Research On Dynamic Optimization of Multi-Beam Bathymetry Based on Computational Geometry

Yufan Rao *

School of Management, Tianjin University of Technology, Tianjin, China, 300382

* Corresponding Author Email: 18879483881@163.com

Abstract. The purpose of this study is to construct a mathematical model of the coverage width W and the overlap rate η between adjacent strips of multi-beam measurement by computational geometry method in the case of uniform slope of seabed topography, and to study the optimization of the channel line in the area to be measured. The purpose of this study is to construct a mathematical model of the coverage width W and the overlap rate η between adjacent strips of multi-beam measurement by computational geometry method in the case of uniform slope of seabed topography, and to study the optimization of the channel line in the area to be measured. By looking for the geometric relationship of the coverage width W, the mathematical model of the repetition rate η related to the coverage width W is obtained, and the data of seawater depth, coverage width and coverage rate η at different distances from the center point are calculated. Secondly, considering the change of the channel angle, the mathematical model between the offset angle ψ and the coverage width W of the aerial survey line is finally obtained. Finally, based on this result, the design of the shortest aerial survey line for sounding in the rectangular sea area to be measured is discussed. The arrangement of the main survey line needs to meet the requirements of the bar overlap rate index [1] In this study, a mathematical model is established for the problem of multi-channel angle sounding with slope topography. The relevant research results can be used for the subsequent research of more complex multi-beam sounding problems.

Keywords: Multi-beam sounding, mathematical modeling, geometrical relationship, trigonometric function, dynamic optimization.

1. Introduction

1.1. Background

With the advancement of technology, the degree of human exploration of the ocean has gradually increased, and the demand for exploration of seabed topography has also increased. Seabed topography is an important basic data for marine scientific research, marine engineering and military applications. Seabed topography measurement is an important part of seabed resource development and offshore planning [2]. It is a qualitative leap in marine exploration technology from measuring depth with hemp rope to drawing a three-dimensional seabed topographic map. The beginning of the turning point is the emergence of single-beam mapping technology. The application of acoustic wave technology has been iteratively optimized to multi-beam sounding system.

At present, the main sounding techniques used are single beam sounding and multi-beam sounding. The single-beam sounding equipment can only obtain a row of water depth points along the track direction of the measuring ship, and there is no water depth data in the water area between the routes, so it is impossible to achieve full coverage scanning of the seabed topography in the established sea area [3].In recent years, it has developed from the point-line measurement mode based on single beam to the full coverage measurement mode based on multi-beam, which greatly improves the measurement accuracy and efficiency [4]. However, in the real environment, there are many unstable factors such as the large difference in the ocean and the influence of waves on the route, which will cause errors in the interference of the multi-beam sounding system, resulting in missed or repeated measurements. In order to reduce the error in the measurement process, the measurement bandwidth of each two adjacent measurement routes will have a certain overlap area, and the coincidence rate η of this overlap area will be maintained in a certain interval.

1.2. Overview of the document

Multibeam sounding system is a popular underwater measurement technology at present. Different from four-beam sounding system and single beam sounding system, it is more efficient in bathymetry of seabed topography. It can not only obtain the depth values and three-dimensional maps of multiple seabed measurement points in complex geomorphological waters, but also measure the important waters such as harbors, berths, anchorages, and waterways from point to surface by loading positioning systems, attitude assistance systems, and computer processing systems. It is a widely used sounding system [5].

In recent years, the problem of multi-beam detection has been studied by many scholars. In the paper " Research on the application of multi-beam detection technology in seabed topography measurement, " Yang Chao proposed the application of seabed topography tracking algorithm based on unscented Kalman filter (hereinafter referred to as the algorithm in this paper). Through the optimization of tracking algorithm, the measurement accuracy and application performance of multi-beam detection technology are further improved [6]. Zhao Xianghong and Bao Jingyang proposed a multi-beam sounding anomaly data detection method based on two-dimensional empirical mode decomposition method for the difficulty of anomaly data detection in complex seabed topography [7].

The working principle of the multi-beam system is as follows: the transmitting array of the transducer emits a fan-shaped irradiated sound wave parallel to the track line and wide perpendicular to the track line to the bottom of the water, and the receiving array of the transducer also has a wide fan-shaped receiving area parallel to the track line and narrow perpendicular to the track line [8].

1.3. Research Purposes

The purpose of this study is to solve the following problems:

(1) Suppose that the complex topography of the ocean is idealized as a uniform slope with slope α, the aerial survey line is parallel to the slope plane, and the angle between the survey line direction and the projection of the normal vector of the seabed slope on the horizontal plane is 90 °.

It is assumed that the multi-beam transducer will scan the ocean with an open angle of θ and scan the ocean with equidistant aerial lines. The mathematical model of the coverage width of the sounding and the overlap rate between adjacent bands is established, and the coverage width d and the overlap rate η between adjacent bands of a series of specified position multi-beam sounding are calculated.

(2) Assuming that the sea area to be measured is rectangular, the direction of the ship survey line of the survey ship changes, and it is no longer perpendicular to the projection of the normal vector of the seabed slope on the horizontal plane. In the case of multiple aerial survey lines, the coverage width of the multi-beam sounding of the survey ship at different distances from the center of the sea area is studied, and the optimization of the aerial survey line layout of multi-beam sounding in a rectangular sea area is studied.

2. Research methods

2.1. Analysis of single direction measurement of measuring line

A series of geometric figures are formed in the detection range and submarine slope during the multi-beam detection of the central sideline and adjacent survey lines. According to these geometric relations, we can use the known conditions (slope α, water depth D) to express the coverage width W of multi-beam sounding and the overlap rate between adjacent strips, establish a mathematical model, and obtain the relationship between the two.

2.2. Multi-direction measurement analysis of measuring line

When the angle of the survey line changes, the coverage width W can be detected by multi-beam sounding. Considering that the single direction detection with the angle of 90 ° between the direction

of the survey line and the normal direction of the seabed slope on the horizontal plane is regarded as a special case after the angle of the survey line changes, that is, when the direction of the survey line is perpendicular to the slope plane, the mathematical model of coverage width W, slope α and seawater depth D is obtained. For this reason, we can change the direction of the survey line to construct a new submarine slope perpendicular to it, and record the new submarine slope angle as r, which can make the survey line in any direction in problem 2 adapt to a new submarine slope. Based on the model established in the unidirectional measurement, it is only necessary to convert the slope angle α in the original mathematical model into the value of the new slope angle r, and then calculate its coverage width.

Based on the references, the geometric analysis of the survey line, submarine slope and multi-beam detection coverage width in this problem is carried out. We believe that the angle between the direction of the survey line and the normal direction of the submarine slope is 90 ° on the horizontal plane, and the set of survey lines are parallel lines to each other, so as to meet the requirements of the shortest total measurement length under the condition of the problem setting.

3. Construction and analysis of the model

3.1. Establishment and solution of single-direction line measurement model

3.1.1 Establishment of the model

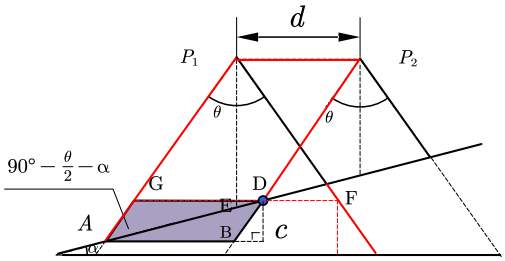


Fig. 1 Schematic diagram of multi-beam detection principle

(1) Establishment of water depth D model

The model is established with the center sideline and an adjacent sideline, as shown in the schematic diagram of the multi-beam detection principle in Fig.1, and the geometric relationship is analyzed. Different from the flat seabed, when considering the seabed slope α, the actual water depth D and the coverage width W will change with the slope α and the line spacing d. Let X be the distance between other survey lines and the central survey line. According to the geometric relationship:

$$D' = D - \tan\alpha \cdot X \tag{1}$$

(2) Establishment of coverage width W model

The core of the model is to solve the projection length L of the multi-beam on the slope, and the coverage width W is the projection length of L on the horizontal plane. Here, L is divided into L_1 and L_2 for solution. Since α and β are known, and the triangles formed by the multi-beam survey line range are isosceles triangles, it can be seen that:

$$\angle P_1AD = \frac{\pi}{2} - \frac{\theta}{2} - \alpha \tag{2}$$

Using the sine theorem, from the geometric relationship in Figure 1, we obtain:

$$L_1 = AE = D \cdot \sin\frac{\theta}{2} \cdot \frac{1}{\cos(\frac{\theta}{2} + \alpha)} \tag{3}$$

$$L_2 = EF = D \cdot \sin\frac{\theta}{2} \cdot \frac{1}{\cos(\alpha - \frac{\theta}{2})} \tag{4}$$

$$L_1 + L_2 = D \cdot \sin\frac{\theta}{2} \cdot (\frac{1}{\cos(\frac{\theta}{2} + \alpha)} + \frac{1}{\cos(\alpha - \frac{\theta}{2})} \tag{5}$$

Simplify to get:

$$L = \frac{2\cos\alpha \cdot \sin\theta \cdot D}{\cos 2\alpha + \cos\theta} \tag{6}$$

$$W = L \cdot \cos\alpha \tag{7}$$

$$W = \frac{2\cos\alpha \cdot \sin\theta}{\cos 2\alpha + \cos\theta}(D - X\tan\alpha)\cos\alpha \tag{8}$$

(3) Establishment of overlap rate η model:

Since the opening angle θ of the transducer does not change during the detection process, the quadrilateral P_1P_2GD is obviously a parallelogram, then there are:

$$GD = P_1P_2 = d \tag{9}$$

By the sine theorem :

$$\frac{d}{\sin(\frac{\pi}{2} - \frac{\theta}{2} - \alpha)} = \frac{AC}{\sin(\frac{\pi}{2} + \frac{\theta}{2})} \tag{10}$$

$$AC = \frac{d \cdot \cos\frac{\theta}{2}}{\cos(\frac{\theta}{2} + \alpha)} \tag{11}$$

$$W' = \frac{2\cos\alpha \cdot \sin\theta}{\cos 2\alpha + \cos\theta}(D - X\tan\alpha)\cos\alpha - \frac{d \cdot \cos\frac{\theta}{2} \cdot \cos\alpha}{\cos(\frac{\theta}{2} + \alpha)} \tag{12}$$

$$\eta = \frac{W'}{W} \tag{13}$$

3.1.2 The solution of the model :

A multi-beam transducer with an opening angle of 120 °, a slope of 1.5 ° , and a seawater depth of 70 m at the center of the sea area can be used to simulate the actual situation of the seabed topography as a slope. By using Matlab programming, the index values of the positions listed in table 1 are calculated by substituting the above model formula into the above model formula. The above formulas and data are obtained as follows:

Table .1. Calculation results of slope line single direction measurement model

The distance from the measuring line to the center point/ m	-800	-600	-400	-200	0	200	400	600	800
Seawater depth / m	90.9487	85.7116	80.4744	75.2372	70	64.7268	59.5256	54.2884	49.0513
Coverage width / m	315.7051	297.5256	279.346	261.1665	242.987	224.8074	206.6279	188.4484	170.2688
The overlap rate with the previous survey line / %	\	33.64	29.59	25	19.72	13.78	6.81	-1.39	-11.17

From the calculation results in Table 1, it can be seen that as the distance between the survey line and the center point is constantly changing, the coverage width and the overlap rate with the previous survey line are constantly changing. It can be seen that the single-direction multi-beam measurement with a projection angle of 90 ° between the survey line direction and the normal direction of the seabed slope on the horizontal plane cannot achieve the expected measurement effect well.

3.2. The establishment of multi-direction line measurement model

Establish an angle r with the new slope for the aerial survey line with a deflection angle of ψ, then the establishment of the model is regressed to the one-way measurement model model. The effect is shown in Figure 2:

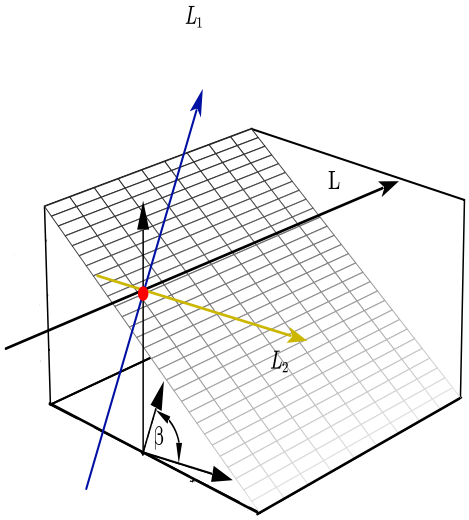


Fig. 2 New slope angle diagram

Establish slope r model:

The key to model establishment is to find the geometric relationship between the new slope r and the original slope α and the deflection angle ψ of the survey line. According to the knowledge of solid geometry, the intersection of a straight line and a plane, and the knowledge of trigonometric function operations, from Figure 3, we can obtain the quantitative relationship of a triangle with a new slope r:

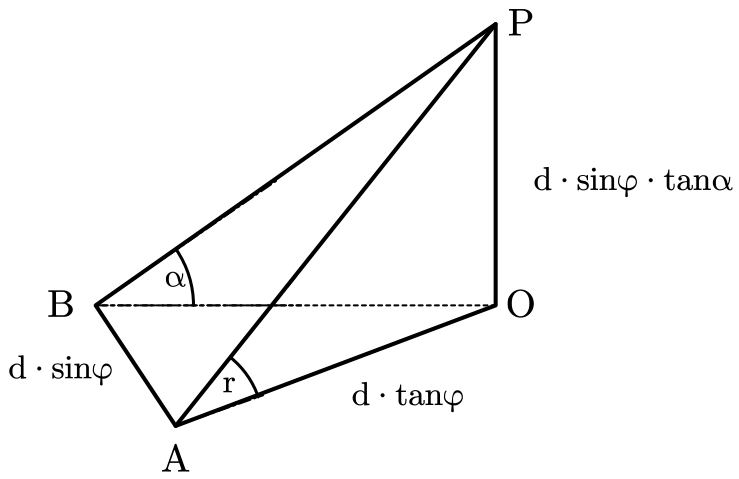


Fig. 3 The schematic diagram of the geometric relationship between r and α

$$\tan r = \cos\varphi \cdot \tan\alpha \tag{14}$$

$$r = \arctan(\cos\varphi \cdot \tan\alpha) \tag{15}$$

Then bring it into the mathematical model established before, and replace the original slope with the value of the new slope r, and find the coverage width, and get:

$$W = \frac{2\cos r \cdot \sin\theta}{\cos 2r + \cos\theta}(D - X\tan r)\cos r \tag{16}$$

4. Conclusion

In this paper, the mathematical model (formulas 8, 12, 13) between coverage width W and coverage rate η in multi-beam detection with submarine topography as slope is established by using the knowledge of computational geometry under ideal conditions. The measurement conditions of multi-directional survey lines are discussed, and the relevant mathematical model (formula 16) is obtained. The idea is clear, and the model is simple and easy to understand. For example, it is assumed that the opening angle of the multi-beam transducer is 120 °, the slope is 1.5 °, and the seawater depth at the center of the sea area is 70 m to simulate the actual situation of the seabed topography as a slope. The coverage width d and the overlap rate η between adjacent strips of multi-beam sounding at a series of specified locations (Table 1).

After analysis, the main factors affecting the measurement effect are the line spacing d and the line direction. When the distance d and of all aerial survey lines are determined, the group of aerial survey lines can be determined. The main survey lines in the sea area to be measured should be parallel, and the direction of the survey line should be consistent with the direction of the isobath. In this way, the coverage of the river bottom can be maximized, and the effective scanning width can be maintained within a certain range [9]. In the multi-beam measurement, the main survey line should generally be arranged in the direction of parallel contour lines [10]. Therefore, we believe that if we want to achieve the shortest total measurement length, the angle between the direction of the survey line and the normal direction of the seabed slope is 90 °on the horizontal plane, and the set of survey lines are parallel to each other.

Because the seabed terrain discussed in this paper is a slope with uniform change, however, the low-lying terrain in the actual measurement is complex, and the problem cannot be simply idealized. The model is no longer applicable, but the complex terrain can be decomposed into several ideal slopes by using the idea of integral after obtaining the actual seabed terrain data. In the face of huge

data and calculation, genetic algorithm, particle swarm optimization algorithm and other optimization algorithms are introduced to optimize the design of aerial survey lines.

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