided into rectangular areas with similar slopes. These areas will be approximated as flat slope surfaces for discussion, with the slope taken as the average slope and the depth as the central depth. Then, the ideal wiring model will be applied to the already divided approximate slope surfaces for survey line design. Finally, calculate the indicators of the wiring plan and discuss them.

3. Model Establishment and Solution

3.1. Ideal Routing Model

This study adopts various survey line arrangements, namely, using oblique parallel survey lines, using segmented parallel survey lines in the east-west direction, using parallel survey lines in the north-south direction, using parallel survey lines in different areas in different regions, and using non-parallel survey lines, etc. The following will be discussed one by one [4][5]. Note that this study will model the first type in detail, with similar steps omitted in subsequent models.

The method of arranging survey lines using oblique parallel traverse lines entirely

In this arrangement method, two unknown variables are set, namely the angle $\beta(0° - 360°)$ between the survey line direction and the due west direction and the distance $d_i(i = 1,2,3 \ldots\ldots)$ between two survey lines. In subsequent problems, as long as these two variables are determined, the survey plan can be determined.

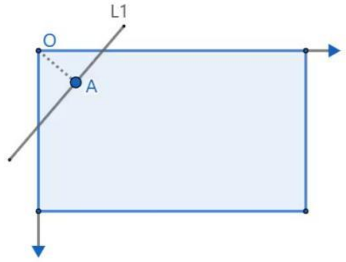
Method for Determining the First Survey Line:

For the first survey line, to facilitate the arrangement of subsequent survey lines, this study decided to start from one corner. First, determine an angle β, which represents the direction of the survey line, specifically, the angle between the survey line direction and the due west direction.

According to the angle β and the seabed slope of $1.5°$, determine the angle between the plane perpendicular to the survey line direction and the seabed slope and the horizontal plane, that is, the 'slope' of the plane that the survey ship can detect. Subsequently, based on

$$\alpha = arctan\big(tan1.5°sin(\beta)\big) \tag{1}$$

set the northwest corner of the sea area as the origin, make a perpendicular line to the first survey line L_1 through the origin, the foot of the perpendicular is point A, so that the ship can detect the origin at point A, as shown in the Figure 2.



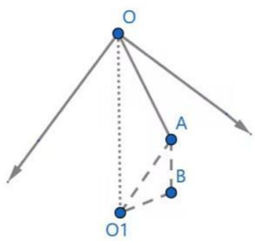


Figure 2. The line that can just detect O(left) and the projection triangle(right)

Then use the sine law in the triangle $\triangle AO_1B$ formed by the projection of point A, B on the seabed and the projection O_1 of point O on the seabed, as shown in the Figure 2.

Where $|O_1A|$ is obtained using the Pythagoras theorem, $|AB|$ is obtained using the depth calculation method. This ensures that the first survey line just covers the northwest corner of the sea area, without missing or wasting detection capabilities.

By above, the coordinates of point A (x_A, y_A) can be solved. Having found point A, the first survey line L_1 can be drawn based on angle β, and the equation of the first survey line L_1 is obtained:

$$y = tan(-\beta)x + (y_A - tan(-\beta)x_A) \tag{2}$$

To ensure full coverage of the seabed by the ship's detection. Point M_1 is taken as the starting point on line L_1, so that when the ship is at point M_1, the detection coverage line just intersects one side of the sea area, i.e., there is only one intersection point; similarly, point N_1 is taken as the end point on line L_1, so that when the ship is at point N_1, the detection coverage line just intersects one side of the sea area. As shown in the Figure 3.

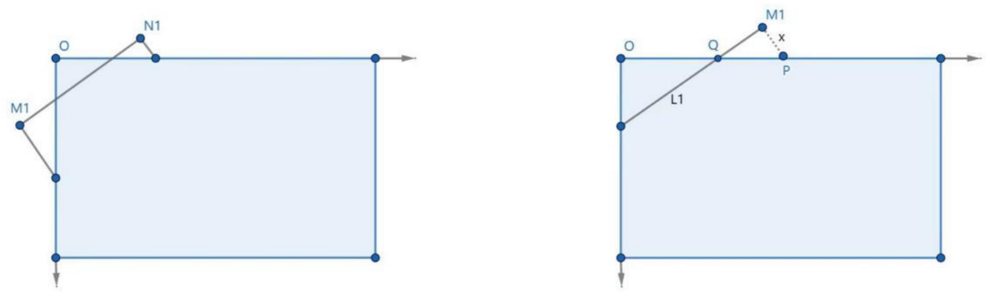


Figure 3. The starting coordinates of the first line

Firstly, solve for the coordinates of point M_1. Draw M_1P from M_1towards the north side of the sea area so that M_1P is perpendicular to the first survey line L_1, and let $|M_1P_1|$ be x, as shown in the Figure 3.

Then make projections of points M_1 and P on the seabed, denoted as M_{11} and P_1. The triangle $\triangle M_1P_1M_{11}$ is as shown in the Figure 4.

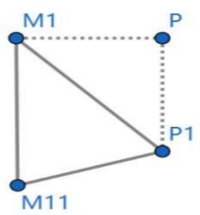


Figure 4. *Geometric diagram* of $\triangle M_1P_1M_{11}$

In triangle $\triangle M_1P_1M_{11}$, the sine law gives:

$$\frac{|M_1M_{11}|}{sin(30^0 + \alpha)} = \frac{|M_1P_1|}{sin(90^0 - \alpha)} \tag{3}$$

Where Q is the intersection of L_1 with the north shore, its x-coordinate is:

$$x_Q = \frac{y_A - tan(-\beta)x_A}{tan(-\beta)} \tag{4}$$

Similarly, to find the end point N_1 of the first survey line so that when the ship is at point N_1, the detection coverage line just intersects with the west side of the sea area. Draw N_1T perpendicular to L_1through point N_1, and let the distance from N_1 to the western shore be x, as shown in the Figure 5.

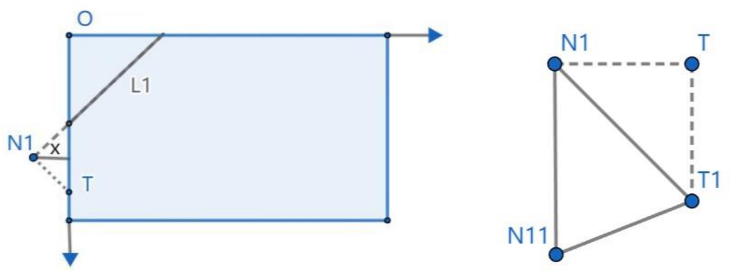


Figure 5. The end point(left) and Geometric diagram of $\triangle M_1P_1M_{11}$(right)

Make projections of points N_1 and T on the seabed to form triangle $\triangle N_1T_1N_{11}$, as shown in the Figure 5.

Using the sine law, can have:

$$\frac{|N_1N_{11}|}{sin(30^0+\alpha)}=\frac{|N_1T_1|}{sin(90^0-\alpha)} \quad (5)$$

The x-coordinate of point N_1 is $-x$. Thus, the y-coordinate of point N_1 is:

$$y_N = kx_N + (y_A - kx_A) \quad (6)$$

Where the slope k in the above equation is the same as the slope k obtained when solving the first survey line, $k = tan(-\beta)$.

Thus, both the starting point M_1 and the end point N_1 of the first survey line L_1 have been determined, and the selection of the first survey line is completed.

Subsequent Survey Line Determination Method:

During the detection process, it is assumed that each survey line is parallel to each other, and the heading is generally from east to west. It is known that the detected strip area is roughly an irregular trapezoid, with both sides of each trapezoid parallel to each other. From a simple discussion, it is determined that the overlap rate of the bands from east to west gradually increases, as shown in the Figure 6.

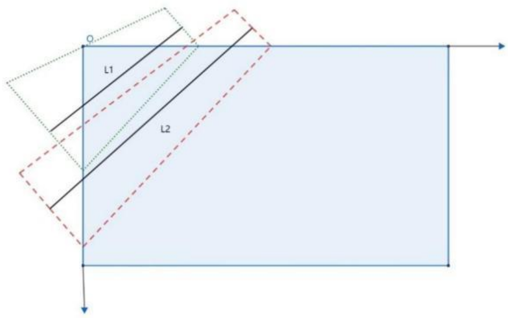


Figure 6. Schematic of overlap rate between survey lines

Subsequently, to achieve the highest measurement efficiency, this study sets the initial overlap rate of the northernmost band to 10%, that is, the overlap rate at point M_1 is 10%.Based on this, the width between the first and second survey lines can be calculated.

Firstly, assume the distance between the first and second survey lines is d_1. It can be deduced that on the cross-section vertical to M_1 and L_2, the following shape exists as Figure 7.

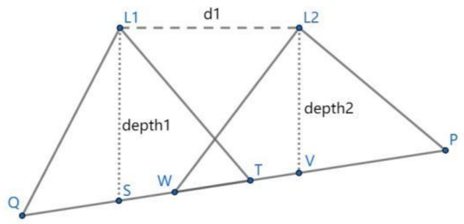


Figure 7. Calculation of the spacing between two survey lines

For this shape, use the sine theorem in triangles ΔL_1QS, ΔL_1TS, and ΔL_2WV, ensuring a 10% overlap rate. The final value of d_1 can be solved, and the difference in intercepts between the first and second survey lines is $\frac{d_1}{\cos(\beta)}$.

Subsequently, based on the equal slope of the first and second survey lines, the equation for the second survey line can be deduced:

$$y = kx + (y_A - kx_A) + \frac{d_1}{\cos(\beta)} \tag{7}$$

Where $k = \tan(-\beta)$

To verify the overlap rate, draw a plane perpendicular to the second survey line L_2 at the endpoint N_1 of the first survey line to calculate the overlap rate.

$$\eta = \frac{\frac{[D - X\tan(\alpha)]\sin\left(\frac{\theta}{2}\right)}{\cos\left(\alpha - \frac{\theta}{2}\right)} + \frac{[D - X\tan(\alpha) - d\tan(\alpha)]\sin\left(\frac{\theta}{2}\right)}{\cos\left(\alpha + \frac{\theta}{2}\right)} - \frac{d}{\cos(\alpha)}}{[D - X\tan(\alpha)]\left\{\frac{\sin\left(\frac{\theta}{2}\right)}{\cos\left(\alpha - \frac{\theta}{2}\right)} + \frac{\sin\left(\frac{\theta}{2}\right)}{\cos\left(\alpha + \frac{\theta}{2}\right)}\right\}} \tag{8}$$

After calculating the equation of the second survey line, continue to deduce the equations for other survey lines in a similar manner and check the overlap rate at the endpoint of each survey line.

Moreover, when the intersection relationship between the survey line and the boundary of the sea area changes,this will result in a change in the calculation method of the endpoint of the survey line,as shown in Figure 8.To address this issue, we need to determine when the intersection relationship between the survey line and the boundary of the sea area changes.

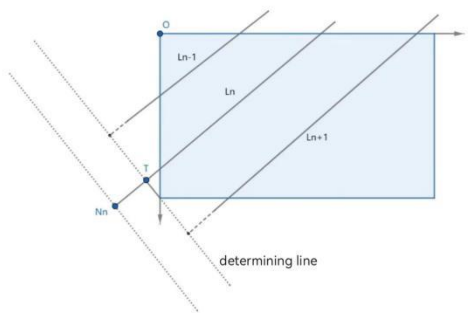


Figure 8. Schematic of the determination method for the straight line

Take a line perpendicular to the survey line at the point (0,3704), with equation $y = -\frac{1}{\tan(-\beta)} + 3704$, called the judgment equation. Find the intersection points of the judgment equation and other survey lines, referred to as judgment points. When the ordinate of the judgment point is less than the ordinate of the endpoint of the survey line, it indicates that the intersection relationship has changed or is about to change. The endpoint N_n found using the previous method will measure many unnecessary sea areas, resulting in waste. However,the ordinate of the judgment point T is less than the ordinate of endpoint N_n of L_n, which meets the judgment condition. For the first survey line that meets the judgment condition, the endpoint of L_n is changed to point T, so that L_n will not waste survey line length.

Also, for the survey line L_{n+1} and its subsequent survey lines, the calculation method of the endpoint will change. Subsequently, the method similar to seeking the starting point of the survey line on the north side of the sea area will be used to determine the endpoint of the survey line on the south side.Similarly, use the same judgment method to determine and calculate when the starting point of the survey line turns from the north side to the east side.

For the selected value of β in this model, traverse and filter out constraints that do not meet the overlap rate requirements[6].It is found that for most angles, except for angles close to $0°$ and $90°$, the overlap rate will exceed the $10-20\%$ limit.

Total Survey Line Length and Survey Line Arrangement Plan:

In this study, we arranged all cases that meet the overlap rate within the $10-20\%$ limit. By calculating and comparing the Euclidean distances between the starting and ending points of each survey line, it was found that aside from angles close to $0°$ and $90°$, the overlap rate will exceed the $10-20\%$ limit. Moreover, near $0°$ and $90°$, the closer the angle is to $0°$ and $90°$, the shorter the total survey line length becomes. The following discussion will specifically address the situation at $0°$ and $90°$, i.e., when using entirely north-south or east-west parallel survey lines.

The method of arranging survey lines when all are oriented east-west

Based on calculations, when using only east-west parallel survey lines, only 6 lines are needed on the farthest west side to achieve an overlap rate between $10-20\%$, while 91 lines are needed on the farthest east side,as shown Figure 9.

Figure 9. Method of arranging survey lines when all are oriented east-west.

Starting from the easternmost side and assuming a 10% overlap rate, the width between two lines is $\frac{5\sqrt{3}}{9}D$, where D is the depth. At a 20% overlap rate, the depth is $\frac{9}{8}D$. Calculations show that at a depth of $\frac{9}{8}D$, if we construct another group of east-west parallel survey lines at a 10% overlap rate, the number of lines needed will not decrease sequentially from 62 but will jump. This indicates that for a certain depth range with an overlap rate between $10-20\%$, fewer than 91 lines could have been used, but 91 lines were still used. Hence, using a linear gradient from 10% at the eastmost side to 20% at the westmost side is not the optimal solution for east-west lines.

The number of survey lines needed at a certain depth changes discontinuously. We will find this "inflection point" to determine the minimum number of lines needed at a certain depth.

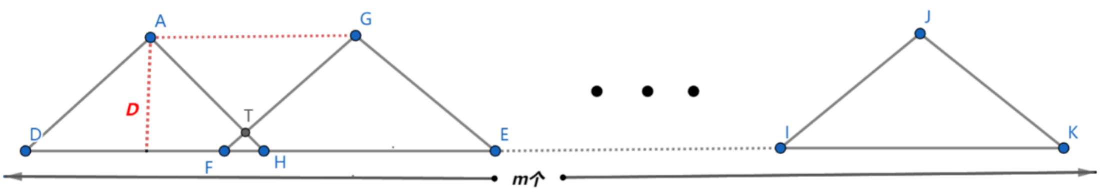


Figure 10. Calculation illustration for critical points

Consider the scenario shown in the Figure 10. At a 10% overlap rate and a depth D, exactly m lines are needed for the survey. The relationship between D and m is given by:

$$(\mathrm{m}-1)\frac{9\sqrt{3}\mathrm{D}}{5}+2\sqrt{3}\mathrm{D}=3704 \quad (9)$$

Thus, through the depth D, we can find the coordinates of the line where the change occurs. Between any two lines, we can use the corresponding number of survey lines to perform the measurement. Continue to compute the above equation to determine the corresponding depth $\mathrm{D}$and the x-coordinate of the critical point $\mathrm{x}_{\mathrm{critical}}$.

In the maritime area between the corresponding $\mathrm{x}_{\mathrm{critical}}$ isogon and the previous $\mathrm{x}_{\mathrm{critical}}$ isogon, it can be measured using only $(\mathrm{m}-1)$ transect lines. Multiplying the length between every two x isogons by $(\mathrm{m}-1)$ and then summing them up gives the total transect line length.

(1) Method of arranging transect lines when using only north-south parallel transect lines

In this scenario, there are two methods to arrange the north-south parallel transect lines: from east to west or from west to east.

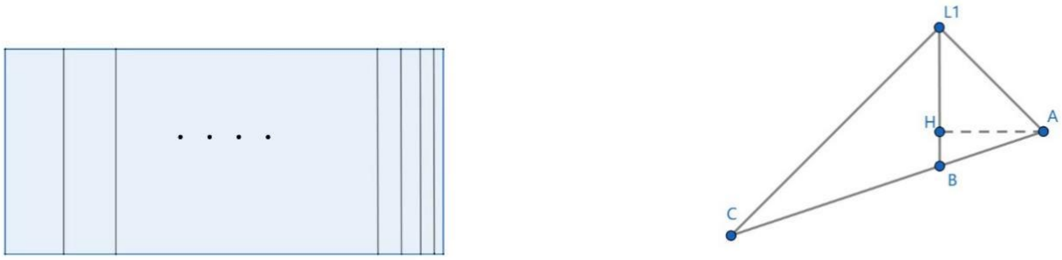


Figure 11. North-south wiring method(left) and the area measured by the first line(right)

This study uses the arrangement from east to west as an example. Assuming the first transect line is a distance x from the easternmost edge, the area measured by the first transect line is shown in Figure 11. Point A is the seabed on the easternmost side of the maritime area. Draw a vertical line AH from point A to $\mathrm{L}_1\mathrm{B}$, let $|\mathrm{AH}|=\mathrm{x}$.

Begin the search for subsequent transect lines. To demonstrate the distance between two transect lines using the previous one, the scenario is depicted in the Figure 12.

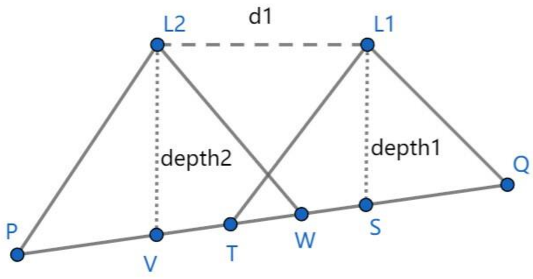


Figure 12. Calculating the distance between two transect lines.

Following the method introduced earlier: Using the sine rule in triangles $\Delta\mathrm{L}_1\mathrm{QS}$, $\Delta\mathrm{L}_1\mathrm{TS}$, and $\Delta\mathrm{L}_2\mathrm{WV}$, while ensuring a 10% overlap, can get it:

$$d_1=-\frac{9\left(\frac{depth1sin(60^0)}{cos(61.5^0)}+\frac{depth2sin(60^0)}{cos(58.5^0)}\right)}{10\left(\frac{tan(1.5^0)sin(60^0)}{cos(58.5^0)}-\frac{1}{cos(1.5^0)}\right)} \quad (10)$$

$$depth\ =\ 110\ +\ (\text{distance from the center in the east}-\text{west direction})\times tan(1.5^0)h$$

This is the distance between the previous transect line and the next one. Following this method, we can find all the remaining transect lines.

(2) For the method of arranging survey lines in parallel directions within different regions

First, set the variable t, indicating that when taking $((t-1)$groups of east-west-oriented survey lines from west to east, it can measure the current depth of the sea. Then, start using north-south-oriented survey lines for measurement from the critical line to the east. By iterating the value of t from 6 to 91, we can calculate the minimum total survey line length in this scenario. A rough plan is shown in Figure 13.

Figure 13. Combined wiring method

Then, take $(t-1)$ groups of east-west-oriented survey lines from east to west and repeat the previous process.

(3) For the non-parallel survey line layout method:

When arranging all diagonal parallel survey lines, when determining the endpoints of the second and subsequent survey lines, change it to the point where the overlap rate is 10% as determined in the same way as the starting point of the previous line. Do not create the second and subsequent survey lines in parallel, but connect the start and end directly. The other processes remain consistent with the diagonal parallel survey line layout method in 6.1. The comparative layout of parallel and non-parallel survey lines is shown in Figure 14.

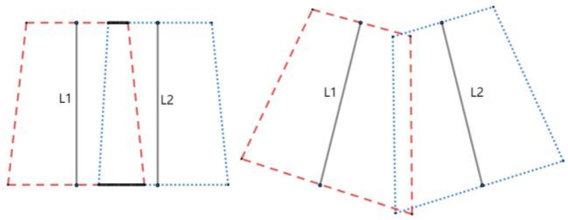


Figure 14. Comparison diagram of parallel and non-parallel wiring

In actual situations, non-parallel survey lines make the overlap rate more controllable and can also be more efficient. However, the overlap rate needs a new definition, and during actual layout planning, using a rectangular sea area as an example, its irregular shape can cause "over-measurement" and "missed-measurement" problems, which can reduce efficiency.

(4) Model Results Analysis:

With respect to the results of the application of each plan, as shown in Table 1.

Table 1: Application results of the plan

Method	Minimum Total Survey Line Length (in meters)
Entirely east-west parallel	121455
Entirely north-south parallel	125936
Combined parallel	121444

The conclusion is: The partitioned survey line layout in different areas using parallel lines in different directions achieves the minimum total survey line length of 121,444 meters, the layout roughly involves taking 85 sets of east-west survey lines, then taking 1 north-south survey line. Therefore, the following research will first select this combination method to solve the ideal problem.

3.2. Practical Wiring Application Model

3.2.1 Slope Sensitivity Analysis

Before performing slope clustering analysis, it's essential to determine the basis for slope clustering, i.e., to what extent a range of slope variation can be approximated as a plane. It's evident that the slope of a curved surface is inconsistent while that of a slope surface is consistent. Therefore, errors will occur when converting curved surfaces to sloped surfaces. The manifestation of these errors is either missed measurements or a high overlap rate. The root cause of this is a change in the transducer's coverage width[7]. To minimize such errors during clustering, we conducted the following sensitivity analysis.

Considering the scenario with the most substantial error, where the transducer's opening angle is consistent, the ship's measurement line is parallel to the slope and remains unchanged at a distance of 600m from the center of the slope, the effect of the slope variation range on the multibeam transducer's coverage width is as shown in the following Table 2 and Table 3.

Table 2: Based on the variation of a 1.5 slope.

Slope	Coverage Width	Percentage Change
0.9	210.017	11.429
1.1	202.840	7.614
1.3	195.673	3.795
1.5	188.513	—
1.7	181.359	3.798
1.9	174.208	7.569
2.1	167.059	11.351

Table 3: Based on the variation of a 20 slope.

Slope	Coverage Width	Percentage Change
19	-776.715	14.356
19.5	-839.316	7.551
20	-907.766	—
20.5	-983.005	8.279
21	-1066.18	17.470

From the analysis above, during the slope clustering process, choosing a slope variation range of 1° ensures that in most cases, the coverage width change does not exceed 10%. This means when the slope of two planes differs by 1°, they can be approximated as one plane.

3.2.2 Slope Clustering Analysis

First, based on seabed data, depth contour map are drawn, shown as Figure 15, revealing strong regional characteristics. After simple clustering analysis, depth clustering maps can be obtained, and the sea area can be roughly divided into four rectangles to ensure that the depth of the area divided during slope clustering does not change abruptly, and the seabed remains smooth[8].

The slope of each point is first calculated by defining the angle between the plane formed by its surrounding four points and the horizontal plane to obtain an approximate slope value. Apply color distinction for simple clustering, shown as Figure 15,the slope map roughly reflects the angle between the tangent of each point and the horizontal plane.

This study gridded the slope map (size 200×200), and each grid (size 35×40) can be regarded as a small slope surface. Using the regional center depth and average slope as slope indicators, based on the slope map and clustering constraints from slope sensitivity analysis, we can perform a rectangular clustering division.

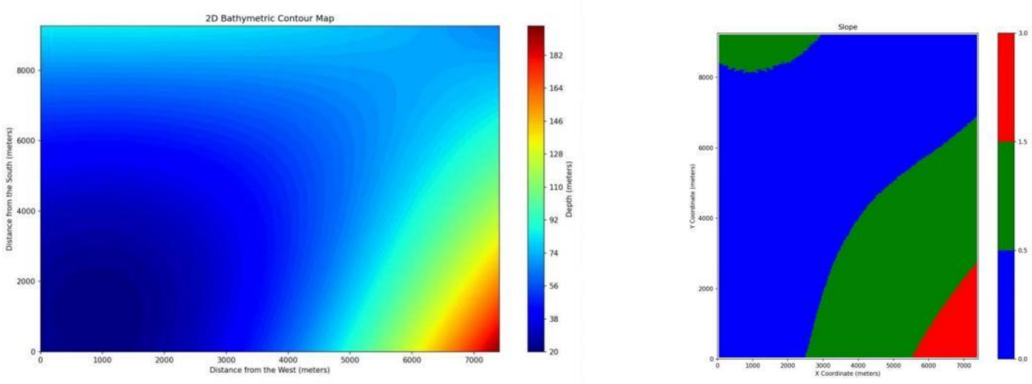


Figure 15. Depth contour map(left) and Slope clustering analysis map(right)

At the same time, it is required to divide the area as much as possible according to contour lines, because it is more in line with the ideal wiring model, which helps to reduce result errors [9].

The final area division is as Figure 16. In the following areas, depth and slope clustering division has been carried out, making the slopes within these areas similar and the seabed continuously smooth. It can be considered as a flat slope surface for problem analysis. The calculation method for the average slope is:

$$\text{Average Slope} = \frac{1}{N}\sum_{i=1}^{N} S(x_i, y_i) \tag{11}$$

Where N is the total number of points in the area, and $S(x_i, y_i)$ is the slope of the ith point.

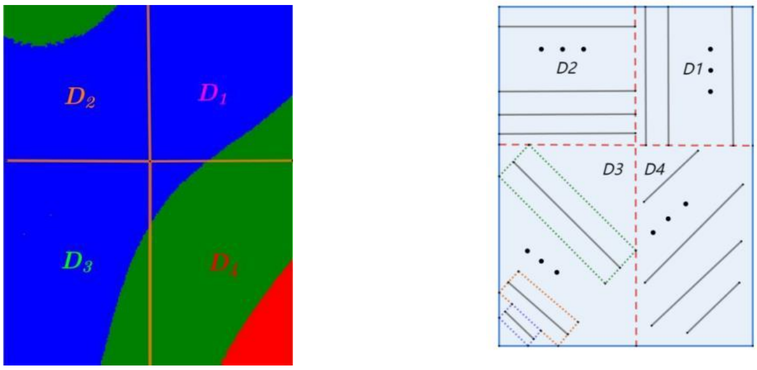


Figure 16. Illustration of rectangular area division(left) and survey line layout scheme(right)

3.2.3 Results and Analysis

In practical application, the aperture angle affects factors such as energy consumption and efficiency. Since the 120° opening angle used in the previous study of this research worked well, we continue to use the 120° opening angle for discussion in actual situations [10].

After clustering analysis, the sea area was divided into four rectangular areas. The layout of the measuring line for each area is discussed as Figure 16. The final results are shown in Table 4.

Table 4: The parameters of each area

Area	Total Line Length/m
D1	92600
D2	106490
D3	109896
D4	106839
total	415852

In this layout, the total measured line length is a minimum of 415,852 meters.

According to the designed wiring scheme, full coverage is achieved in areas D1 and D2. In areas D3 and D4, a diagonal parallel line scheme is adopted. In order to ensure that the total line length is shorter, we do not consider the ship going out of the sea area. Thus, there will be missed measurements at the boundary, as shown in Figure 17.

The total area of the sea is 68,598,080㎡, the missed measurement area is 2,817,897㎡, and the missed measurement rate is 4.11%.

Figure 17. Missed survey situations(left) and Repeated occurrences(right)

In the above wiring scheme, the situation where the overlap rate is too high will only appear at the boundary of the rectangular division area, as shown in the purple area in Figure 17. The total length of the lines with an overlap rate exceeding 20% is 35,382m.

4. Conclusions

In summary, this study, focusing on the line layout problem of multi-beam depth measurement technology in the field of marine surveying, successfully established five wiring models based on computational geometry technology and demonstrated multi-modality universality under ideal conditions. At the same time, for real seabed surface parameters, through block clustering technology and the use of the center difference method, the line layout problem under complex seabed topography has been effectively solved.

The research results show that, under ideal conditions, the total length of the optimal line layout scheme is 121,444 meters, using a vertical parallel combination scheme, with a total of 86 lines. Considering actual conditions, dividing the seabed into four areas can yield the most reasonable results, with a total line length of 415,852 meters and a missed measurement rate of 4.11%. It is particularly noteworthy that the length of lines with an overlap rate exceeding 20% is 35,382 meters, providing a useful reference for the optimization of subsequent line layout schemes.

Therefore, this study provides an economical and efficient line design method for multi-beam transducer technology in the marine surveying field based on multi-modality and clustering technology. The proposed line model and calculation scheme not only enrich the research in the related field at the theoretical level but also provide strong support and guidance for the practical application of marine depth measurement technology. Future research can further optimize the line layout scheme to improve the efficiency and accuracy of the line layout, providing more reliable technical support for the development of marine surveying technology.

References

[1] Grządziel A. Method of Time Estimation for the Bathymetric Surveys Conducted with a Multi-Beam Echosounder System [J]. Applied Sciences,2023,13(18).

[2] Tianyu Y, Xianhai B, Zhe X, et al. Erratum to: Automatic calibration for wobble errors in shallow water multibeam bathymetries [J]. Journal of Oceanology and Limnology, 2023, 40(6).

[3] Wang J, Tang Y, Jin S, et al. A Method for Multi-Beam Bathymetric Surveys in Unfamiliar Waters Based on the AUV Constant-Depth Mode [J]. Journal of Marine Science and Engineering, 2023,11(7).

[4] Aniol M, Jordi P, David A, et al. Compression of Multibeam Echosounders Bathymetry and Water Column Data [J]. Remote Sensing, 2022, 14(9).

[5] Qiang G, Chuanyu F, Yikang C, et al. Application of multi-beam bathymetry system in shallow water area [J]. Journal of Physics: Conference Series, 2023, 2428(1).

[6] WANG Junsen, JIN Shaohua, BIAN Zhigang, et al. Residual Correction of the Rolling Motion in Multibeam Bathymetry Using Overlapping Area of Adjacent Survey Lines [J]. Ocean Technology, 2023, 42(04): 35-42.

[7] LIU Lin. Reasons and Solutions for the Distortion of Multibeam Sounding Data [J]. Value Engineering, 2023, 42(21): 125-128.

[8] DONG Yu. Research on the Application of Multibeam Bathymetry System in Marine Hydrographic Survey [J]. Engineering Technology Research, 2023, 8(15): 122-124. DOI: 10.19537/j.cnki.2096-2789.2023.15.040.

[9] MA Zhenghai LIN Dang LI Shengxuan, et al. Underwater terrain mapping of Jingjiangmen river reach based on multi-beam bathymetry system [J]. Express Water Resources & Hydropower Information, 2022, 43(12): 36-40. DOI: 10.15974/j.cnki.slsdkb.2022.12.006.

[10] YU Qiyi. Seabed Topography Measurement Based on Multi-beam Bathymetry Technology [J]. Geomatics & Spatial Information Technology, 2022, 45(09): 262-264.