TELKOMNIKA, Vol. 11, No. 8, August 2013, pp. 4306~4316
e-ISSN: 2087-278X

Detection Parameters Design for Compound Survey Seafloor Targets by Multibeam Sonar

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Abstract

Swath bathymetry system surveys with wide swath, high location resolution, and is used to detect sea bottom terrain. But the object resolution detected decreases as the depth increasing, its data processing with high mistake, used rarely in sea floor object survey.So GeoSwath, a multibeam sonar does. Although it covers an angular range of -120°to 120 °from the vertical direction, providing high density and high quality bathymetry data along with side scan like amplitude imagery, the data processing is more relied on human intervention to get accurate depth contour and sonar image which prevent its propular use in survey of seafloor targets. The purpose of this article presents survey parameter setting during survey and data processing technique to survey seafloor target by GeoSwath system, which set the proper detect parameters including ping length, ship velocity to increase the points over targets, setting navigation line parallel to the maximum dimension of target during survey, adopting appropriate filter to depth data processing and using TVG control over amplitude data to get accurate depth grid and sonar image of seafloor target. Finally, the way is used to measure the artificial object in harbor and two ship wrecks at sea, compound with the sonar image taken by the forward looking sonar, to search the ship wreck near harbor, to help to recognize the targets and locates its real position. This technology improves GeoSwath survey capability with compound detection and is helpful for make precise map for waterway. Also this work is helpful to achieve detecting seafloor objects fast, accurately, effectively in underwater large scale area during salvation and rescue task.

Keywords: *multibeam sonar, seafloor target, detection parameters, data processing*

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1. Introduction

It is important to detect seafloor target fast and accurately in large scale area in urgent salvage task, especially for the shipwreck, for it may be a latent risk of pollution representing a serous risk for marine environment or it may be dangerous to other ship navigation if it sunk in the limited depth waterway. Acoustic system such as side scan sonar, echo sounder or multi beam sonar [1, 2] can be used to measure acoustical information from targets utilized for detection and classification. Among many acoustic sytems, multibeam system, commonly used for bathymetric purpose started in the 1970s, their potential for seafloor characterization from acoustic reflected energy measurements has emerged mostly in the last two decades [3-6] due to provide more data every ping along ship track. A number of different approaches to characterization via backscatter have been developed [7-11], with the primary aim of acoustic segmentation to get the clear outline of target.

But less is on how to improve data acquisition quality over target which may result in poor data to process or no data coverage over target. Although a few results from research have been published, they have not be evaluated by sail. For example, Reference [12] derived the spatial resolution model of Seabat8101 multi beam bathymetric system and get maximum speed and the range of bathymetric coverage for different water depth by quantization according to full coverage standards defined by the International Hydrographic Organization. Refference [13] analyzed that beam coverage footprint is like a trapezoid and studied its feature along the changes of the ship attitude, which give a great help in real multi beam bathymetric error analysis, accuracy and target identification. But in situ investigations how to decide the relation inside the ship velocity, the swath width and the object size is even less well

Received January 23, 2013; Revised May 10, 2013; Accepted May 20, 2013

documented, some only give results about the maximum velocity about different multi beam [14]. To get acoustic information of target out of that of seafloor, it is not only reply on data processing ,but also on how to get effective data. This paper uses GeoSwath, a multi beam echo sounder, a seafloor mapping system in shallow water of which a single swath covering an angular range of -120° to 120° from the vertical direction, with maximum 12 swath width vs. depth, to survey seafloor target. GeoSwath's chapability to get lots of data every ping and wide swath is attactive for surey seafloor target in large scale area fastly in urgent salvage task. But up to now it is commonly used in seafloor mapping in different depth, but less used in survey seafloor target. These issues will be discussed in this paper.

2. Research Method

2.1. GeoSwath Multi Beam System

The GeoSwath, from GeoAoustics Ltd, operating as a frequency of 250kHz, is a phase measuring bathymetric sonar. Compared with conventional multi beam system, it can not only offer simultaneous swath bathymetry and side scan seabed mapping, but also with wider transmission angle. The nominal apex angle is 0.9° along track and 0.5° across track during receiving with an effective 0.9°×0.5° per single beam arranged with some overlap over an arc of 240°. GeoSwath is easily portable and deployed using an over side mount on vessels of opportunity or a hull mount for more permanent installation, getting wide swath bathymetry over seafloor.

The system contains deck unit, two transducers, peripheral sensors DGPS (Differential Global Positioning System), gyro compass, echo sounder, tide master, SVP (Sound Velocity Profile), a motion sensor). A gyro compass and a motion sensor monitored the movement of the surface vessel to compensate for the orientation of the sonar head at each time. The ship position were accurately positioned by real time dynamic global positioning (Trimble DSM232). Vertical sound velocity profiles were recorded every ping to compensate for acoustic veolicity error in depth profile. Positions and altitudes are output in World Geodatic System 1984 (WGS 84). For mapping, horizontal positions were projected on to Universal Transverse Mercator 32 (UTM32) map projection and altitudes transformed with respect to the normal chart datum. The individual measurements were further processed in a digital terrain model (DTM) with a grid size of 1m×1m. Details of the methods and error estimations are described elsewhere [15].

2.2. Spatial Resolution Model of Multi Beam System

Multi beams are all oblique incidence except the middle beam which are more efficient during detection. The spational resolution is shown in Figure 1, which establishes the body fixed coordinate system o-xyz moving together with the surface ship. The x axis points to the bow, with y axis to starboard, z axis to seabed. Supposing a slant beam transmitting angle is θ, the horizontal beam angle is α , while longitudinal beam angle is β , in the horizontal direction, the time for nearest sound pulse arriving is t_0 , and the time for farthest sound pulse arriving is t , the diffence is τ . And the longitudinal and horizontal beam angles are very small, then the beam footprints of three directions are shown in Equation 1, Equation 2, Equation 3, where $\sigma_x, \sigma_y, \sigma_z$, is spacial resolution in x axial, y axial, z axial respectively.

$$\sigma_x = H \times (\beta \times \pi / 180) / 2 \quad (1)$$

$$\sigma_y = C\tau / 2 \times \sin\theta \quad (2)$$

$$\sigma_z = C\tau / 2 \times \cos\theta \quad (3)$$

For multi beam sonar, the effective beam is slant beam, while the middle beam is always used as dead point. There are many slant beams, whose spatial resolution is used as that of multi beam system, but with some difference that horizontal resolution are determined by the footprint with largest transmitting angle, while in longitudinal the full footprint is used. Then the multi beam spatial resolution is shown as Equation 4, 5, 6.

$$\sigma_x = H g(\beta \times \pi / 180) \quad (4)$$

$$\sigma_y = H g(\alpha \times \pi / 180) / \cos^2 \theta \quad (5)$$

$$\sigma_z = C\tau / 2 \times \cos\theta \quad (6)$$

$$p_r = \frac{C}{4L_p} \quad (7)$$

$$L_1 = V \ / \ p_r \times N \quad (8)$$

$$L_1 = \frac{4V \times L_p \times N}{C} \quad (9)$$

2.3. Target Size Recognized by Multi Beam System

The longitudinal resolution of multi beam is related to the velocity of survey ship. According to the international hydrographic survey standards, the longitudinal dimension of target surveyed has to be above L_1 (shown in Figure 2). The relation between L_1 and velocity of ship V, ping length L_p, ping rate P_r can be derived by Equation 7, 8, 9.

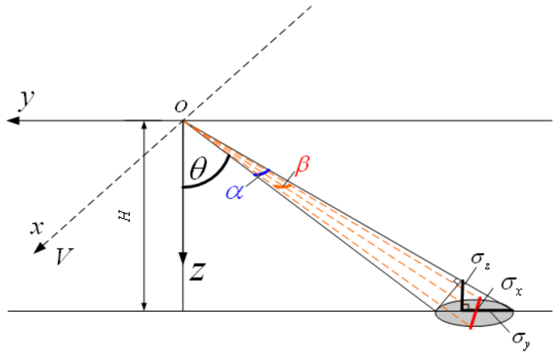

Figure1. Spatial Resolution of Slant Beam Resolution

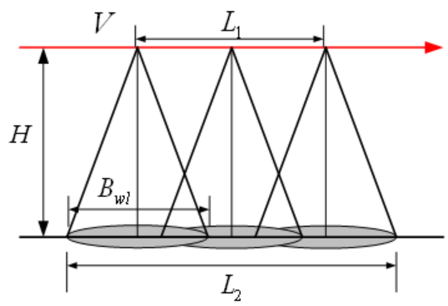

Figure 2. Longitudinal Coverage for Multi Beam Sonar

Suppose the least points number to detect target is N (usually $N \geq 3$). To realize the complete coverage, just as Figure 2, the object dimension must be above L_2, shown in Equation 10, where C is velocity of sound with 1500m/s in default. L_p is the ping length influenced by features of multi beam system and water depth. Now, the discernable object dimensions of multi beam bathymetric system in three directions can be present in Equation 11.

$$L_2 = L_1 + B_{wl} = \frac{4V \times L_p \times N}{C} + H \cdot (\beta \times \pi / 180) \quad (10)$$

$$\begin{aligned} \sigma_x &= \frac{4V \times L_p \times N}{C} + H g(\beta \times \pi / 180) \\ \sigma_y &= H g(\alpha \times \pi / 180) / \cos^2 \theta \\ \sigma_z &= C\tau / 2 \times \cos\theta \end{aligned} \quad (11)$$

It is now clear that the longitudinal resolution of multi beam is related to the velocity of ship, sound velocity, water depth and longitudinal beam angle. The horizontal resolution is related to the depth, beam transmitting angle, horizontal beam angle. The greater the transmitting angle is the more width of detection is, while with the lower resolution of detection. The depth resolution is related to the transmitting angle of horizontal beam and time difference of beams.

2.4. Design of Multi Beam Parameters
2.4.1. Velocity of Surface Ship

The interval of time between two pings, T_R, must guarantee the multi beam system can receive the echo of most marginal beam. If unilateral transmitting angle is below 90°, for instance single channel system as Seabat 8101, its full transmitting angle is 150°, the starboard or port maximum transmitting angle is 75°, then the farthest beam returns after time T_R, shown in Equation 12.

If unilateral transmitting angle is above 90°, for example, GeoSwath, which transmitting by two side transducers in turn [16], with full fan angle 240°, the biggest angle in one side is 120°, then the time of receiving pulse is decided by the ping length. As GeoSwath Plus system transmits and receives by two channel transducers, where T_R for interval time of two emitted pulses is twice as much as echo time for farthest beam like the Equation 13. As the longitudinal resolution of beam is given in Equation 14. The accurate digital terrain map needs full coverage between pings, which determine the largest ship veloc -ity as Equation 15.

$$T_R = 2H / \left(C \cdot \cos\theta_{\max}\right) \quad (12)$$

$$T_R = \frac{4L_p}{C} \quad (13)$$

$$S_L = B_{wl} = H g\left(\beta \times \pi / 180\right) \quad (14)$$

$$V_{\max} = \frac{S_L}{T_R} \quad (15)$$

For one channel multi beam system with the largest transmitting angle less than 90°, then the maximum survey ship velocity is shown in Equation 16. While for two channel multi beam system with the largest transmitting angle more than 90°, that is shown in Equation 17. But, the ship velocity is not considered enough in Equation 16 or Equation 17, for it doesn't according to the longitudinal resolution σ_x. For GeoSwath, with ping length related to swath width and depth as shown in Equation 18, then we can derive the relation between ship velocity and swath width as Figure 3.

$$V_{\max} = \frac{H g\left(\beta \times \pi / 180\right)}{2H / \left(C \cdot \cos\theta_{\max}\right)} = 13.1\cos\theta_{\max}\beta \quad (16)$$

$$V_{\max} = \frac{S_L}{T_R} = \frac{H g\left(\beta \times \pi / 180\right)}{4L_p / C} = 6.55\frac{H g\beta}{L_p} \quad (17)$$

$$L_p = \sqrt{\left(\frac{B}{2}\right)^2 + H^2} \quad (18)$$

2.4.2. Ping Length Design

Horizontal resolution is related to depth, largest transmitting angle, which shown in Equation 11, if depth (can get by echo sounder) and the target size are given, then we can get largest transmitting angle, which is shown in Figure 4. From Figure 4, we can see, with a defined horizontal resolution, the deeper the depth, the smaller the largest transmitting, the swath width vs. depth is decreasing, which reducing survey efficiency. The relation with ping length L_p and the horizontal resolution, horizontal beam angle and depth is shown in Equation 19, 20.

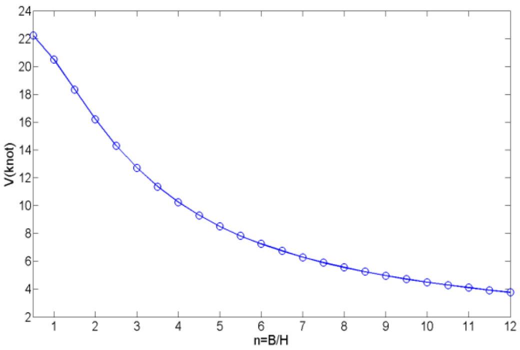

Figure 3. Coverage Width Vs Ship Velocity

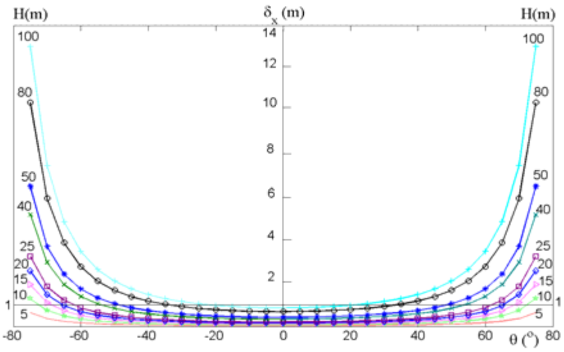

Figure 4. Horizontal Resolution Vs Depth, Largest Transmitting Angle

$$\sigma_y = H \cdot (\alpha \times \pi / 180) / \cos^2 \theta = \frac{L_p^2}{H} \cdot (\alpha \times \pi / 180) \tag{19}$$

$$L_p = \sqrt{57.3 \frac{\sigma_y g H}{\alpha}} \tag{20}$$

For GeoSwath Plus system, where $\alpha = 0.5^\circ$, to recognize a target with $\sigma_y = 1m$ in different depth, the ping length can be pictured as Figure 5. Figure 5 shows the relation among the horizontal resolution, depth and ping length, which means how can set suvey parameter of ping length to capture the given size of target in given depth, that is, if we want to survey a target, whose horizontal resolution is 10m in depth of 40m, then we can set maximum ping length as 200m, about 10 times swath width vs. depth. If the same target in depth of 100m, then we can set maximum ping length as less than 350m, about 6 times swath width vs depth. If we want to find a target with 1m resolution in 10m depth water, such as in basin, the ping length is less than 25m, with maximum swath width less than 5 times of depth. By this means, we can find small size target with small ping length in given depth.

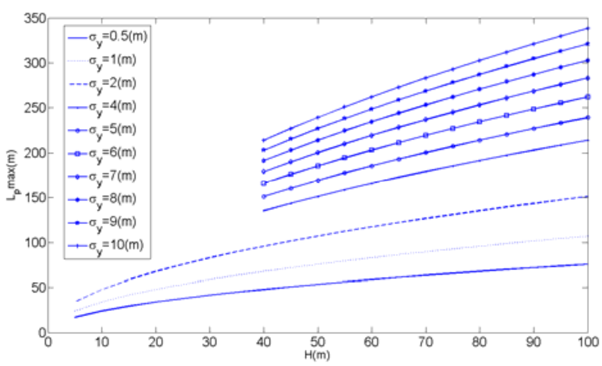

Figure 5. Ping Length Vs Depth and Horizontal Resolution

2.4.3. Survey Parameters Design Process for Multi Beam System

During searching task using multi beam system in sea, we often know the size of target, and the depth, we need detect the object's location, attitude in sea floor accurately and fast, which needs to full coverage detection, including beam footprint coverage and line coverage, we need know the character of the multi beam system, also how to set the related detection factor as soon as possible, which can be got by these steps, and programmed by a simple computer algorithm before searching task.

1) Given depth H, and the target's horizontal resolution, with Eq. 11, we can get the largest transmitting angle θ;
2) Given the largest transmitting angle, to decide the largest swath width, which expressed as the times of the depth, $n = 2\tan\theta$, the line width is B=nH／2;
3) Given the largest transmitting angle, to get the ping length as $L_p = H/\cos\theta$;
4) To get the max ping rate, for two channel transducer, it emits and receives sound with two sides, then $\Pr = \frac{C}{4L_p}$, for single channel, $P_r = \frac{C}{2L_p}$;
5) To get the ship velocity, suppose the minimum points is $N = 3$, using Equation 16 for single channel, Equation 17 for two channel, and joint with longitudinal resolution in Equation 11, the minimum is the appropriate velocity.

According to the process, we get the program, which can easily give the target size in different depth, ping length, ship velocity, fan like angle needed. Table 1 gives GeoSwath survey factor design.

Table 1. The Relation between Target Resolution and Detection Parameters for GeoSwath

Measurements grades	target dimension [m3]	Water depth H[m]	Ping Length L_p [m]	Ping rate p_r	Transmitting angle Θ[°]	Ship velocity V[knots]	Swath width n(×d)
	0.5	5	16.9	22	72.8	3.4	6.4
	0.5	10	23.9	15	65.3	3.5	4.3
	1	5	23.9	15	77.9	2.4	9.3
	1	10	33.8	11	72.8	3.4	6.4
	1	15	41.5	9	68.8	4.1	5.2
	1	20	47.9	8	65.3	3.5	4.3
special	1	25	53.5	7	62.2	2.8	3.8
	2	15	58.6	6	75.2	2.9	7.6
	2	20	67.7	6	72.8	3.4	6.5
	2	25	75.7	5	70.7	3.8	5.7
	2	40	95.7	4	65.3	3.5	4.3
	5	50	169.3	2	72.8	3.4	6.5
	8	80	270.8	1	72.8	3.4	6.5
1a	10	100	338.5	1	72.8	3.4	6.5

2.5. Data Processing Technique

During acquisition, GeoSwath collects depth and amplitude data, using GS+ software to postprocessing the data to get swath file to map depth contour, which can be shown in grid mode, and get swape file to create a mosaic of sonar image. So the data processing technique inlcudes two sides, one is on depth data, the other is on amplitude data. There are four filters used to process the depth data, such as amplitude filter, limits filter, across track filter and along track filter. According to ping length setting during survey target, we can set the amplitude filter by the minimum slant range and the maximum slant range to delete the noise beneath the transducers, using the minimum and maximum depth to limit the effective data, using along track filter to track the depth of target as setting navigation line parallel to the heading of the target after first surveying, which is a effective way for detect seafloor target fast and completely. For side scan analogue data, using slant range and slant correction mode, and adjust TVG control by increasing or dicreasing point number to capture the signal strength, with the point just on the tip of the signal crest, then we can process amplitude to get clear side scan data to mosaic a sonar image of target.

3. Seafloor Target Survey

3.1. Artificial Target Survey

The GeoSwath multi beam system and peripheral sensors are installed in boat like Figure 6. The target survey is first done in harbour pool of DMU (Dalian Maritime University), part of Huanghai sea. When in ebb tide, the maximum depth of the pool is near 5.6m, when in flood tide, the maximum depth is near 7.6m. Prior to release targets in seabed, we have mappped of DMU pool with GeoSwath, shown in Figure 7, for evlalution the function of GeoSwath, and giving the bathymetry picture for the coast office.

Figure 6. GeoSwath System Installation in Boat

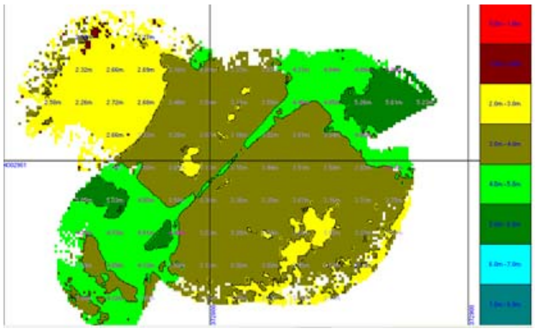

Figure 7. Multibeam Bathymetry in DMU Harbor

After that, we release the artificial target, which are three metal barrels in series, shown in Figure 8, with single size of $\phi 0.6m \times 0.9m$. The target is released horizontally in seafloor, with the minimum resolution size of 0.6m in depth of 5m. During searching, according to the ping length setting algorithm, shown in Figure 5 and Table 1, we set ping length about 16m, and then we search it through three different paths, which are Line 1, Line 2 and Line 3, shown in Figure 9, 10 and 11 respectively, with the target located in different oblique beam. The measurement results are shown as Figure 12, 13 and 14 respectively. The target position in Figure 12, Figure 13, Figure 14 is determined by the floating GPS coordinate with E:372802 , N:4302895 before releasing. The small flag in the flat floor marks the detecting target position, which is E372800 N:4302893. Obviously, there's deviation between the real location of the target detection and corresponding float location, which may be that the floating position is deviated from the barrels in seabed. Comparing the line and result graph of corresponding detection, the Line 1 and Line 3 are close to releasing point, means that the target is more close to the middle beam with less footprint, where target features are clear. Like Figure 12 and Figure 14, target resolution is high. While Line 2 is remote to the target, transmiting angle or ping length is much bigger, making the Figure 13 vague with decreasing of horizontal resolution and depth resolution. According to the depth gridfly of Line 1, the target is just put on the waterway whose bottom material is rock. Intense barrels' echo-sound makes it hard to detect target from acoustic shadow image by multi-beam. Instead we can only use difference in depth. This is complement feature of GeoSwath which discern the depth and acoustic shadow [17].

Figure 8. Three Artificial Barrels in series

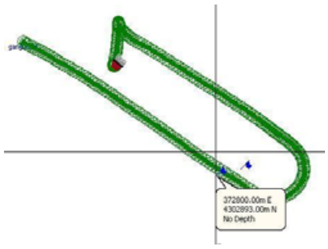

Figure 9. Line 1

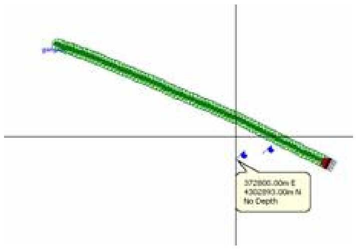

Figure 10. Line 2

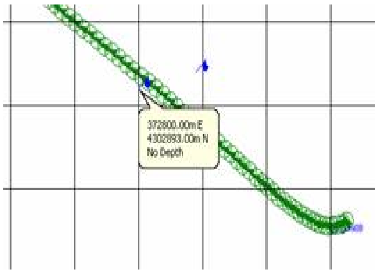

Figure 11. Line 3

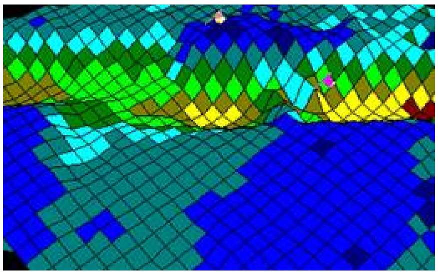

Figure 12. Depth Gridfly of Line 1

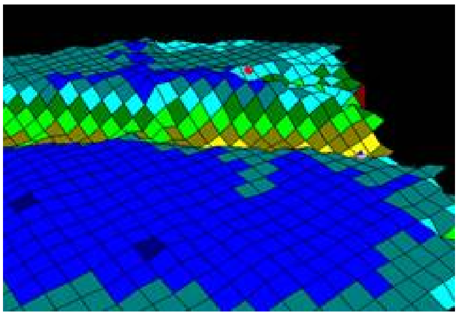

Figure 13. Depth Gridfly of Line 2

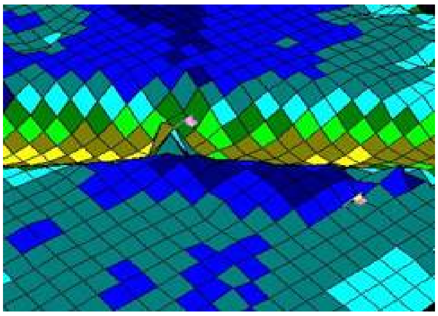

Figure 14. Depth Gridfly of Line 3

3.2. Ship Wreck Near Harbour

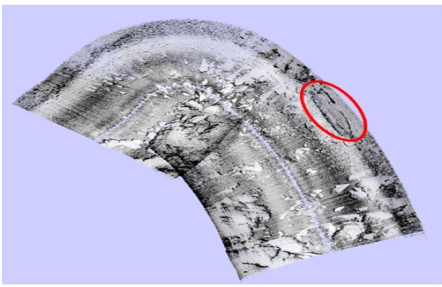

Figure 15. Gridfly of Ship Wreck at 5m Depth

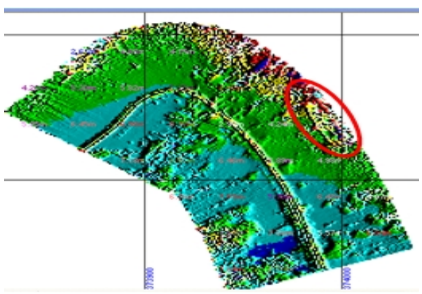

Figure 16. Sonar Image of Ship Wreck at 5m Depth

A shipwreck is lying in the harbour entrance to the Huanghai Sea near DLMU (Dalian Maritime University), which is oblique in seafloor, when in ebb tide, some part of the bow ship can be seen beneath the water, the depth is near to 5m. This time, the dimension of target is unknown, we set pinglength as 30m, then we sail to suvey it with navigation line parallel to the longest dimension of the target, then we get the depth gridfly and sonar image as in Figure 15 and Figure 16 respectively. In gridfly, we can see there are rocks near ship wreck, which backscatter more intervention with that of target to difficult to recognize the target. While in sonar image, it can get more clear outline of the target for its material' strength scatter chabability. The dimension of the ship wreck is about $L80m \times B10m$. To verify the detection, the sonar image got by forward looking sonar is given in Figure 17, which can see the outline of the ship wreck.

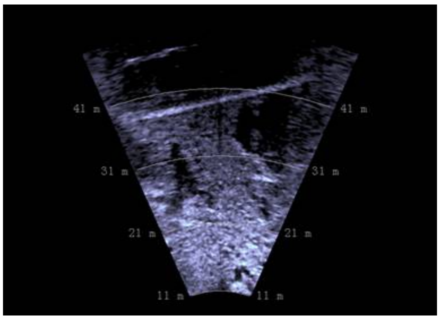

Figure 17. Sonar Image of Wreck Near Sea by Blueview

3.3. Ship Wreck in the Huanghai Sea

A shipwreck is sunk in Huanghai Sea, about 100nmiles from Dalian, known from the National Hydrographic Office who provides information such as dimensions of wreck and its position. So we sailed to the area to survey it with GeoSwath. The depth is about 50m, the dimension given is about 100m, with the resolution of 10m in size, to have its clear attitude and real dimension, we should set the ping length less than 220m according to Figure 5, here we set pinglength as 100m to get more points above the target to grid its character more clearly. After we find the target, and calculate its heading angle, then we choose a navigation line parallel to the heading to get as many points as possible in the aim to give the clear outline of the ship wreck. The bathymetry of wreck ship is shown in Figure 18, followed by the side scan picture in Figure 19. The wreck ship is lie on seafloor many years, it is some buried with sediment of sand and mud, making the bathymetry less to discern, while it is made of metal, creating a stronger acoustic eco than from sullage in seabed, that is shown with sounder image picture in Figure 18, which can assess ship wreck presence. The dimension of the ship wreck is near to $L100m \times B20m \times D7m$.

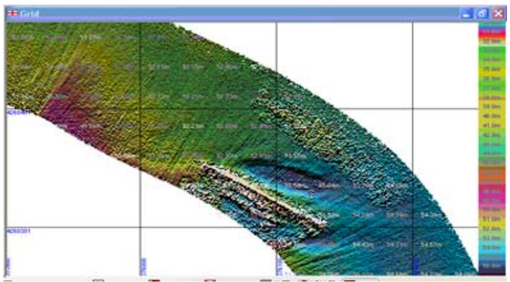

Figure 18. Bathymetry of Ship Wreck at 50m Depth

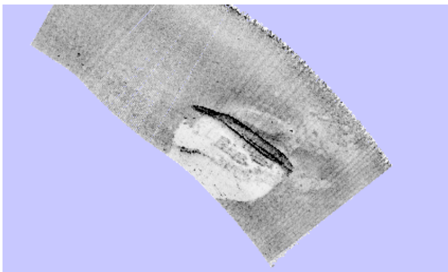

Figure 19. Sonar Image of Ship Wreck at 50m Depth

4. Conclusion

We have analyzed spatial resolution of multi beam system, deduced fixed relation between target detection and multi beam transmitting angle, ping length and water depth, velocity of ship with multi beam system installed, given data processing technique on depth and amplitude data, in aim to get clear character of seafloor target. Applying this method, we have surveyed three kind sizes of seafloor targets in different depth by GeoSwath and proved the rationality and necessity of the detection parameters design for multi beam system based on target recognition. According to the formula and research, we have several conclusions as follows:

1) Longitudinal resolution of Multi beam is related to ship velocity, ping length, acoustic speed, water depth and longitudinal beam angle. Horizontal resolution is related to depth, beam emission angles and horizontal beam angle. Bigger the transmitting angle is, wilder the swath width is and lower the detection resolution is. The vertical resolution is related to the horizontal beam angles and beam intervals;
2) For the same target, the measured angles are shown differently on different navigation channels and the clarity of target is also different with best way to get high target resolution, which can be calculated by procedure of determining sounding parameters for multi beam;
3) Suppose that the target is located on the area where geology is similar to the target. For example, the barrel lying on the waterway in the experiment above, making the sound amplitude similar from the seabed and the target, resulting in the image hard to discern. Then the target can only be detected from depth graph, according to continuity of target. In the other case, if the target made of metal is buried by sand and mud many years, it can be discerned by sonar image, not the depth graph.

Acknowledgements

This work is Funded by the projects in the National Science & Technology Pillar Program (No.2009BAG18B03), the National Natural Science Foundation of China (No.51009016), and supported by the State Key Laboratory of Robotics. We thank the crews of underwater teams ‘An yang’, ’Yang Shuai-feng’, ’Cai Ren-jie’ for heavy work during the operation of the bathymetric surveys in sea from 2010 to 2011. We thank for ‘Zang Li-long’ supporting in processing data. Helpful comments on an earlier draft of the manuscript by Wang Wen-bo and Ji Da-xiong as well as the constructive criticisms are gratefully ackowledged.

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