BOTTOM BACKSCATTERING COEFFICIENT ESTIMATION FROM WIDEBAND CHIRP SONAR ECHOES BY CHIRP ADAPTED TIME-FREQUENCY REPRESENTATION

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ABSTRACT

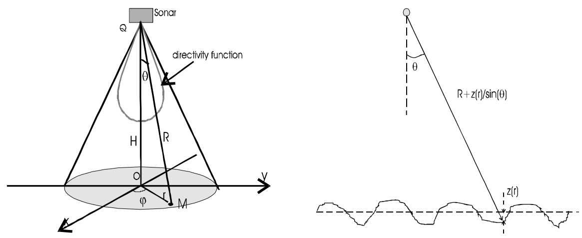
This work is concerned with the estimation of the bottom backscattering coefficient as a function of frequency and of incident angle. Generally, the backscattering coefficient is studied for a given frequency at various angle. But the backscattering depends not only on the angle, but also on the frequency. In our work, a wideband chirp sonar (20-140kHz) with -3dB half-angle 12° has been used to collect the lacustrine bottom echoes, that makes it possible to study the backscattering coefficient as a function of frequency and of angle. For this purpose, a Chirp Adapted time-frequency representation is used, which can provide an approximate energy distribution in the time-frequency plane for multicomponent chirp signals. The obtained time-frequency representation is converted to the angle-frequency plane by the relationship between the time and the incident angle. The estimated backscattering coefficients for sand bottom and pebble bottom are analyzed.

1. INTRODUCTION

The bottom backscattering coefficient is an important parameter for bottom identification, which is generally studied for a fixed frequency at various angle. But this parameter depends not only upon the incidence angle but also upon the frequency [1]. In our work, the bottom backscattering coefficient as a function of frequency and incident angle is studied at the same time from the echoes collected with a constant beamwidth wideband sonar (20-140kHz). The transmitted signal is a chirp with center frequency 80kHz, frequency modulation rate 140kHz/ms, and duration 1ms. Since the sonar beam is vertical to the bottom in our experiment and the sonar half-open angle is 24°, the studied incident angle in this paper is from 76° to 90°. The chirp adapted time-frequency representation [2] is used in order to obtain the echo's approximate energy distribution in the time-frequency plane. With the relationship between the time and the incident angle, the backscattering coefficient as a function of frequency and of incident angle is estimated. This result will be helpful for the sea bottom sediment identification and imagery.

2. BOTTOM BACKSCATTERING MODEL

As the working frequency of our sonar is from 20kHz to 140kHz, the penetration phenomenon is weak enough to be neglected for hard bottoms, such as sand bottom and pebble bottom. In this case, the backscattered signal from the bottom comes mainly from the water/sediment interface insonified by the sonar beam as illustrated in figure 1(a). We assume that the sonar is located at the height *H* above the bottom, and the incident beam is vertical to the bottom which is the same case as our experiment for collecting the lacustrine bottom echoes in lake Geneva.



(a) (b)

Fig 1. (a) Echo collection configuration., (b) *Description* of local roughness

Suppose that an impulse signal P_0 is transmitted by the sonar and that the bottom local roughness $z(\boldsymbol{r})$ to be much smaller than the average distance between the transducer and the bottom average *H* as shown in figure 1(b). Under this condition, the roughness will not influence the Green function amplitude, but only the phase. So the received signal for a fixed frequency *f* at point *Q* backscattered by the insonified surface *A* can be described by Helmholtz-Kirchhoff integration [2]:

$$P(f) = \int_A -j2\pi f P_0(f) G_r(\bar{r}) \Phi_r(\bar{r}, f) R(\bar{r}, f) G_p(\bar{r}) \Phi_p(\bar{r}, f) \sin(\theta) ds \qquad (1)$$

where P_0 is the source pressure, G_p and G_r are the Green function, c is the acoustic velocity in the water, Φ_p and Φ_r

are the sonar transmitting and receiving directivity functions, and R is the bottom backscattering coefficient. The insonified surface A is proportional to the sonar maximum open angle α_m and the distance H: $A = \pi(H \tan \alpha_m)^2$. Since the signals backscattered in the same radius in the insonified area are received at the same time which is equivalent to the same backscattering angle, we can estimate the backscattering coefficient as a function of frequency and backscattering angle.

3. BACKSCATTERING COEFFICIENT ESTIMATION METHOD

3-1. Time-frequency representation adapted to chirp

From the backscattering model, the received signal is composed of a sum of transmitted signals with different time delays. In our experiment, the transmitted signal is a chirp which is a signal with linear frequency modulation:

$$e(t) = ae^{i2\pi(f_o - \frac{B}{2} + \frac{B}{2}t)t} \qquad (2)$$

For analysis purpose of the received echo signal s(t), the Chirp Adapted time-frequency representation (CA) [2] is used

$$P_s(t,f) = \iint \left| g(\frac{\tau}{2}) \right|^2 h(t-u)e^{j2\pi\alpha\tau(t-u)} s(u+\frac{\tau}{2}) s^*(u-\frac{\tau}{2}) e^{-j2\pi f\tau} du d\tau \qquad (3)$$

This CA distribution is a kind of smoothed Wigner distribution, which has a kernel function adapted to the transmitted chirp signal with a frequency modulation rate α. With a suitable set of parameters, this CA representation can give an approximate signal's energy distribution for multicomponent chirp signal.

3-2. Incident angle-frequency representation

From the CA method proposed above, we propose to give a representation which is related to the backscattering coefficient as a function of frequency and angle. Let us suppose that the spectrum of the chirp is flat in the working frequency band, so an impulse signal can be obtained by a dechirping processing

$$x(t) = s(t) \cdot e^{j2\pi \frac{\beta}{2} t^2} \qquad (4)$$

where the modulation rate β equals to:

$$\beta = \frac{\pi}{2} - \alpha \qquad (5)$$

in the time-frequency plane. α is the signal modulation rate. Because the operation changes the chirp to another frequency modulation rate, the time-frequency representation of the modulated signal is obtained by rotating that of the original signal s(t):

$$P_x(t, f) = P_s(t - \frac{f}{\beta}, f) \qquad (6)$$

This equation means that the chirp modulation is simply a rotation of the original signal's time-frequency representation which is very easy to be realized. The resulted time-frequency representation is the time-frequency representation of the impulse response or the backscattering coefficient, if the transducer and propagation effects are removed from the echo.

In order to obtain the angle-frequency representation of the backscattering coefficient, the time axis is then converted to the angle axis by the relationship:

$$t = \frac{2R}{c} = \frac{2H}{c\cos(\theta)} \qquad (7)$$

This relationship can only be used when the backscattering comes from the water/sediment interference. As this relation is nonlinear, the interpolation has to be used when transfer the time-frequency representation into the angle-frequency representation $P(\theta, f)$.

4. EXPERIMENTAL DATA ANALYSIS

From the backscatting model, the backscattering coefficient is estimated with the bottom impulse response. In order to obtain this coefficient by the time-frequency method mentioned above, the transducer's transfer function, the directivity function and the propagation attenuation have to be removed from the echo. So before applying the time-frequency method, echoes are at first treated with the deconvolution to eliminate the transducer's transfer function and the propagation attenuation. Then in the angle-frequency plane, the transducer's directivity function is compensated.

4-1 Deconvolution for eliminating the transducer's influence

Since the transducer's transfer function in the working frequency band is not as flat as ideal chirp, a water/air interface echo is used to compensate the transducer's influence. The acoustic impedance in the water is much important than that in the air, so the water/air interface could be supposed as a perfect reflection surface:

$$R(\bar{r}, f) = \delta(\bar{r}) \qquad (8)$$

Replacing this equation into the backscattering model (4), we obtain:

$$p_s(t) = \int_{-\infty}^{\infty} -j2\pi f P_0(f) \frac{e^{-j2\pi f\tau}}{H_0^{\,2}} \Phi_p(f)\Phi_r(f) e^{j2\pi t f} df \qquad (9)$$

where H_0 is the vertical distance between the surface and the transducer. Hence, the surface echo contains only the transducer's transfer function and the transmitted signal e(t):

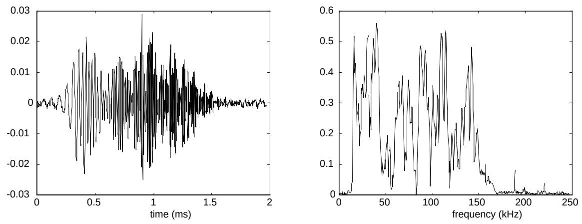
$$s_{surf}(t)=p_s(t)*e(t) \qquad (10)$$

Comparing equation (9) with equation (4), the transducer's transfer function can be canceled by the deconvolution of the bottom echo with the surface echo:

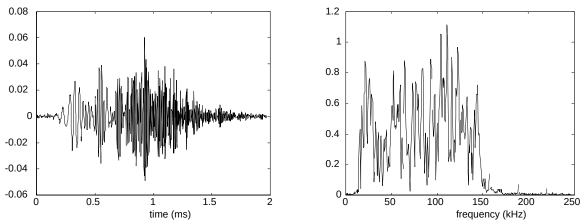
$$y(t)=\begin{cases} F^{-1}\left\{\dfrac{S(f)H^2}{\left|S_{surf}(f)\right|H_0^{\,2}+q}\right\}, & f\in[f_0 \quad f_1] \\ F^{-1}\left\{\dfrac{S(f)H^2}{H_0^{\,2}}\right\}, & f\notin[f_0 \quad f_1] \end{cases} \qquad (11)$$

where *S(f)* and $S_{surf}(f)$ are the spectrum of bottom and surface echoes, *H* and H_0 are the distances between the transducer and bottom and between the transducer and surface, *q* is a constant to be determined, in our work which is chosen as [4]:

$$q = 0.01\left|S_{surf}(f)\right|_{\max} \qquad (12)$$



(a) sand bottom



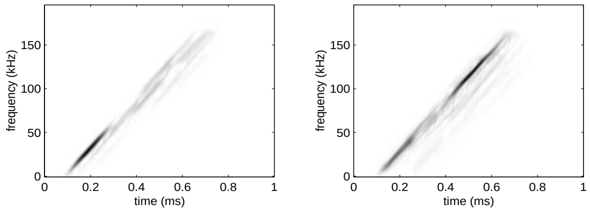
(b) pebble bottom

Fig. 2 deconvolved signals and their spectrum

In this deconvolution, we consider only the spectral amplitude but not the phase, so the obtained signal is still a chirp signal that will be analyzed by the chirp adapted time-frequency representation. A processed sand bottom echo and a pebble bottom echo which are collected in the lake Geneva with the wideband sonar and their spectrum are presented in figure 2.

4-2 Backscattering coefficient estimation

The deconvoluted echoes are then analyzed by the chirp adapted time-frequency representation as shown in figure 3. Then the time-frequency representation is modulated as the impulse response representation. By the relationship between the time and the incident angle of equation (7), the time-frequency representation is converted into the angle-frequency representation.



(a) sand bottom (b) pebble bottom

Fig. 3 Chirp adapted time-frequency representation of bottom echoes

Since the surface is assumed to be a perfect reflection plan, its impulse response is a delta function as given in equation (8). Under this condition, the transducer directivity function has not been considered in the deconvolution procedure. Then the obtained angle-frequency representation is compensated by the used sonar directivity function which is identity in the whole working frequency band [6]:

$$\Phi(\theta)=\left[\frac{\sin(90\theta/\alpha_v)}{90\theta/\alpha_v\ \sin\theta}\right]^{1/2}\cos(90\theta/\alpha_v) \qquad (13)$$

where α_v is the maximum open angle which equals to 24° in our sonar of which the directivity function is given in figure 4.

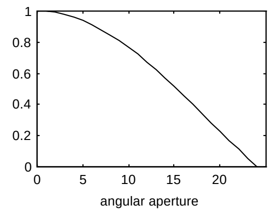
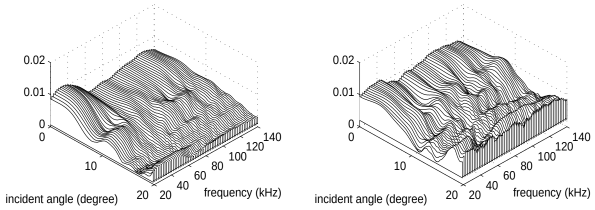


Fig.4 The directivity function of our used sonar

After the compensation of the directivity function, the angle-frequency representation of the backscattering coefficient is obtained by the square root of the representation. In practice, the representations of 36 echoes for the both types of bottom collected successively in the same place are averaged. which is shown in figure 5. From the 3-D figures, we can see that the backscattering coefficient of the sand bottom decreases as a function of frequency and of incident angle also. These phenomena can be caused by little roughness interface, the reflection is important, so the backscattering will decrease when incident angle increases. In the contrary, for the bottom with greater roughness, the pebble bottom, the backscattering coefficient is nearly independent of the incident angle and frequency. That is because the roughness is great, the scattering phenomenon becomes important and independent of the incident angle.



(a) Sand bottom (b) Pebble bottom

Fig. 5 Estimated backscattering coefficient as a function of frequency and incident angle

4-3. Bottom classification

The backscattering coefficient estimated by the method mentioned above is used to the classification of different types of lacustrine bottom: clay bottom, sand bottom, gravel bottom, pebble bottom, and rock bottom. The parameters used for the classification are the signal energy and the concentration/dispersion of the energy in the angle-frequency plane which is defined as the number of efficient elements in the time-frequency representation. Each element is a rectangular cell of 0.02msx6kHz. The efficient element means that its energy exceeds 10% of the maximum value of all the element energy in the analyzed signal time-frequency distribution. For the classification, the method of discriminant factorial analysis is used and the classification result is given in table 1. 108 echoes for each type of bottom are used for training and other 108 echoes are used for test. Since only two parameters are used, the calculating time for classification is much shorter than the earlier work and the results are the same [7].

	Learning	Testing
	Recognition rate (%)	Recognition rate (%)
clay	88.81	88.17
sand	77.52	77.59
gravel	81.74	81.78
pebble	76.78	75.81
rock	74.53	73.94
average	79.88	79.46

Tab 1. Classification result of 5 types of bottom

5. CONCLUSION

In this article, we have estimated the bottom backscattering coefficient as a function of incident angle and frequency. The backscattering coefficient is very different for the smooth bottom and rough bottom. The dependence of the incident angle and frequency of the backscattering coefficient can be studied at the same time which is helpful for establishing the bottom backscattering model. The bottom classification based on this distribution is more efficient than earlier work.

6. REFERENCES

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