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Research on Measurement of Multi-beam Transducer Based on Analytic Geometry Method

Haoxuan Xu[1, *], Fangyan Zhu[1, #], Chenghang Dai[2, #]

[1] College of electrical and power engineering, Taiyuan University of Technology, Shanxi, 030024, China
[2] College of chemistry, Taiyuan University of Technology, Shanxi, 030024, China

* Correspondending author: XuHaoxuan1105@outlook.com

#These authors contributed equally.

Abstract: The ocean is inseparable from the survival and development of human beings. It not only provides rich resources for human beings, but also provides a large number of samples for human scientific research. For the efficient development of the ocean, detailed and accurate seabed topography and geomorphology information is needed as a prerequisite. In this paper, aiming at the problem of multi-beam detection system detecting full coverage water depth strip in waterway, the measurement model of multi-beam transducer under different survey lines is established. Based on the combination of numbers and shapes, firstly, this paper considering the special situation that the survey line is perpendicular to the horizontal component of the normal of the seabed slope, it is concluded that the depth of seawater is positively correlated with the width of the survey line. Secondly, when the angle of the survey line is arbitrary, and the spatial rectangular coordinate system model is established, this paper considering the law of the width of the survey line at different angles and distances. Finally, through analytic geometry method, the measuring line equations at different positions and angles are expressed in this paper, and the measuring line width is quantified according to the distance formula between two points. The results show that the coverage width is unchanged at the center of the sea area or when the direction of the survey line is perpendicular to the horizontal component of the normal of the submarine slope. The coverage width is symmetrically distributed at the survey line angle. The results show that the multi-beam transducer measurement model is effective.

Keywords: Multi-beam transducer, Coordinate system, Analytic geometry.

1. Introduction

As a way to obtain hydrological environment elements, marine surveying is an important part of marine environment monitoring[1].Bathymetric mapping is traditionally implemented using ship born single-beam, multi-beam, and side-scan sonar sensors[2].In recent days, modern multi-beam echo sounder (MBES) techniques have made the conventional single-beam echo sounder (SBES) obsolete whereby, the use of MBES has greatly improved the accuracy, efficiency, and spatial resolution of coastal and ocean mapping[3].In many fields, due to its high-resolution imaging capability, MBES is widely used for seabed geomorphology surveying and scientific research with various purposes[4].The key of multi-beam detection system lies in the design of coverage width and overlap rate. However, in practical application, the real seabed situation is complex, so it is necessary to design the survey line interval according to the specific situation.If the spacing between survey lines is too narrow, although the resolution requirements of the seabed topography are met, it increases overwork and reduces operation efficiency; if the spacing between survey lines is too wide, it greatly reduces the resolution of the seabed topography and cannot guarantee the quality of the measurement results[5].In the more than 40 years of development of multi-beam sounding technology, wide coverage and high precision sounding performance have always been the focus and difficulty of multi-beam sounding technology[6].Therefore, the design and calculation of coverage width and overlap rate in actual detection is of great significance for detection.

In view of this kind of problem, some scholars have done relevant research work. Regarding the survey line, theoretical studies by a research group in China have indicated that the optimal survey line radius is $\sqrt{2}$ times the depth of the seafloor site, which is the radius when the smallest geometric dilution of precision (GDOP) is achieved[7].In a word, by reasonably selecting the line spacing of multi-beam measurement, can increase the overall accuracy of a bathymetric survey and provide additional oceanographic data about the study area[8].The high-resolution of the multi-beam bathymetric data allowed us to identify and analyse any submarine landslides with seafloor expression[9].

2. Establishment and Solution of The Model

First of all,analyze the model and establish the flow chart of the model,which is shown in Figure 1. The mind map of the model.

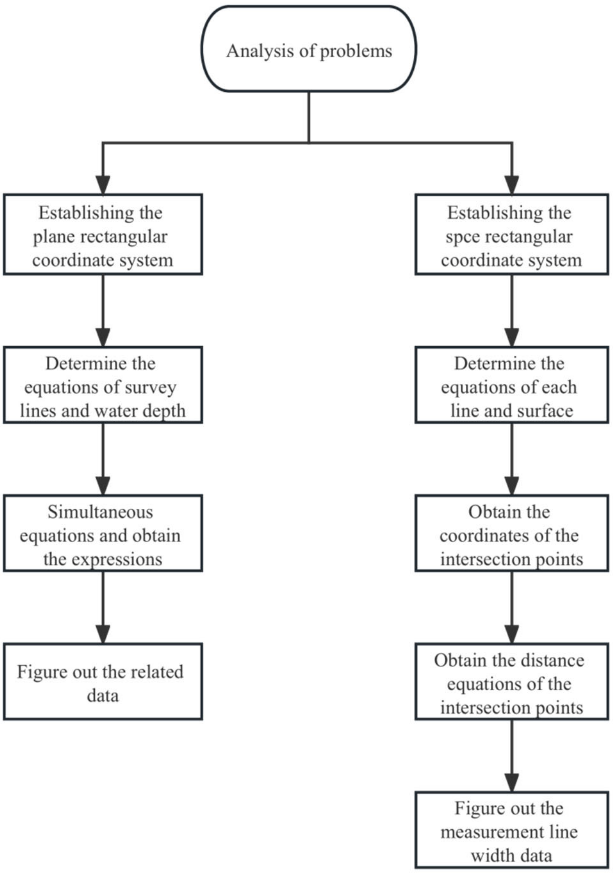

Figure 1. The mind map of the model

2.1. Construction of plane model based on analysis of measurement repetition rate, water depth and measurement coverage width at a fixed angle

Considering the special situation that the measuring direction is perpendicular to the horizontal component of the normal of the seabed slope, a plane rectangular coordinate system is constructed with the water depth of 70m at the center of the sea area as a reference. After the coordinate system is established, the interval between fixed survey lines is 200m, and the integer k is specified as the interval number, so that the measurement boundary equation can be obtained according to the position of the survey ship and the measurement opening angle y_{1k}; According to the distance formula between two points, the distance equation of the intersection point between the survey line and the seabed surface can be obtained d_{12k} . According to the above equation, the plane model of multi-beam transducer measurement can be constructed.

$$y_{1k} = 0.577(x - 200k) + 70 \tag{1}$$

$$y_{2k} = -0.577(x - 200k) + 70 \tag{2}$$

$$d_{12k} = \sqrt{(18.1894k - 242.9876)^\wedge 2 + (0.4766k - 6.3663)^\wedge 2} \tag{3}$$

2.2. Construction of solid geometric model based on analysis of coverage width measured by multi-beam transducer at any angle

For a more general case, the direction angle of the survey line is changed to an arbitrary value, and the spatial rectangular coordinate system is constructed with the water depth of 120m at the center of the sea as a reference. On the same survey line, the interval of each recording is fixed at 0.3 nautical mile, the interval number is expressed by integer k, and the direction angle of the survey line is β. Among them, write down the normal plane equation A of the survey line and the measurement plane equation B of the multi-beam transducer, determine the survey line equation of the ship according to the intersection relationship between the two sides, and finally obtain the survey line width according to the intersection point between the survey line and the seabed surface.

$$A\text{：} cos\beta(x - 555.6kcos\beta) + sin\beta(y - 555.6ksin\beta) = 0 \tag{4}$$

$$\text{B：} z = 120 - \sqrt{(x - 555.6k\cos\beta)^\wedge 2 + (y - 555.6k\sin\beta)^\wedge 2/3} \tag{5}$$

2.3. Solution steps of the model

Step one

Firstly, for the special case when the direction of the survey line is 90 degrees, the plane rectangular coordinate system is constructed, and the seabed equation is set, and the boundary equations of the transducer at different measurement positions are obtained. According to the equation of straight line and distance constructed in the plane model of multi-beam transducer, the measurement coverage width at different survey lines is derived w_k, seawater depth y_{dk} and measuring the overlap rate η_k, which are:

$$w_k = cos1.5° d_{12k} \tag{6}$$

$$y_{Dk} = -0.0262(kd_0) + 70 \tag{7}$$

$$\eta_k = 1 - (^{200}/_{W_d}) \tag{8}$$

Secondly, for the case that the direction angle of the survey line is arbitrary, the spatial rectangular coordinate system is constructed, and the boundary equations of the transducer in different positions, such as the seabed plane, different survey lines and their corresponding normal planes, are expressed. According to the plane intersection equation constructed in the solid geometric model of multi-beam transducer, the relationship between the measurement coverage width and β, k is:

$$\cos 1.5° * \frac{(415.70 sin\beta + 50.44k cos\beta sin\beta)}{(cos\beta)^2 + 0.9979(sin\beta)^2} * |sec\beta|, sin\beta \neq 0 \tag{9}$$

$$2\sqrt{3}(120 \pm 14.5567k), sin\beta = 0 \tag{10}$$
$$(\beta = 0° \ to \ add, \beta = 180° \ to \ subtract)$$

Step two

Combine the relevant data and substitute the data into the above formula. Using MATLAB software to make schematic diagram of the model,which is shown in Figure 2. Space rectangular coordinate system of the model,the solution program is compiled and the required results are obtained.

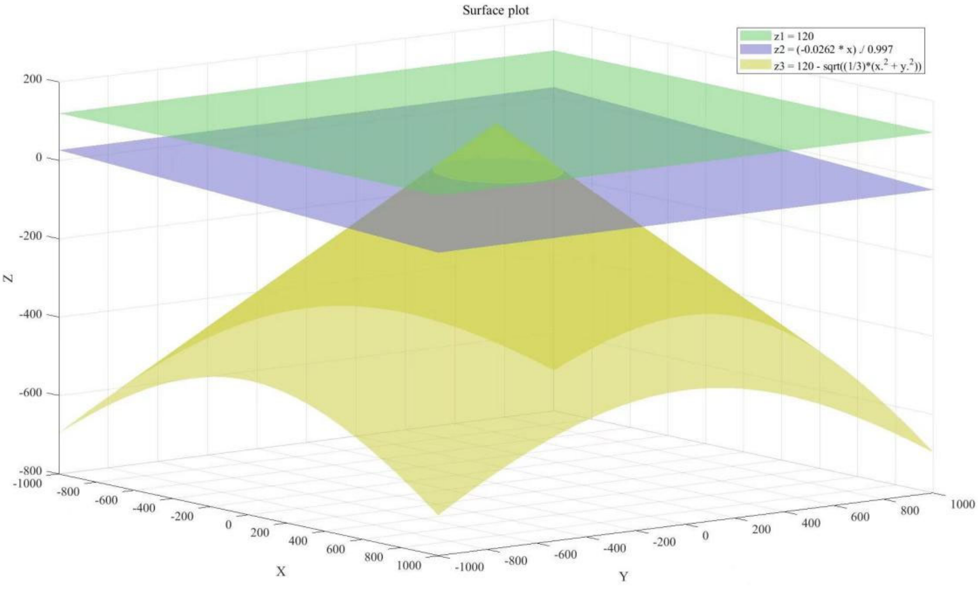

Figure 2. Space rectangular coordinate system of the model

3. Results Analysis and Discussion

Through the analysis and solution of the above model, the corresponding solution data in two cases are obtained and recorded in Table 1. The measurement table of each indicator when the direction angle of the survey line is 90°; Table 2. The coverage width of the survey line in different measurement positions and arbitrary direction angles.

Table 1. The measurement table of each indicator when the direction angle of the survey line is 90°

The distance between the measuring line and the center point/M	-800	-600	-400	-200	0	200	400	600	800
Sea depth/M	90.95	85.71	80.47	75.24	70	64.76	59.52	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
Overlap rate with the previous line/%	——	36.71	32.78	28.40	23.42	17.69	11.04	3.21	-6.13

Table 2. The coverage width of the survey line in different measurement positions and arbitrary direction angles

Coverage width/M		The distance between the survey-vessel and the center point of the sea/NMI							
		0	0.3	0.6	0.9	1.2	1.5	1.8	2.1
The angle between different measuring line directions/°	0	416.00	465.74	516.15	566.50	616.89	667.20	717.59	767.97
	45	416.00	451.69	486.26	523.07	558.29	593.95	629.61	665.27
	90	416.00	416.00	416.00	416.00	416.00	416.00	416.00	416.00
	135	416.00	379.98	344.61	308.92	273.23	237.54	201.84	166.15
	180	416.00	365.17	314.79	264.41	214.02	163.63	113.26	62.85
	225	416.00	379.98	344.61	308.92	273.23	237.54	201.84	166.16
	270	416.00	416.00	416.00	416.00	416.00	416.00	416.00	416.00
	315	416.00	451.69	486.26	523.07	558.29	593.95	629.61	665.27

According to the data obtained in Table 1, it is observed that the measurement coverage width and measurement repetition rate gradually increase with the increase of water depth. At the distance of -600 to 0 m from the center point, the repetition rate of measurement reaches more than 20%. At the distance of 800 m from the center point, the repetition rate of measurement is below 0%, resulting in missing measurement; According to the data obtained in Table 2, a fixed angle is observed, and the deeper the water is along the survey line, the wider the coverage is. The shallower the water, the smaller the coverage width of the survey line; The depth of water is unchanged, and the coverage width of survey line is basically unchanged. When the distance from the midpoint is fixed, the coverage width of the survey line first decreases and then increases with the increase of angle. The conclusions obtained from the above analysis are consistent with the actual phenomenon, which shows that accurate results can be obtained by using this model under the conditions of low measurement accuracy or ideal actual situation.

4. Conclusion

First of all, this paper starts from a simple situation and adopts the method of combining numbers and shapes, which is intuitive and easy to understand. Secondly, according to the results of this paper, combined with the actual situation, the accuracy of the model in a certain range is proved, which is suitable for some actual situations. However, because the situation considered in this paper is too simple, there are some limitations in solving complex seabed topography, and at the same time, there will be great errors. In view of the above limitations, the model established in this paper can introduce more variables and correct the offset according to the actual situation, improve the practicability of this model in general cases, and make a more accurate determination of seabed topography.

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