The study of the direction of navigation of ships in a particular sea area

Yitong Wang[1, *], Ziyi Lu[1], Dihao Ma[1], Zixin Yang[2]

[1]Department of communication engineering, Xi'an University of Posts and Telecommunications, Xi'an, 710100, China

[2]Department of electronic engineering, Xi'an University of Posts and Telecommunications, Xi'an, 710100, China

* Corresponding Author Email: 13313321443@163.com

Abstract. Multibeam bathymetric system is a further development of single-beam bathymetric system, which can send and receive hundreds of beams at the same time during the working process, and carry out full-coverage bathymetric strip measurements in the smooth sea area on the seabed. In this paper, we model the coverage width and the overlap rate to further reduce the errors occurring in the measurement process, and at the same time, we design a scheme for the given data and constraints to solve the practical problems. The process analysis facilitates the practical application of multibeam bathymetry system, improves the problems of failing to achieve the full coverage of the sea area and the high overlap rate, and provides a new idea for the seabed detection of multibeam bathymetry.

Keywords: Multi beam bathymetry, Full coverage water depth strip, Sine theorem, Overlap rate analysis.

1. Introduction

Single-beam bathymetry is a technique for measuring the depth of a body of water by utilizing the propagation characteristics of acoustic waves in water. The principle is that the acoustic wave in a uniform medium for uniform linear propagation, reflections at different interfaces, from the measurement of the ship transducer vertically to the seabed transmitting acoustic signals, and record the propagation time from the acoustic wave emission to the signal received by the acoustic wave propagation speed and time of propagation in seawater calculated by the depth of seawater[1].Because the single-beam bathymetric process takes a single continuous measurement, the distribution of the bathymetric data is characterized by very dense data along the trajectory and no data between survey lines.

With the national emphasis on the development of marine resources increasing year by year, the status of marine resources detection is rising. However, single-beam bathymetry has the disadvantages of low accuracy, low efficiency, low resolution[2] , and susceptibility to underwater obstacles [3].Therefore, in order to reduce the inconvenience caused by single-beam bathymetry, the study of multibeam bathymetry systems is rapidly becoming a hot topic nowadays. Since the system can emit as many as several hundred beams at a single time on its course, it can measure the water depth strip with a certain width as the centerline of the ship's course, then its coverage width can be derived.

2. Components and principles of multibeam bathymetric systems

2.1. Components of a multibeam bathymetric system

Multibeam bathymetric system is actually a complex combination of multi-sensor system, which is a high degree of integration of modern signal processing technology, high-performance computer technology, high-resolution display technology, high-precision navigation and positioning technology, digital sensor technology and other related high-tech and other technologies.

A typical multibeam system shall consist of three subsystems[4] (as shown in figure 1):

①The multibeam acoustic subsystem consists of a multibeam transmitter-receiver transducer array (sonar probe) and a multibeam signal control processing electronic system;

② Auxiliary equipment:DGPS differential satellite positioning system to provide geodetic coordinates, attitude sensors to provide attitude data such as transverse rocking, longitudinal rocking, bowing, lifting and sinking of the measuring vessel, tide gauges to provide tide level data in the measured sea area, and sound velocity profilers to provide information on sound velocity profiles in the measured sea area, and so on;

③Data post-processing software (typically such as Hypack) and related software and data display, output, and storage equipment).

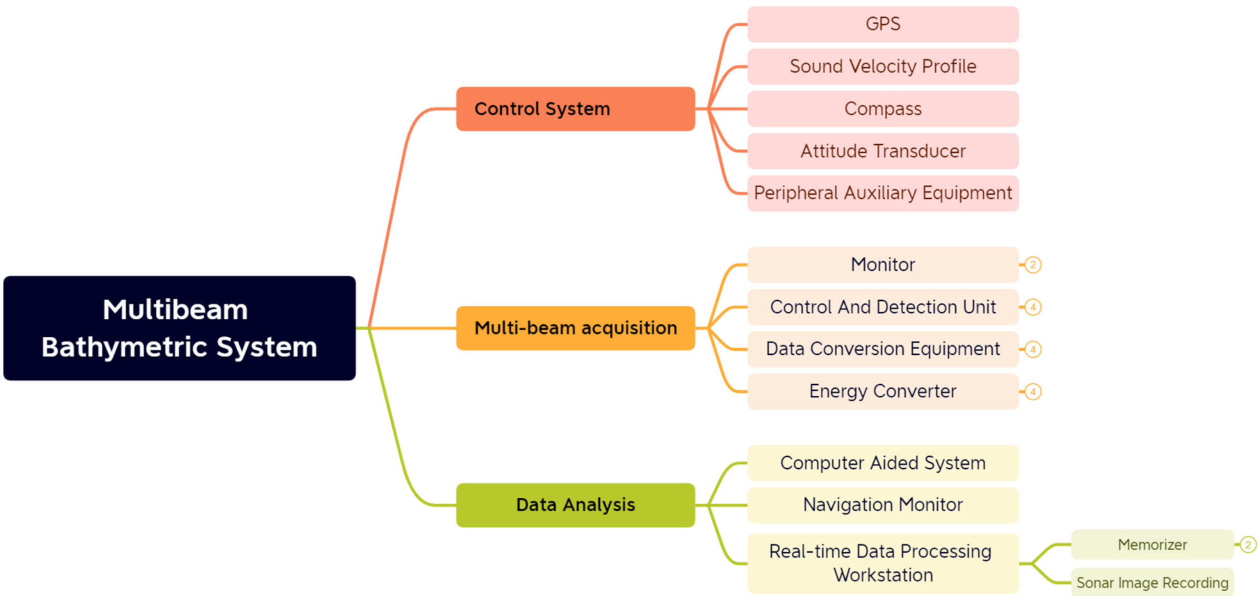

Figure 1. Composition of multi beam system

2.2. Principles of multibeam bathymetric systems

The working principle of the multibeam bathymetric system is to use the transmitting transducer array to transmit wide sector coverage of acoustic waves to the seabed, and use the receiving transducer array to receive the acoustic waves with narrow beams, and then form the irradiated footprints of the seabed topography through the orthogonality of the pointing of the transmitting and receiving sectors, and then, through the proper handling of these footprints, a single detection can give the bathymetric values of hundreds or even more seabed points to be measured in the vertical plane perpendicular to the heading direction[5], so as to be able to accurately and rapidly measure the size, shape, and height change of the underwater targets along the course of a certain width and to relatively reliably depict the three-dimensional characteristics of seabed terrain[6]

Multibeam bathymetric systems were developed on the basis of single-beam bathymetric surveys and were originally designed to improve the efficiency of seafloor topographic surveys. Compared with the traditional single-beam bathymetric system, which can only obtain one seafloor measurement depth value vertically below the survey vessel for each measurement, multibeam sounding can obtain the seafloor depth values of multiple measurement points in a strip-covered area, which realizes the leap from point-to-line measurement to line-to-plane measurement. .At the same time, multibeam bathymetry has a small overlap rate to ensure the accuracy and completeness of the measurement, the schematic diagram is shown in Figure 2[7].This paper mainly discusses the requirements for the degree of coverage and overlap rate of the sea area to be surveyed by the multibeam bathymetric system under different sea conditions, as well as the design of the survey line of the survey vessel under the given conditions.

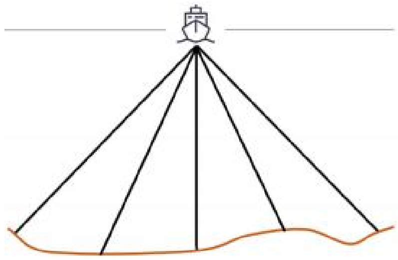

Figure 2. Principle of operation of multibeam bathymetry
(Multiple independent beams hitting the seafloor)

2.3. Precautions for the application of multi beam detection system

①The transducers need to be installed in a location with low noise, minimal bubble generation, and close to the center of the hull. They should be securely fixed for long-term use. The attitude sensors should be installed in a position that can accurately reflect the attitude of the multibeam transducers or the survey vessel. Their orientation should be parallel to the bow-stern line of the vessel.

②After establishing the ship coordinate system, the offset of each supporting equipment from the origin should be measured multiple times with an accuracy of 1cm. The average value of these measurements should be taken as the measurement result.

③The survey lines should be laid out parallel to the contour lines or the direction of the currents, with spacing not exceeding 80% of the effective swath width. In important water areas, the spacing should be further reinforced and preferably not exceed 50%. The ends of the survey lines should be extended appropriately to ensure that the equipment on the ship is in a stable state when going on-line. Strict control of ship speed is also necessary to ensure the accuracy and reliability of the measurement data.

④Due to the large amount of data collected by the multibeam system, it is necessary to adjust the transmission frequency in real-time and filter out unnecessary false signals during the measurement period according to the needs.

⑤There is a significant correlation between the accuracy of depth measurement and the surface sound velocity. It is recommended to install a surface sound velocity sensor during the usage, or alternatively, measure the surface sound velocity separately and input it into the 7K control center.

⑥The system is susceptible to interference from frequencies and harmonics close to the depth sounder signals, resulting in more false signals. Therefore, it is recommended not to perform synchronous operations with single-beam sonars during measurements to avoid mutual interference and ensure data quality[8].

3. Modeling and Solving

In order to solve the problem of measuring the depth of the water in the sea and the direction of navigation of the survey ship in a certain sea area, the installation of multibeam bathymetric system on the ship can transmit dozens or even hundreds of beams at a time in the plane perpendicular to the trajectory, and then by the receiving transducer to receive the acoustic wave returned from the seabed to measure the measurement of the ship's measurement line as the axis of a certain width of the full-coverage of the water strips, but in order to ensure that the sea area is detected by all the direction of the survey ship needs to be controlled to enable the overlap of the two neighboring full-coverage of water strips to maintain the overlap rate of between 10% -20%.Due to the large changes in seabed topography, if the line spacing is designed at the average depth of the sea, although the average overlap rate between strips can meet the requirements, there will be missed measurements at shallower depths, affecting the quality of the measurement; if the line spacing is designed at the shallowest depths of the sea, although the overlap rate at the shallowest depths can meet the requirements, there will be excessive overlap at deeper depths, resulting in a large amount of redundancy in the data, which will affect the efficiency of the measurements.

For the rectangular sea area to be measured (as shown in the figure 3), if the direction of the measurement line and the normal direction of the seabed slope projected on the horizontal plane of the angle of β, the multibeam transducer opening angle of $120°$, the slope of $1.5°$, the depth of seawater at the center of the sea area is 120[9], the measurement of the ship each time to travel a distance of 0.3 nautical miles, the establishment of a mathematical model to explore the width of the coverage of the multibeam bathymetry.

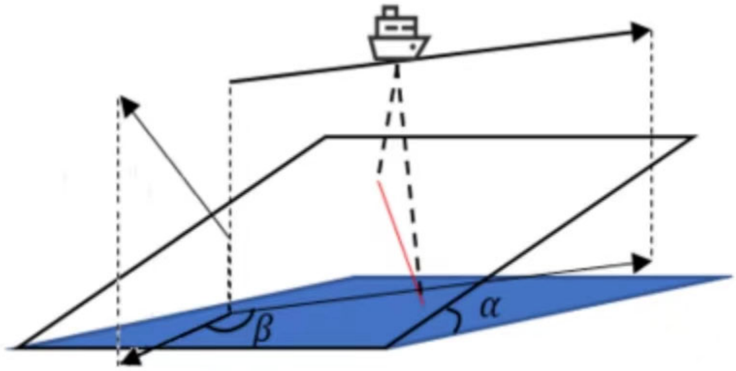

Figure 3. Rectangular sea area to be surveyed

In the first case, $0°$is either $0°$or $180°$, dividing the ship into the direction of the survey line and the direction of the antilaterals, and drawing Figure 4.

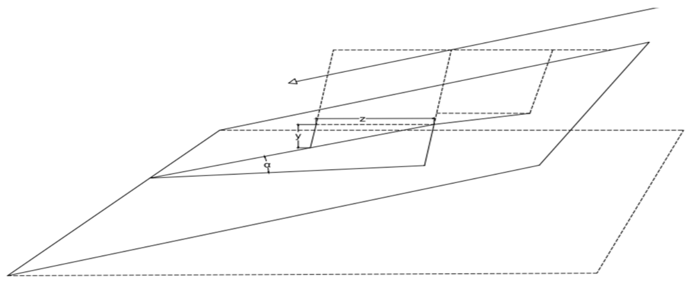

Figure 4. Schematic diagrams at $0°$or $180°$

As shown in the figure, along the direction of the arrow is $0°$direction, the depth of the sea water at the center of the sea area is $120m$, recorded as D_0, at this time the increase or decrease in the depth of the following formula can be calculated as follows.

$$y = z \tan \alpha \tag{1}$$

Corresponding to the current depth of the sea at this time:

$$D = D_0 + y \tag{2}$$

The data in the table were first preprocessed for unit conversion, and the bathymetric coverage width model was schematized and formulated as shown in figure 5.

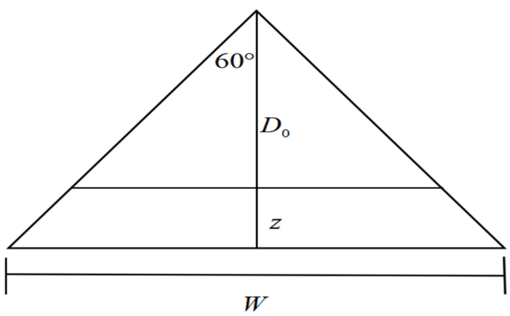

Figure 5. Schematic diagram of depth measurement coverage width

$$W = 2D\, tan\frac{\theta}{2} \tag{3}$$

That is to say, it is calculated that the width of bathymetric coverage is 415.6922 meters when the angle of the direction of the survey line is 0°and the distance of the ship from the center of the sea area is 0 nautical miles, and 466.0911 meters when the distance is 0.3 nautical miles, and so on and so forth, and then Fill in the required data in Table 1.

In the second case, the modeled bathymetric coverage widths for β of 45°, 135°, 225°, and 315° are shown in Figure 6.

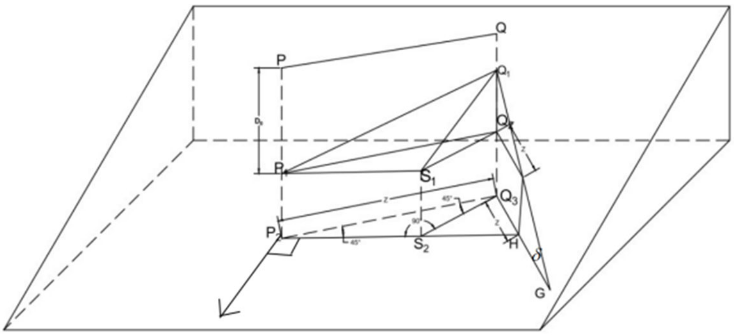

Figure 6. Schematic at 135°

PQ is the direction of the ship sailing on the sea surface, do P_2Q_3 parallel to PQ, at P_2 along the direction of the slope leads to the coordinate axis for the projection of the normal vector of the seabed slope, and P_2Q_3 angle of P_2Q_3, that is, $\angle Q_3P_2S_2$ is 45°. Move $\Delta Q_3P_2S_2$ parallel, and the slope to form a trigonometric cone $Q_1 - Q_2P_1S_1$, known as P_2Q_3 for the ship's distance from the center of the sea, then in the $\Delta Q_3P_2S_2$ in Q_3S_2 for $z\, sin45°$by the triangle where $\angle Q_1S_1Q_2$ is located and the slope angle of the triangle where the existence of a similarity between the relationship between the angles of the triangle, resulting in the angle and the slope angle of the same as 1.5°. S_1Q_2 for $z\, sin45°$, then to find the drop or Ascending depth Q_1Q_2 is $z\, sin45° tan1.5°$,then the boat distance from the center point of the sea at the distance is:$Q_1Q = D_0 - Q_1Q_2$,from the figure can be obtained ΔQ_1Q_3G has a similar small triangles, that is, the slope angle with the boat travel change:

$$tan\,\delta = \frac{Q_1Q_2}{z} \tag{4}$$

$$\delta = arctan\frac{Q_1Q_2}{z} \tag{5}$$

Find the slope angle δ. At this point, find the width of the bathymetric coverage as shown in Figure 5.

From the above analysis a generalized formula for δ is obtained.

$$\delta = arctan[|sin(\pi - \beta)|tan\alpha] \tag{6}$$

$$y = [z \times sin(\pi - \beta)tan\alpha \times 1852] \tag{7}$$

$$D = D_0 \pm y \tag{8}$$

When the measuring line angle of 45°, 315°, the measurement of the ship downhill, (8) type to take the positive sign; when the measuring line angle of 135°, 225°, the measurement of the ship against the slope, (8) type to take the negative sign.

According to Figure 7, $\gamma_1 = 30° - \delta, \gamma_2 = 90° + \delta, \gamma_4 = 30° + \delta, D = 120m$,the width of the bathymetric coverage is modeled from Problem 1, and the sine theorem is applied to find the length of the base of the triangle.

$$\frac{l_{11}}{sin60^\circ} = \frac{D}{sin\,\gamma_1} \tag{9}$$

$$\frac{l_{12}}{sin60^\circ} = \frac{D}{sin\,\gamma_4} \tag{10}$$

$$l_{11} + l_{12} = D \times sin60^\circ \times \left(\frac{1}{sin\,\gamma_1} + \frac{1}{sin\,\gamma_4}\right) \tag{11}$$

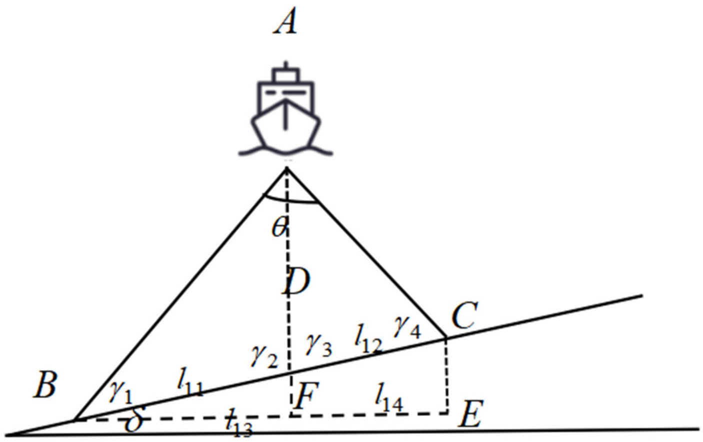

Figure 7. Change the depth measurement coverage width at the foot of the slope

This yields a bathymetric coverage width.

$$W = (l_1 + l_2) \times cos\,\gamma \tag{12}$$

When the survey vessel is 0 nautical miles from the center of the sea area and the angle of the survey line is 135°, the width of the bathymetric coverage is $416.1202m$, and when it is 0.3 nautical miles, the width of the bathymetric coverage is $380.4461m$, and so on and so forth, and then fill in the table with the calculated data.

When the angle of the measuring line is 90° or 270°, the coverage width is constant.

$$W = 120 \times sin60^\circ \times \left(\frac{1}{sin28.5^\circ} + \frac{1}{sin31.5^\circ}\right) \times cos1.5^\circ \tag{13}$$

Find the constant value of 416.5491m. Enter the data in Table 1.

Table 1. Calculation results of depth measurement coverage width

Bathymetric coverage width/m	0	0.3	0.6	0.9	1.2	1.5	1.8	2.1
0°	415.692	466.091	516.490	566.889	617.288	667.687	718.085	768.484
45°	416.120	451.794	487.468	523.142	558.817	594.491	630.165	665.839
90°	416.549	416.549	416.549	416.549	416.549	416.549	416.549	416.549
135°	416.120	380.446	344.772	309.098	273.424	237.750	202.076	166.402
180°	415.692	365.293	314.895	264.496	214.097	163.698	113.299	62.900
225°	416.120	380.446	344.772	309.098	273.424	237.750	202.076	166.402
270°	416.549	416.549	416.549	416.549	416.549	416.549	416.549	416.549
315°	416.120	451.794	487.468	523.142	558.817	594.491	630.165	665.839

The third case: is any angle other than the first case and the second case. The distance of the measuring ship from the center of the sea area is 0 nautical miles, and the mathematical model in the second case is used to investigate the size of the bathymetric coverage width under the known distance of the measuring ship from the center of the sea area and the angle of $1^\circ - 89^\circ$ in the direction of the measuring line, which is simulated using Matlab software and plotted in the following figure 8.

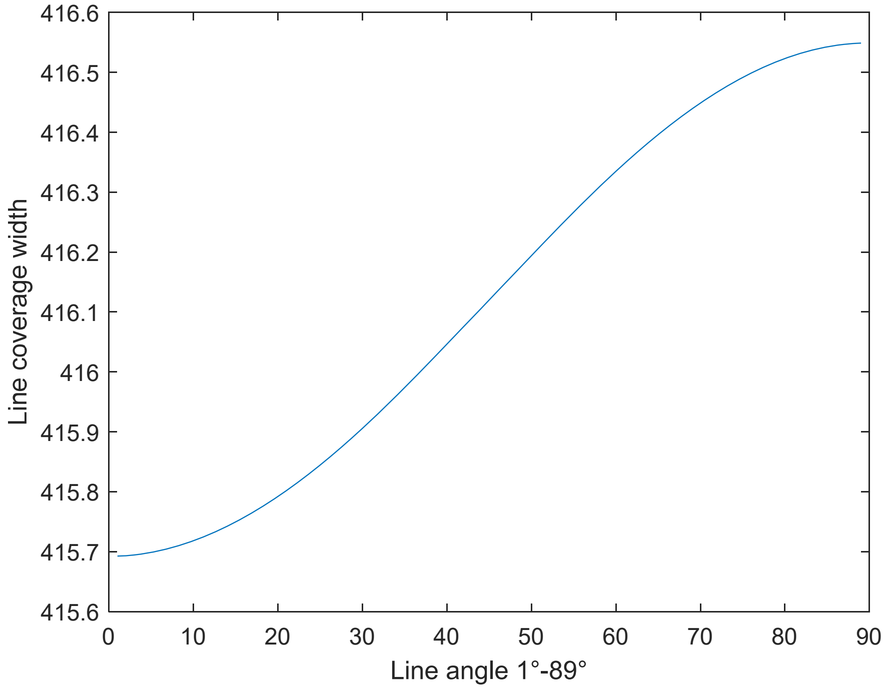

Figure 8. Depth measurement coverage width maps from different angles

By comparing and analyzing the above results, it is found that the other angles of the survey line direction of the survey vessel, except 90°and 270°, will result in missed measurements or excessive overlapping, which will affect the efficiency of the measurement. Therefore, it is concluded that the best sailing direction of the survey vessel should be 90°or 270°, the sailing direction of the survey vessel should be parallel to the seawater isobath.

4. Conclusion

Through this research, it can be concluded that using a multibeam detection system for data collection and analysis can quickly and efficiently obtain the desired results, and is in line with the current development of technological devices. With accurate analysis results, we can visually determine the water depth and navigation direction in the measured sea area.

The multibeam detection system is an efficient method for underwater terrain collection and depth measurement. With the integrated development of multibeam technology, its usage is becoming more and more widespread. Additionally, due to strong support from the government in this field, more and more enterprises are recognizing the importance of multibeam detection. This has led to continuous improvements in measurement accuracy and decreasing prices of multibeam devices, laying a solid foundation for the development of multibeam depth measurement systems[10].

References

[1] Xiao J. Application of intelligent unmanned ship single-beam depth measurement system in underwater terrain measurement[J]. Surveying and Mapping Engineering, 2023, 32(01): 63-70.

[2] Wang M, Zhou G, Chen N, et al. Research on high-resolution multibeam measurement scheme[J]. Water Resources and Hydropower Engineering (English Edition), 2021, 52(S2): 385-389.

[3] Zhang T, Qin S, Tang J, Wang X. Status quo and prospect of deep-water multibeam depth measurement system[J]. Bulletin of Surveying and Mapping, 2018(05): 82-85.

[4] Yuan J. Research on sound speed correction of multibeam depth measurement system for underwater terrain measurement[J]. Geomatics & Spatial Information, 2019, 42(12): 211-213.

[5] Dong Yu. Research on the Application of Multi beam Sounding System in Ocean Channel Surveying [J]. Engineering Technology Research, 2023,8 (15): 122-124.

[6] Hu H. Research on adaptive sound speed correction model and method for multibeam depth measurement[D]. Jinan: Shandong University of Science and Technology, 2019.

[7] Zhou Xiangyun. Error Analysis of Multi beam Sounding System and Application of Sound Velocity Correction Model [J]. Jingwei Tiandi, 2023 (02): 13-16.

[8] Zhou F, Zhao J, Zhou C. Determination of the optimal sound speed formula for multibeam depth measurement system[J]. Journal of Applied Oceanography, 2001, 20(4): 411-419.

[9] Zhang Chuqi. Application of Multibeam Sounding System in Bathymetric Survey of North Port of Hainan Port [J]. Journal of Ezhou University, 2022,29 (05): 103-105

[10] Liu Jingnan, Zhao Jianhu. The Status and Development Trends of Multi beam Sounding Systems [J]. Ocean Surveying and Mapping, 2002 (05): 3-6