

A short discussion on artifact creating conditions using multibeam bathymetric systems in a highly reflecting and smooth bottom

Bishwajit Chakraborty

National Institute of Oceanography, Dona Paula, Goa: 403 004, India

E-mail: bishwajt@csnio.ren.nic.in

185

Abstract

Using multibeam system, artifact creating conditions are dominant when functioning in highly reflective and flat bottom areas. This simulation study manifests the causes responsible for creating such conditions which influence seafloor classification using bathymetry as well as seabottom backscatter models. The quantitative study results provide some insights into the extent of variability in the estimated seabottom spectral parameters under highly reflective and flat bottom conditions.

1. Introduction

Bathymetric mapping and seabottom backscatter study using multibeam systems have been recognized as commendable tool to study the seabed morphology (De Moustier, 1986). Along with the bathymetry, the quantitative angular backscatter function of the seabottom is employed to draw certain important inferences related to roughness (De Moustier and Alexandrou, 1991 and Chakraborty et al., 2000). In a multibeam system, a filtering scheme is used in which a sidelobe threshold level is set around 12 dB down from the highest available beam peak amplitude. Generally, this filtering scheme combined with a bottom tracking algorithm works well, except in a highly reflective and flat bottom conditions. However, the effect due to highly reflective and flat seabottom, may lead to backscatter signal saturation in near normal incidence beam which allows registering wrong depth as well as backscattering strength. Because of this effect, the flat bottom area appears as a tunnel-like feature on a bathymetric map, known as a 'tunnel effect'. In this respect, Alexandrou and De Moustier (1988), had emphasized sidelobe interference removal as an important step, should be carried out before performing backscatter energy computations. As already mentioned that the artifact creating conditions are anticipated to be dependent on bottom backscatter characteristics, where angular backscatter strength has extremely higher values at near normal incidence direction than other directions. The higher value at 0° incidence angle causes saturation of beam, which sets incorrect signal threshold value for the outer beams and leads to artifact creating conditions. Therefore, a study of the artifact creating conditions including bottom backscatter effect is essential to understand the multibeam systems performance. In this paper, a simulation study is attempted to examine the extent of connection between the artifact creating conditions and the bottom backscatter characteristics using multibeam systems. The bottom backscattering

strength values employing power law assumptions in Helmholtz-Kirchhoff's formulation (Jackson et al., 1986) has been used here. The study results show the effect of the angular backscatter strength on the multibeam techniques especially for the smooth bottom area.

2. Multibeam simulated backscatter signal

In a multibeam system, a sinusoidal source signal of certain pulse length (τ), $g(t) [= A \text{ rect}(t/\tau) \cos(2\pi f t)]$, is transmitted through the transmitting array transducer in a water medium. The time (t) extends from $-\tau/2$ to $\tau/2$ (τ , pulse time, is assumed to be 0.01 s. for present study). The pulse amplitude A , is considered to be unity, and f is the operating frequency which is equivalent to the 15.0 kHz here. The transmitting array is installed along the ship's axis. The bottom return signals are received through the array elements in a separate receiving array transducer (the receiving transducer array is installed perpendicular to the ship's axis). Beamforming technique is used to obtain preformed received beams in different directions. The preformed beams from different directions undergo a TVG (Time Varied Gain) correction based on $20 \log(r)$, where r is a slant range in the required directions. And, gain corrected preformed beams are processed for bottom tracking. The array beam pattern for a linear array is computed in this study. We have assumed that the linear array lie in the x-axis, which is positioned at the origin of the coordinate system. The array consists of total 40 transducer elements. The inter-transducer element separation is assumed to be 0.5λ , where λ is the design wavelength (equivalent to the 10 cm in this study). The amount of delay required between the elements to steer the beams towards the specific direction (θ_0, ϕ_0) [for a steering direction of θ_0 in a $\phi_0 = 0^\circ$ - plane], is being considered in the array beam pattern function. The half power beamwidths for the receiving array toward the direction of 0° , is estimated to be 2.4° . The highest sidelobe

level appears very close to the mainbeam direction, and is around 13 dB down from the main beam level. For present array, the steered beampatterns up to 8° are computed for further use. The array elements are uniformly excited and no shading techniques are used to suppress the sidelobe levels. Using linear system theory in the frequency domain (applied only to receiving mode of the transducer array), the output response $O(f)$ is the product of the source response of a transmitted signal $G(f)$ and receiver array output $F(f)$ (Bardsley and Christensen, 1981). The system function $F(f)$, describes the amplitude of the response of the receiver array functions to an input frequency component of frequency (f) located at a known direction. As we know that the beampattern function represents the beam output as a function of (θ, ϕ) for a constant wavelength λ' . Substituting $1/\lambda' = f'/c$ into the beampattern function gives the system function. $[F(f)]$. The system function $F(f)$ has the same form in the frequency domain as the beampattern function has in the space domain. The input source signal frequency response $G(f)$ is obtained by Fourier transform of the transmitted pulse signal, $g(t)$. The spectrum of the source signal $G(f)$ (centered around f') will line up with $F(f)$ for a specific direction of (θ, ϕ) , to create a resultant response. Multiplying source response $G(f)$, and system response $F(f)$, and subsequent application of the IFT (Inverse Fourier Transform) allows us to obtain waveforms. In a multibeam system, the time width of the echo waveform signals are dependent of angular beam directions and sonar operational parameters, i.e., the expected time width, is a function of the operational geometrical conditions of the multibeam sounder (Morgera and Sankar, 1984). The expected echo duration becomes higher for outer beams. Because, the acoustic wave impinges upon the aperture over a longer time duration as the angle becomes oblique. From a frequency domain viewpoint, the frequency spectrum of the resultant response $O(f)$ for oblique incidence beams will be narrower than the near normal incidence beams i.e., effectively filtering many of the frequency components and therefore decreasing the magnitude of the response as well as lengthening the time duration. We have assigned uniform sampling frequency of 0.5 Hz and total sampling points of 800 is selected for IFT. In order to maintain a constant number of frequency components in the output response $O(f)$, for different steered beam directions, the samples are zero padded before being subjected to IFT.

3. Artifact creating conditions using simulated backscatter signals

As we already know that in a multibeam system, the interference from the sidelobes of the near normal incidence beam directed towards the outer main beam, is a matter of great concern. This situation, is a major

cause for the generation of artifact creating conditions expressed as 'tunnel effect'. Under such circumstances, to derive array beampattern for a known steering directions, the beampattern for other look angles (θ°) [beampatterns starting from angle $\theta = 0^\circ$ to the beampatterns close to the steered directions (θ_0°)] are also computed. For example, in a beampattern of $\theta_0^\circ = 8^\circ$ - steering angle, the beampatterns of look angles varying from $\theta^\circ = 0^\circ, 2^\circ, 4^\circ$, and 6° directions are also combined. This exercise is necessary to create simulated multiple beam waveforms which include the effect of sidelobe interference. Here, the maximum possible steering angle of 8° is chosen arbitrarily based on the understanding that the shape of smooth bottom backscatter strength decays very sharply (within the 8° incidence angle) with respect to normal incidence value. In order to include the seawater-bottom interface roughness backscattering effect, backscattering strengths are estimated based on the Helmholtz - Kirchhoff roughness theory as a function of the power spectral parameters (α, β). Present study includes two different kinds of bottom computed in terms of roughness power spectral parameters. The computations of the backscattering part is given in details (Jackson et. al., 1986) and will not be repeated here. In order to understand the extent of seawater-bottom interface roughness effect using power spectral parameters, we have chosen two different kind of bottom roughness parameters [power spectral related parameters, which is related to the structure function (C_h)]. The reflection coefficient is assumed to be equivalent to the 0.206 (i.e., coarse grained clayey sand sediment at the seawater- sediment interface) for both the areas.

The backscattering coefficient (S_s) is generally expressed as, $S_s = I_b / I.A$, where I_b is the measured backscatter intensity, which is corrected due to system gain and range. I is the source intensity and assumed to be unity, where the term, A is the insonified area. In Table 1, the backscatter strength values are presented for two different bottom roughness conditions i.e., for different spectral parameters. The incidence angles and corresponding angular backscattering strengths are written in first two columns. The computed backscatter strengths for different steered and look angles (using bottom tracking window) are expressed in the subsequent columns. The diagonal values represent the backscattering strength using accurate part of the waveform within the window of a particular steered direction. The non-diagonal values for a particular row represent computed backscatter strength for a part of the waveform if incorrectly gated for a given look direction. For example in the Table 1, for 2° beam direction (column 1), there exists two backscatter strengths values (second row): towards the 0° look angle (non-diagonal- using incorrectly gated waveform) and 2°

Table 1. Computed Backscattering Strengths (BS) using simulated waveforms

| BS values used in Simulation for $\alpha=0.5$ and $\beta=0.005$ | | | Computed BS towards different steered & look angles | | | | |
|---|------------------------------|------------------------------|---|-----------|-----------|-----------|-----------|
| Beam Direction \Downarrow | Backscattering Strength (dB) | Beam Direction \Rightarrow | 0° | 2° | 4° | 6° | 8° |
| 0° | 0.34 | | 0.11 | | | | |
| 2° | -3.4 | | -6.9 | -3.7 | | | |
| 4° | -8.8 | | -7.2 | -8.0 | -8.7 | | |
| 6° | -13.2 | | -17.0 | -8.4 | -12.8 | -13.0 | |
| 8° | -16.5 | | -11.2 | -21.5 | -16.1 | -20.0 | -16.4 |

| BS values used in Simulation for $\alpha=0.5$ and $\beta=0.0025$ | | | Computed BS towards different steered & look angles | | | | |
|--|------------------------------|------------------------------|---|-----------|-----------|-----------|-----------|
| Beam Direction \Downarrow | Backscattering Strength (dB) | Beam Direction \Rightarrow | 0° | 2° | 4° | 6° | 8° |
| 0° | 6.37 | | 6.13 | | | | |
| 2° | -2.86 | | -0.8 | -3.2 | | | |
| 4° | -10.6 | | -1.23 | -7.4 | -10.4 | | |
| 6° | -15.5 | | -10.9 | -7.8 | -14.4 | -15.3 | |
| 8° | -19.2 | | -5.2 | -20.8 | -18.3 | -22.0 | -19.0 |

steered direction (diagonal- correct value). In a similar fashion, more number of backscattering strength values may be obtained using incorrectly gated (responsible for artifact creating conditions) received signals for higher angle of incidences. The sidelobe interference effect due to the high near normal incidence returns is not so prominent for the spectral parameters of $\alpha=0.5$ and $\beta=0.005$ [the bottom roughness is relatively rough while comparing with the other spectral values, based on the $C_n r^\alpha$ (root mean square height difference) of 0.025m and 0.793m for a separation (r) between the points of 1m and 1000m respectively]. The possibility of signal saturation towards the 0° direction is not seen. However, artifact creating conditions due to the sidelobe interference effects are observed to be dominant for a spectral parameters of $\alpha=0.5$ and $\beta=0.0025$ [significantly smooth bottom- $C_n r^\alpha$ (root mean square height difference) of 0.017m and 0.560m for a separation between the points of 1m and 1000m respectively]. From Table 1, we observe that the computed backscattering strengths values are significantly higher especially for the near normal incidence beam, and may lead towards the incorrect

windowing for the receiving beams. Such situations ultimately creates tunnel like features for a smooth bottom.

A quantitative example given here, shows how a multibeam user can be misguided using a dataset containing artifact for backscatter study. For backscatter modeling study, the system calibration is impossible due to large transducer size, hence, normalization of backscatter values (with respect to the 0° incidence angles) are usually carried out. The curve fitting algorithm using MMSE (Minimum Mean Square Error) for the determination of the spectral parameters from the normalized bottom backscatter data of 0° to 12° (though, we have presented values only up to 8° incidence angle in the Table 1, we may use values up to the 12° angle). In order to avoid bias in the best fitted spectral parameters due to the volume roughness, we restricted ourselves up to arbitrarily chosen incidence angle of 12° (volume backscatter strength is dominant beyond normal incidence angle) (Jackson et. al., 1986). Based on the given values in Table 1, the highest backscattering values are chosen irrespective of the look direction to generate artifact creating conditions. For curve fitting purposes, we

have computed backscatter strength of the sidelobes (highest backscattering strengths values) which is interfering from normal incidence beam directions towards the different steered directions. Firstly, the MMSE estimation of the spectral parameters of the normalized bottom backscatter strength values of the artifact created data [as mentioned, we have considered highest backscatter values of the simulated backscattering strength matrix (Table 1) of: $\alpha=0.5$ and $\beta=0.0025$] is carried out. The values between 0° to 12° angle derives the spectral parameter of $\alpha=0.5$ and $\beta=0.006$. The extent of estimated roughness variations can be understood from the computed spectral parameters. The rms height difference at the separations of 1 m and 1000 m are estimated to be 0.027m and 0.87 m respectively. These results show higher roughness when compared with the values of actually considered spectral parameters of $\alpha=0.5$ and $\beta=0.0025$. Secondly, in order to sense the effect of saturation near the normal incidence beam backscatter value, we assume that the measured saturated backscatter strength signal for a 0° angle is equivalent to the 3.13 dB (the actual value at 0° is computed to be 6.13 dB i.e., 3 dB less from the backscattering strength values at 0°). Employing the MMSE method for the estimated backscatter values reduced by 3 dB, the determined α, β values are $\alpha=0.5$ and $\beta=0.008$. In this case, the rms height difference at the separations of 1 m and 1000m are computed to be 0.0317 m and 1.002 m respectively, i.e., comparatively more seabottom roughness. Again, following Ulaby et al. (1983), the backscattering strength, close to the near normal incidence beam region, i.e., in the beam region, is highly variable. This beam region exists up to twice the half power beamwidth. This is a region which approximately lies up to the incidence angle of 5° for the current array used. In view of that, we have used normalized values with respect to the 5° angular value (instead the highest value at 0°), and spectral parameters are estimated as: $\alpha=0.94$ and $\beta=0.0004$. The rms height differences at separations of 1 m and 1000 m are computed to be the highest 0.0831 m and 54.93 m respectively. These estimated spectral

parameters reveal the highest roughness due to the artifact creating conditions in the area of very smooth bottom ($\alpha=0.5$ and $\beta=0.0025$).

4. Conclusions

This study leads to conclude that there is no direct solution to the difficulties of multibeam techniques in highly reflective and flat bottom conditions. In general, the effects due to artifacts are not significant for moderately rough or rough bottom, and therefore, the bathymetry/ backscatter data can be useful for seafloor classification studies. A presentation of the two different situations are considered here to demonstrate the importance of bottom backscatter function's on artifact creating conditions. This is NIO's publication No. 3576.

References

- Alexandrou, D., and C De Moustier, 1988. Adaptive noise canceling applied to Sea Beam sidelobe interference rejection. *IEEE JOE*, 13: 70-76.
- Bardsley, B.G. and Christensen, D.A., 1981. Beampatterns from pulsed Ultrasonic Transducers using Linear System theory. *Jour. Acoust. Soc. Am.*, 69:25-30.
- Chakraborty, B. H.W.Schenke, V.N. Kodagali, and R.A. Hagen, 2000, Seabottom Characterization using multibeam Echosounder Angular Backscatter: an application of the Composite roughness theory, (In press- *IEEE TGARS*).
- De Moustier, C., 1986. Beyond Bathymetry: Mapping acoustic backscattering from the deep seafloor with Sea Beam. *Jour. Acoust Soc. Am.*, 79: 316-331.
- De Moustier, C., and M.C. Kleinrock, 1986. Bathymetric artifacts in Sea Beam data: How to recognize them, what causes them. *Jour. Geophys Res.*, B3, 91: 3407-3424.
- Jackson, D.R., D.P. Winebreuner, and A. Ishimaru, 1986. Application of the Composite Roughness model to high frequency bottom backscatter. *Jour. Acoust. Soc. Am*, 79: 1410-1422.
- Morgera, S.D. and R. Sankar, 1984. Digital signal processing wide-swath Bathymetry. *IEEE JOE.*, 9: 73-84.
- Ulaby, F.T. and C.T. Allen C.T. and A.K. Fung, 1983. Method for retrieving the true backscattering coefficient from measurement with a real antenna., *IEEE TGARS*, 21: 308-313.