Survey of Seafloor Targets with Varied Sizes by Multi Beam Sonar in Different Depth Water

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Abstract. Multi beam sonar needs complex data processing lying on human intervention to get accurate depth contour and low accuracy in sonar image which prevent its popular use in surveying seafloor targets. To survey seafloor target in different depth by GeoSwath, this article presents survey parameter setting method such as ping length, ship velocity to increase points over targets, navigation line parallel to heading of target during survey, adopting along track 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, which improve 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.

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 systems, multi beam 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[3,4] due to provide more data every ping along ship track. A number of different approaches to characterization via backscatter have been developed [5,6], 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 been evaluated by sail. For example, Ref [7] derived 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. Ref [8] 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 among ship velocity, swath width and object size is even less well documented, some only give results about the maximum velocity about different multi beam[9].To get acoustic information of target out of seafloor, it is not only reply on data processing, but also on how to get effective data. This paper uses GeoSwath multi beam sonar, a seafloor mapping system in shallow water of which a single swath covering an angular range of -120°to 120 °from the vertical direction, to survey seafloor target by setting appropriate survey parameters.
Spatial Resolution Model of Multi Beam System

Slant Beam Resolution. Multi beams are all oblique incidence except the middle beam. The spatial resolution is shown in Fig.1, which establishes the body fixed coordinate system o-xyz moving together with surface ship. The x axis points to bow, with y axis to starboard, z axis to seabed. Supposing a slant beam transmitting angle is $\theta$, the horizontal beam angle is $\alpha$, while longitudinal beam angle is $\beta$, in the horizontal direction, the time for nearest sound pulse arriving is $t_0$, the time for farthest sound pulse arriving is $t$, and the difference is $\tau$. For the longitudinal and horizontal beam angles are very small, horizontal resolution are determined by the footprint with largest transmitting angle, while in longitudinal the full footprint is used, then the beam footprints of three directions are shown in Eq.1, Eq. 2, Eq. 3, where $\sigma_x, \sigma_y, \sigma_z$ is spatial resolution in x axis, y axis, z axis respectively.

$$\sigma_x = H \cdot (\beta \times \pi / 180)$$  \hspace{1cm} (1)

$$\sigma_y = H \cdot (\alpha \times \pi / 180) / \cos^2 \theta$$ \hspace{1cm} (2)

$$\sigma_z = C \tau / 2 \times \cos \theta$$ \hspace{1cm} (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 $L_a$ (shown in Fig. 2). The relation between $L_a$ and velocity of ship $V$, ping length $L_p$, ping rate $p_t$ can be derived by Eq.4, Eq.5.

$$p_t = \frac{C}{4L_p}$$ \hspace{1cm} (4)

$$L_a = V / p_t \times N = \frac{4V \times L_p \times N}{C}$$  \hspace{1cm} (5)

Suppose the least points number to detect target is $N$ (usually $N \geq 3$). To realize the complete coverage, just as Fig. 2, the object dimension must be above $L_2$, shown in Eq.6, where $C$ is sound velocity with 1500m/s default. $L_p$ is the ping length influenced by features of multi beam system and water depth. Now, the discernable object dimensions for multi beam bathymetric system in three directions can be present in Eq.7.

$$L_2 = L_a + B_{wl} = \frac{4V \times L_p \times N}{C} + H \cdot (\beta \times \pi / 180)$$ \hspace{1cm} (6)

$$\sigma_x = \frac{4V \times L_p \times N}{C} + H \cdot (\beta \times \pi / 180)$$ \hspace{1cm} (7)

$$\sigma_y = H \cdot (\alpha \times \pi / 180) / \cos^2 \theta$$ \hspace{1cm} (7)

$$\sigma_z = C \tau / 2 \times \cos \theta$$ \hspace{1cm} (7)

It is now clear that longitudinal resolution of multi beam is related to velocity of ship, sound velocity, water depth and longitudinal beam angle. Horizontal resolution is related to 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. Depth resolution is related to the transmitting angle of horizontal beam and time difference of beams.
Design of Multi Beam Parameters

**Ship Velocity.** The interval of time between two pings, $T_R$, must guarantee multi beam system to receive echo of most marginal beam. GeoSwath transmits by two side transducers in turn [13], with full fan angle 240°, the biggest angle in one side is 120°, then the receiving pulse time is decided by the ping length. $T_R$ is twice as much as echo time for farthest beam like the Eq. 8, the longitudinal resolution of beam is given in Eq. 9. And the accurate digital terrain map needs full coverage between pings, which determine the largest ship velocity as Eq. 10.

$$T_R = \frac{4L_p}{C}$$  \hspace{1cm} (8)

$$S_L = B_{wl} = H \cdot (\beta \times \pi / 180)$$  \hspace{1cm} (9)

$$V_{\text{max}} = \frac{S_L}{T_R}$$  \hspace{1cm} (10)

The ship velocity for GeoSwath is shown in Eq. 11. with ping length related to swath width and depth as shown in Eq. 12, we can derive the relation between ship velocity and swath width as Fig. 3.

$$V_{\text{max}} = \frac{S_L}{T_R} = \frac{H \cdot (\beta \times \pi / 180)}{4L_p / C} = 6.55 \frac{H \cdot \beta}{L_p}$$  \hspace{1cm} (11)

$$L_p = \sqrt{\left(\frac{B^2}{2}\right) + H^2}$$  \hspace{1cm} (12)

**Ping Length.** Horizontal resolution is related to depth, largest transmitting angle, which shown in Eq. 7, if depth (can get by echo sounder) and target size are given, then we can get largest transmitting angle, which is shown in Fig. 4. From Fig. 4, we can see, with a defined horizontal resolution, the deeper the depth, the smaller the largest transmitting is, the swath width vs. depth is decreasing, reducing survey efficiency. The relation with ping length $L_p$ and the horizontal resolution, horizontal beam angle and depth is shown in Eq. 13, Eq. 14.

For GeoSwath to recognize a target with $\sigma_y = 1m$ in different depth, the ping length can be picture as Fig. 5. Fig. 5 Shows the relation among the horizontal resolution, depth and ping length, which means how to set survey parameter of ping length to capture 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. By this means, we can find small size target with small ping length in given depth.

\begin{align*}
\sigma_y &= H \cdot (\alpha \times \pi / 180) / \cos^2 \theta = \frac{L_p}{H} \cdot (\alpha \times \pi / 180) \hspace{1cm} (13) \\
L_p &= \sqrt{57.3 \frac{\sigma_y \cdot H}{\alpha}} \hspace{1cm} (14)
\end{align*}
Data Processing Technique
During acquisition, GeoSwath collects depth and amplitude data, using GS+ software to post-processing 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 includes two parts, 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 decreasing 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.

Seafloor Target Survey
**Artificial Target Survey.** GeoSwath and peripheral sensors are installed in small lifeboat. Target survey is first done in pool of DMU (Dalian Maritime University) harbour, 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 a map of DMU pool with GeoSwath, for evaluating the function of GeoSwath, and giving bathymetry picture for the coast office.

After that, we release the artificial target, which are three metal barrels in series, shown in Fig.6, with single size of $\phi0.6m \times 0.9m$. The target is released horizontally in seafloor, with the minimum resolution size of 0.6m at 5m depth. During searching, according to ping length setting algorithm, 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 Fig. 7,8 and 9 respectively, with the target located in different oblique beam. The measurement results are shown as Fig. 10, 11 and 12, respectively.

![Fig.6 Three artificial barrels in series](image1)
![Fig.7 Line 1](image2)
![Fig.8 Line 2](image3)
![Fig.9 Line 3](image4)

![Fig. 10 Depth gridfly of Line 1](image5)
![Fig. 11 Depth gridfly of Line 2](image6)
![Fig. 12 Depth gridfly of Line 3](image7)

The target position in Fig.10, 11, 12, is determined by GPS with E372802, N4302895 before releasing. The small flag marks the detecting target position, as E372800, N4302893. Obviously, there’s deviation between real location and corresponding float location, which may be the floating position is deviated from the barrels. Line 1 and Line 3 are close to releasing point, means target more close to the middle beam with small footprint, where target features are clear, like Fig.10 and Fig.12. While Line 2 is remote to target, transmitting angle or ping length is much bigger, making Fig.11 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. Instead we can only use difference in depth. This is complement feature of GeoSwath which discern the depth and acoustic shadow [10].

**Ship Wreck near Harbour.** A shipwreck is lying in the harbour entrance to Huanghai Sea near DMU, which is oblique in seafloor, when in ebb tide, some part can be seen beneath the water, and its depth is near to 5m. This time, the dimension of target is unknown, we set ping length as 30m, we survey it with navigation line parallel to the heading, then we get the depth gridfly and sonar image as in Fig.13 and Fig.14 respectively. In gridfly, we can see there are rocks near ship wreck, which backscatter more intervention from rocks to difficult to recognize the target. While in sonar image, it can get clearer outline of the target. The dimension of the ship wreck is about $L80m \times B10m$.

![Fig. 13 Gridfly of ship wreck at 5m depth](image1.png) ![Fig. 14 Sonar image of ship wreck at 5m depth](image2.png)

**Ship Wreck in Huanghai Sea.** A shipwreck is sunk in Huanghai Sea, about 100nmiles from Dalian, known from the National Hydrographic Office. 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 Fig.5, here we set ping length 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. The bathymetry of ship wreck and sonar image is shown in Fig.15,16, respectively. The wreck is lying on seafloor many years, some buried with sediment of sand and mud, resulting in the bathymetry less to discern, while it is made of metal, creating a stronger acoustic eco than sullage in seabed, which can assess ship wreck presence. The ship dimension is about $L100m \times B20m \times D7m$.

![Fig.15 Bathymetry of ship wreck at 50m depth](image3.png) ![Fig.16 Sonar image of ship wreck at 50m depth](image4.png)

**Conclusions**

We have analyzed spatial resolution of multi beam system, derived fixed relation between target detection and multi beam transmitting angle, ping length and water depth, ship velocity, 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. we have several conclusions as follows.
1) Multi beam longitudinal resolution 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.

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.

3) We can detect target from depth graph or sonar image or together, this is the advantage of multi beam sonar.

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