

Research on Coverage Width Calculation and Analysis Based on Multibeam Bathymetric Model

Junmeng Zhang

Haide College, Ocean University of China, Qingdao, China, 266100

2249156816@qq.com

Abstract. As multibeam bathymetry is widely applied to the detection of complex terrain on the seafloor, how to optimize the coverage width and overlap rate by reasonably setting the measurement parameters has become a key issue in improving the accuracy and efficiency of the measurement. Starting from the actual situation, this study establishes a spatial geometric model based on the seabed topography. It combines the MATLAB programming tool to accurately calculate and analyze the coverage width of multibeam bathymetry and the overlap rate between neighboring strips under different circumstances. For example, when the opening angle of the multibeam transducer is 120° , the slope is 1.5° . The depth of seawater at the center point of the sea area is 70m, the model can calculate that when the distance of the measuring line from the center point is 200m, the coverage width is 224.81m and the overlap rate is 11.1%. On this basis, the influence of the position of the survey ship and the angle of the measuring line on the coverage width is discussed. For example, if the angle of the measuring line direction is 45° and the distance of the survey ship from the center of the sea is 0.3m, the coverage width of the beam is 451.79m. Through the calculation and analysis of the model, the working principle of the multibeam detector is accurately and concretely demonstrated to portray and describe the complex seabed terrain.

Keywords: Multibeam Bathymetric; Overlap Rate; Coverage Width; Measuring Line Angle.

1. Introduction

With the continuous progress in the development of marine resources and seabed topography detection technology, multibeam bathymetric technology, as an efficient means of seabed measurement, has been widely used [1, 2]. By transmitting multiple acoustic beams, multibeam bathymetry acquires a large range of seafloor topography data in a relatively short period, thus greatly improving the measurement efficiency and accuracy [3, 4]. However, in the actual measurement process, the complexity of the seafloor topography and the variation of the survey line parameters significantly affect the multibeam coverage width and overlap rate [5, 6]. In multibeam bathymetry, the coverage width and overlap rate are important factors affecting the measurement accuracy and data integrity.

Based on the seabed-sounding data, this paper tries to establish a mathematical model of the coverage width and overlap rate between adjacent strips in multibeam bathymetry. The model is abstracted as a spatial geometry problem and computationally processed with MATLAB, which is proposed to obtain the depth of seawater at the corresponding position, the coverage width, and the overlap rate of two measuring lines. Furthermore, the direction of the measuring line and the position of the ship are transformed, the coverage width of the multibeam sounding is calculated again, and the relationship between the three is obtained [7].

2. Establishment of Multibeam Bathymetric Model and Overlap Rate Analysis

2.1. Detection modeling and solving for coverage width and overlap rate

Data for this study were obtained from <https://www.mcm.edu.cn/>. The multibeam sounder is able to measure a full-coverage bathymetric strip with a certain width on the axis of the survey vessel's measuring line in a flat seabed as shown in Figure 1 and Figure 2. The coverage width W of the



multibeam bathymetric strip varies with the transducer opening angle θ and the water depth D . If the lines are parallel to each other and the seafloor topography is flat, the overlap between neighboring strips is defined as $\eta = 1 - \frac{d}{W}$, where d is the spacing between the two neighboring lines and W is the coverage width of the strip. Suppose $\eta < 0$, a missed measurement is indicated. In order to ensure the convenience of measurement and data integrity, the overlap rate between neighboring strips should be 10%~20%.

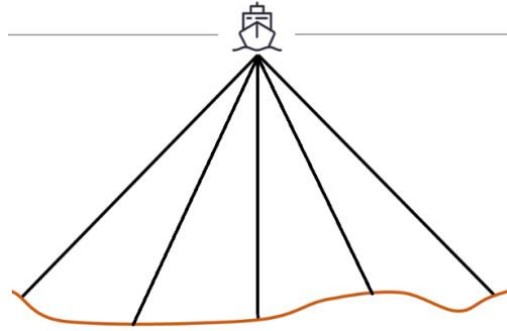


Figure 1. How multibeam bathymetry works

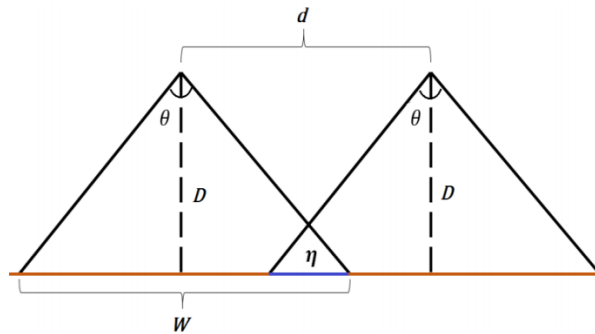


Figure 2. Relationship between W , d , and η

However, the real seabed topography is not flat and is often more complicated. Assuming that the intersection line between the plane perpendicular to the direction of the measuring line and the seafloor slope constitutes an oblique line with an angle α with the horizontal plane. In this case, the simplified schematic diagram of the multibeam bathymetry model is shown in Figure 3, where A and E are two neighboring beam emission points.

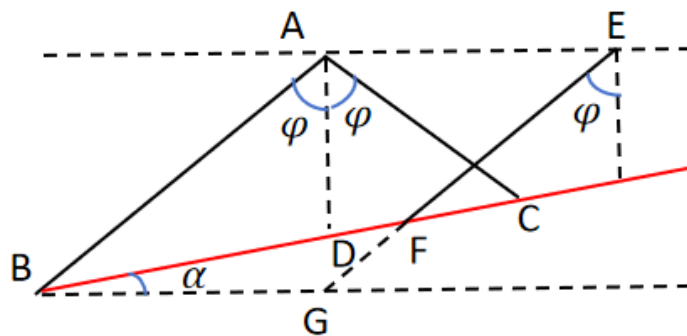


Figure 3. Simplified schematic of the multi-beam detection model

In Figure 3, the length of AD is the depth of the seawater, which will be denoted by H . And suppose, h_0 is the seawater depth at the center point of the sea area, b is the distance between two adjacent measuring lines, and n is the number of measuring lines from the center point. Then, according to the geometric relationship can have the equation (1).

$$H = h_0 - b \cdot n \cdot \tan \alpha \quad (1)$$

Next, based on the geometric relationship diagram shown in Figure 3, apply the sine theorem to solve for the length of BD in triangle ABD, and do the same to solve for the length of CD in triangle ACD, which are

$$l_{BD} = \frac{H \sin \varphi}{\cos(\alpha+\varphi)} \quad (2)$$

$$l_{CD} = \frac{H \sin \varphi}{\cos(\varphi-\alpha)} \quad (3)$$

The coverage width, which is the length of the projection of the BC line segment in Fig. 1 onto the plane, denoted as W, then we have

$$W = (l_{BD} + l_{CD}) \cos \alpha = \frac{H \sin \varphi [\cos(\alpha+\varphi) + \cos(\varphi-\alpha)]}{\cos(\alpha+\varphi) \cos(\varphi-\alpha)} \cos \alpha \quad (4)$$

Then the overlap rate can be calculated, which is

$$\eta = 1 - \frac{200 \cos(\varphi+\alpha) \cos(\varphi-\alpha)}{H \cos^2 \alpha \sin 2\varphi} \quad (5)$$

2.2. Practical application cases

Here in this study, the opening angle of the multibeam transducer is set to be 120° , the seafloor slope is 1.5° , and the depth of seawater at the center of the sea area is 70m. That is $\alpha = 1.5^\circ$, $\varphi = 60^\circ$, $h_0 = 70m$, $b = 200m$. Bringing the values of these parameters into equation (5), we get

$$\eta = 1 - \frac{200 \cos(60^\circ+1.5^\circ) \cos(60^\circ-1.5^\circ)}{(70-200n \tan 1.5^\circ) \cos^2 1.5^\circ \sin 120^\circ} \quad (6)$$

When the number of lines n from the center point is taken from -4 to 4, the distance of the line from the center point, the depth of the seawater, the coverage width, and the overlap rate with the previous line can be calculated for the corresponding position, as shown in Table 1.

Table 1. Depth of seawater, coverage width, and overlap rate at different locations

Number of measuring lines from the center point	-4	-3	-2	-1	0	1	2	3	4
Distance of the line from the center point/m	-800	-600	-400	-200	0	200	400	600	800
Depth of seawater/m	90.95	85.71	80.47	75.24	70	64.76	59.53	54.29	49.05
coverage width/m	315.71	297.53	279.35	261.17	242.99	224.81	206.63	188.45	170.27
the overlap rate/%	—	32.82	28.45	23.47	17.75	11.10	3.27	-6.06	-17.38

The relationship between n and seawater depth, coverage width, and overlap rate with the previous measuring line is obtained by making a function image of the calculation results using MATLAB, as shown in Figure 4.

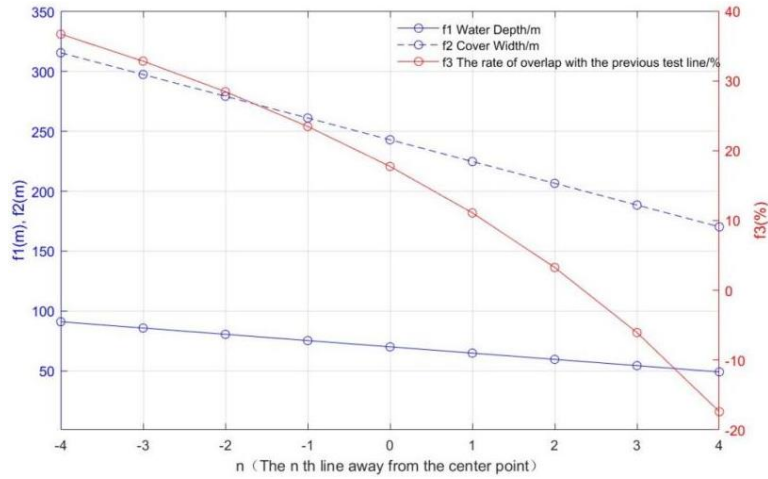


Figure 4. Schematic of the relationship between seawater depth, coverage width, and overlap rate

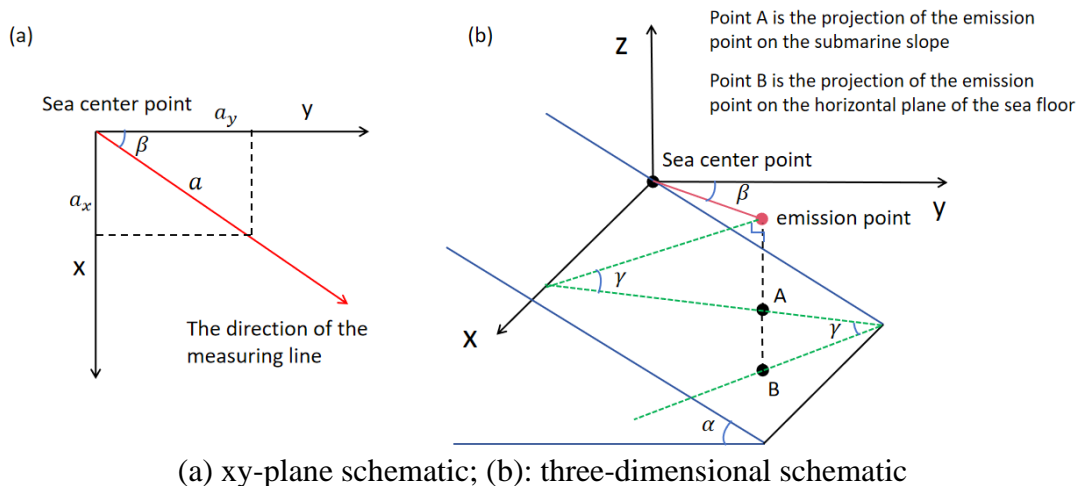
When the distance of the measuring line from the center point increases from -800m isotropically to 800m, the depth of seawater and the width of coverage are monotonically decreasing isotropic series. In the function image, it is shown as two straight lines with a slope less than zero.

The overlap rate with the previous measuring line is decreasing with the increase of n . Among them, since the position at -800m is the first line, there is no overlap with the previous line, so the overlap rate does not exist. When the distance of the line from the center is 400m, 600m, and 800m, the value of η is less than zero. The reason is that there is a problem of missed measurements at these points [8, 9].

3. Influence of Survey Ship Position and Line Angle on Coverage Width

Let the distance from the center of the sea area be a . Take the center of the sea area as the origin, and take the direction of the straight line parallel to the horizontal plane and form a slope angle α with the slope of the seabed as the y -axis direction, and the direction parallel to the horizontal plane and perpendicular to the y -axis as the x -axis direction. Decompose a along the x -axis and y -axis, and set the corresponding distance of each direction as a_x and a_y , respectively.

In order to simplify the model and facilitate the computation, we first consider the case that the measurement vessel is located in the first quadrant. The simplified schematic is shown in Figure 5.



(a) xy-plane schematic; (b): three-dimensional schematic

Figure 5. Schematic of the coordinate system

Let the change in height of the slope be h , then we have

$$h = a_y \cdot \tan \alpha = a \cdot \cos \beta \cdot \tan \alpha \quad (7)$$

Let the depth of the seawater be H , and the depth of the seawater at the center point of the sea be h_0 , then:

$$H = h_0 + h = h_0 + a \cdot \cos \beta \cdot \tan \alpha \quad (8)$$

Setting the angle formed by the beam breadth line and its projection in the horizontal plane of the seafloor to γ , then

$$\tan \gamma = \tan \alpha \cdot \cos(90^\circ - \beta) \quad (9)$$

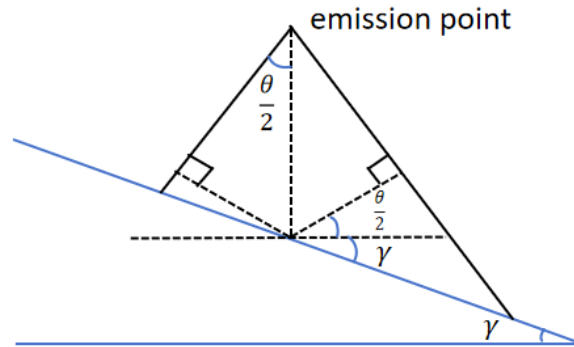


Figure 6. Section of the plane perpendicular to the measuring line

Denoting the coverage width of the multibeam detection as W and still, let θ be the transducer opening angle. Based on the geometrical relationship exhibited in Figure 6 and the above analysis, the coverage width calculation formula is

$$W = \frac{H \cdot \sin \frac{\theta}{2}}{\cos(\frac{\theta}{2} + \gamma)} + \frac{H \cdot \sin \frac{\theta}{2}}{\cos(\frac{\theta}{2} - \gamma)} \quad (10)$$

Table 2 shows the values of the coverage width at different measuring line direction angles and the distance of the survey vessel from the center point of the sea area, calculated according to the above formula [10, 11].

Table 2. Coverage widths at different locations

Coverage widths/m	The distance of the ship from the center sea point/nautical mile								
	0	0.3	0.6	0.9	1.2	1.5	1.8	2.1	
	0	415.69	466.09	516.49	566.89	617.29	667.69	718.09	768.48
	45	416.12	451.79	487.47	523.14	558.82	594.49	630.16	665.84
	90	416.55	416.55	416.55	416.55	416.55	416.55	416.55	416.55
measuring line direction angle/°	135	416.12	380.45	344.77	309.10	273.42	237.75	202.08	166.40
	180	415.69	365.29	314.89	264.50	214.10	163.70	113.30	62.90
	225	416.12	380.45	344.77	309.10	273.42	237.75	202.08	166.40
	270	416.55	416.55	416.55	416.55	416.55	416.55	416.55	416.55
	315	416.12	451.79	487.47	523.14	558.82	594.49	630.16	665.84

In order to visually show the effect of the direction of the measuring line and the distance between the ship and the center of the sea on the coverage width, the relevant three-dimensional scatter plot is drawn, as shown in Figure 7.

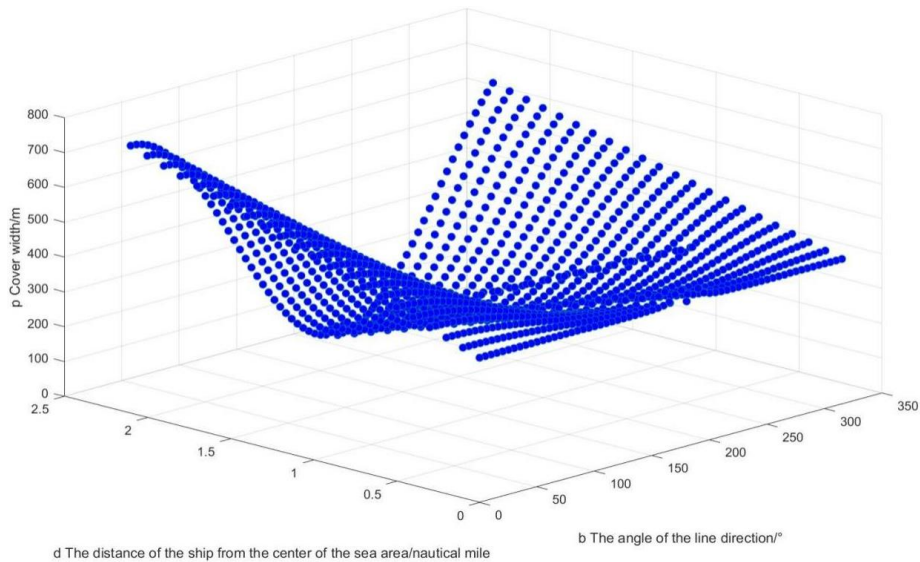


Figure 7. Three-dimensional scatter plot

For analysis, the cover width of the multi-beam detector increases when the ship moves to a deeper depth and the direction angle of the measuring line is fixed. However, when the distance from the measuring ship to the sea center is fixed and the angle of the measuring line gradually increases from 0, the coverage width shows a trend of decreasing first and then increasing.

4. Conclusion

This paper provides a research idea and framework for the field of ocean measuring field, proving the feasibility of the multiple beam detection method:

First of all, a plane geometric model based on the relationship between the coverage width and the distance between the measurement point and the center point is established to obtain the correspondence relationship between the seawater depth and the distance from the center point. At the same time, the influence of the slope on the coverage width is considered, and the mathematical model of the coverage width of the multiple beam depth and the overlap rate between adjacent bands is established.

On the basis of the above model, through the geometric relationship, the slope change γ along the coverage width direction along different line angles is obtained. Bring γ and the distance from the central sea into the model as parameters to obtain the coverage width in different angles of the line directions and different distances from the central sea.

Multi-beam detection systems are now widely used around the world to accurately map the seabed topography. Despite occasional interference from echo and noise that affect detection accuracy, scientists are constantly working to overcome these effects to further improve the accuracy of multi-beam detection.

References

- [1] Qiang Guo, Fu Chuanyu, Chen Yikang, et al. Application of multi-beam bathymetry system in shallow water area [J]. *Journal of Physics: Conference Series*, 2023, 2428 (1): 12042.
- [2] H-D Kim, Aoki S, Kim K-H, et al. Bathymetric Survey for Seabed Topography using Multibeam Echo Sounder in Wando, Korea [J]. *JOURNAL OF COASTAL RESEARCH*, 2020, 527-531.
- [3] Jie Liu, Zhang Qi, Wang Di. Building DBM and web services based on global multibeam bathymetry data [J]. *Hydrographic Surveying and Charting*, 2024, 44 (2): 14-17.
- [4] T-H Mohammadloo, Snellen M, Simons D-G. Assessing the Performance of the Multi-Beam Echo-Sounder Bathymetric Uncertainty Prediction Model [J]. *APPLIED SCIENCES-BASEL*, 2020, 10 (13).

- [5] Linjun Qi, Zhai Renjian, Li Anping. A Thinning Algorithm of Multibeam Sounding Data Considering Slope and Elevation [J]. *Journal of Geo-Information Science*, 2023, 25 (1): 142-152.
- [6] J-S Wang, Tang Y-L, Jin S-H, 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).
- [7] F-L Yang, Xu F-Z, Fan M, et al. An Intelligent Detection Method for Different Types of Outliers in Multibeam Bathymetric Point Cloud [J]. *IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING*, 2022, 60.
- [8] Z-Y Yuan, Zhao J-H, Li T. SVP Inversion for Weakening Multibeam Bathymetry Errors by Constraint of Check Line Depth [J]. *IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING*, 2023, 61.
- [9] K Zwolak, Marchel L, Bohan A, et al. Automatic Identification of Internal Wave Characteristics Affecting Bathymetric Measurement Based on Multibeam Echosounder Water Column Data Analysis [J]. *ENERGIES*, 2021, 14 (16).
- [10] Tian Zhou, Yuan Weijia, Du Weidong, et al. Autonomous data quality monitoring and depth gate control of multibeam bathymetric sonar [J]. *Journal of Harbin Engineering University*, 2024, 45 (5): 902-909, 921.
- [11] X-H Bu, Mei S, Yang F-L, et al. A Precise Method to Calibrate Dynamic Integration Errors in Shallow- and Deep-Water Multibeam Bathymetric Data [J]. *IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING*, 2022, 60.