SINGLE RECEIVER RAPID GEOACOUSTIC INVERSION IN SHALLOW WATER

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Abstract

The sediment density and compressional sound speed in shallow water can be estimated using a single receiver PANDA (Pop-up Ambient Noise Data Acquisition system) deployed by a small vessel which then tows a small source, before returning to collect the PANDA. The impulse response function of the shallow water channel is estimated through deconvolution processing that can highly improve the time resolution of signal. Based on this processing, more accurate estimations of the geometry and corresponding bottom-reflecting coefficients can be achieved. The sediment density and compressional sound speed can then be estimated through optimum processing. Such geoacoustic inversion method is presented in this paper with some simulation results applicable to local waters.

Introduction

Geoacoustic inversion can be used to indirectly measure the acoustic properties of marine sediments, which is important for predicting sonar performance and environmental acoustic impact. Conventional geoacoustic inversion relies on matched field processing [1], generally requiring a receiving array and a sophisticated acoustic propagation model. The output value of some performance metric, such as a least square mismatch function, is used to select the best estimate of the environmental parameters used in the acoustic field prediction model. The drawbacks of such an approach are the high computational load (both in applying the prediction model and in conducting the global optimization search) and the poorly constrained inverse that can result in multiple solutions for the layer structure. A faster, more robust method is desirable for rapid environmental assessment in shallow waters. At typical mid-range sonar frequencies, the most important characteristics of the seabed are the density and sound speed of the superficial sediment, followed perhaps by roughness. If we restrict our attention to these parameters in the first instance, we are able to develop a technique that gives a more robust and quicker solution. The sediment density and compressional sound speed can be estimated using a single receiver PANDA [2] deployed by a small vessel which then tows a small source, before returning to collect the PANDA. Data collection and basic results can be obtained for a new site in 30 minutes.

Basic idea for this method will be introduced in the second part, followed by some practical considerations. Some simulation results applicable to local waters will be given in the fourth part. The last part will conclude the whole paper.

Basic Idea

The geometry described in Fig. 1 gives the basic idea of the technique. Supposing the single receiver PANDA (developed in ARL, see Fig. 2) is anchored h_2 meters off sea bottom, the transmitting source is with the depth of h_1 meters from the surface, water depth is h_0 meters, we can easily employ the image source principle to estimate the source horizontal position x with respect to the center of PANDA, if we could accurately measure the range difference, dr_1, between direct path and surface-reflected path, or the range difference, dr_2, between direct path and bottom-reflected path. Assuming the sound speed in water is constant and known, a rather simple relationship can be constructed as follows,

$$x = \left[\left(\frac{d_1^2 - d_0^2 - dr_1^2}{2dr_1}\right)^2 - d_0^2 \right]^{1/2} \text{ or } x = \left[\left(\frac{d_2^2 - d_0^2 - dr_2^2}{2dr_2}\right)^2 - d_0^2 \right]^{1/2} \quad (1)$$

where

$d_0=h_0-h_1-h_2$; $d_1=h_0+h_1-h_2$; $d_2=h_0-h_1+h_2$

Due to the small values of dr_1 or dr_2 at larger x, the estimation based on Eq. 1 will be affected by measurement error to a great degree. Therefore, more accurate measurement of the dr_1 or dr_2 is required to reduce this error. Also, two estimations coming from two equations above can be compared with each other to check the estimation quality.

Once we get the estimation of source horizontal position x, the incident angle to the bottom θ and other unknown variables in Fig. 1 can be calculated. Hence, by comparing the amplitudes of direct path signal and bottom reflected signal, we can obtain the bottom-reflecting coefficient at this source position. Of course, the difference of geometry spreading and absorption should be deducted if any. Furthermore, the scattering loss due to the possible roughness of the bottom can be taken into account. That will provide the possibility to invert the roughness of bottom, another important parameter describing the sea bottom acoustic property.

During the data collection, the acoustic source (suspended on the vessel) periodically transmits sound pulses while the vessel is freely drifting away from the PANDA. A large number of data points will be obtained constructing the bottom-reflecting coefficient curve, which the final inversion of the bottom properties will be based on and the more accurate estimation will be made from.

Practical Considerations

In the first step of study, we just concern about two parameters of the sediment (ρ and c). So, the frequency we intend to select should be lower enough to guarantee the scattering in the specular direction dominates. Meanwhile, this frequency should be kept to be high enough to minimize the coupling between different propagation modes, so that ray model holds true. 2k~4kHz frequency band seems to fulfill this criteria. In this band, the time resolution produced by matched filter processing will not be better than 0.5ms, which is not accurate enough to distinguish each path in shallow water. In order to separate each path and measure the differences between them, we need to consider both the signal processing and the deployment configuration. Apparently, if we adjust the depths of the source and PANDA, the range differences of dr_1 and dr_2 will change. Therefore, we could separate each path by optimizing these two depths. In the next section of simulation we will give an example to show how to make this selection. Meanwhile, some suitable signal processing can be adopted to improve the time resolution of signal. Since the transmitted waveform is known, one way of achieving this is to employ deconvolution processing to estimate the impulse response function of the underwater acoustic channel, which approximates a series of Delta function and provide more accurate arrival time of each path than other conventional processing.

Numerical Simulations

According to the idea stated in previous section, we have conducted some numerical simulations as preparation for trials. We assume the water depth is 20m, typical to most local waters; the transmitted signal is chosen to be a CW pulse with center frequency of 2kHz, pulse duration of 5ms and source level is 135dB; the sampling rate in PANDA is 10kHz, the received bandwidth is 500Hz. We add band-limited Gaussian noise with spectrum level of 50dB in the simulated raw data. The environmental parameters considered in the case are, the density of water is 1024kg/m^3, the sound speed in water is 1500m/s, the bottom density is 1200kg/m^3 and the sound speed in sea bottom is 1650m/s. Suppose the boat with the source drifts slowly away from the center of PANDA (therefore the Doppler effect is assumed negligible and not considered here), the space sampling rate is 1m and total sampling length is 100m, thus we have 100 received signals to be used.

Fig. 3 shows the optimization of depths of the PANDA and source. Suppose our system is able to distinguish the range difference dr of 1m, we can draw the working zone for deploying the PANDA and source. In Fig. 3 (a), the horizontal axis represents the PANDA's depth off the bottom, while vertical axis represents the source's depth from the surface. The 1st curve represents $dr_1=dr$. The source depth should be selected above the curve in order to keep the direct signal and surface-reflected signal apart. The 2nd curve represents $dr_2-dr_1=dr$. PANDA's depth should be selected bellow this curve in order to keep the surface-reflected signal and bottom-reflected signal apart. The intersection of the two zones, represented in yellow color, meets both criteria. Here, we assume without loss of generosity that h_1 is less than h_2 and then the surface-reflected signal is ahead of the bottom-reflected signal in time domain of received signal. We can also see that, when PANDA is closing to the middle depth of water (10m of 20m water column depth), the depth scope to deploy the source is largest, which means we could unnecessarily deploy it in particular depth although we should know its depth as accurate as possible. Fig. 3 (b) describes dr_1 and dr_2 at different positions if we set the depth of PANDA is 10m and the depth of source is 6m achieved from Fig. 3 (a). We can see that the two lines are well separated even at the horizontal position of 100m. The following simulations are under the assumption of h_1=6m and h_2=10m. When the water depth is shallower or the system resolution is not high enough, solution for the optimized depths perhaps does not exist to separate these paths. In such case, this method will not work or work with larger errors.

Fig. 4 describes the simulation results when the source is at positions of x=0m and x=100m. We observe that the direct signal and surface-reflected signal (phase-reversed) are detected in both of (a) and (b). The bottom-reflected signal in (a) is nearly invisible due to its much lower amplitude (about -33dB below the direct path), while in (b) it is well detected where the signal strength of direct path and that of the bottom-reflected path are comparable. In both (a) and (b), the three paths are well separated after deconvolution processing, although they are heavily overlapped in the raw received signal of (b).

Based on deconvolution processing, the geometry relationship and the transmission losses for different paths at different positions can be estimated. In Fig. 5 (a) and (b), the estimated values (the red lines) are well fitted with the theoretical ones (the blue lines). In (b), the ambient noise level is plotted in dashed line along with these transmission losses. We estimate the worst SNR is about 12dB, which is enough to support the application of deconvolution.

The calculated&smoothed (red line) and theoretical (blue line) bottom reflecting coefficients with different incident angles are plotted in Fig. 6. The search region covers the incident angles from 0° to 75°, and the theoretical critical angle for this bottom is 65.4°. For most of actual bottom, the sound speed and density are greater than these and better results (due to better SNR) can be expected. Least mean square criteria can be applied to Fig. 6 to get the final estimations. Newton optimization scheme with initial values through some forward processing can help to accelerate the search process, which has been shown in Fig. 7.

Conclusion and Works being done

A new single receiver rapid geoacoustic inversion method has been studied through simulations, which is best suitable for superficial sediment inversion in range-dependent shallow water environment. The arrival time structure of the recorded sound pulses is employed to estimate the geometry and helps to estimate the bottom reflecting coefficients. Basic results can be obtained for a new site in 30 minutes or so. This advantage makes it most suitable for rapid geophysical survey along the coast. The superficial sediments properties along with some ambient noise information acquired by the same PANDA can be integrated into GIS system.

Experimental system is being developed and the plan to sample actual data that will be compared with the ground-truthing results is going on. The model used in this simulation should be further improved, because the ambient noise in local waters can change very large due to the snapping shrimp [3]. Extra energy loss coming from the bottom roughness and other factors should be included in the present model. And we are looking for a new transducer to acquire higher source level. Deconvolution processing algorithm needs to be more robust. All of these are being studied in ARL.

Reference

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[2] Teong Beng Koay; Potter, J.R.; Johansson, T.; Venugopalan, P., OCEANS, 2001. MTS/IEEE Conference and Exhibition , Volume: 3 , 2001

[3] Potter J.R. and Koay T.B., Do snapping shrimp chorus in time or cluster in space? Temporal-spatial studies of high-frequewncy ambient noise in Singapore waters. European Conference on Underwater Acoustics 2000, Lyons, France. July 2000

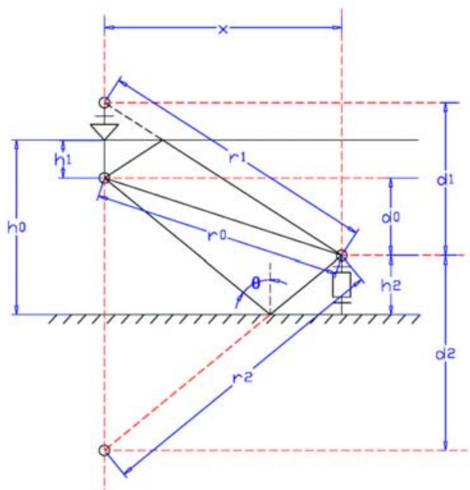
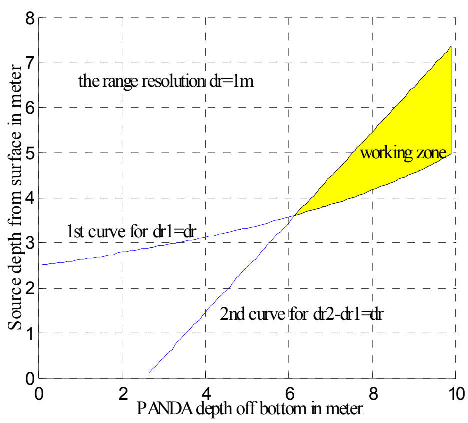
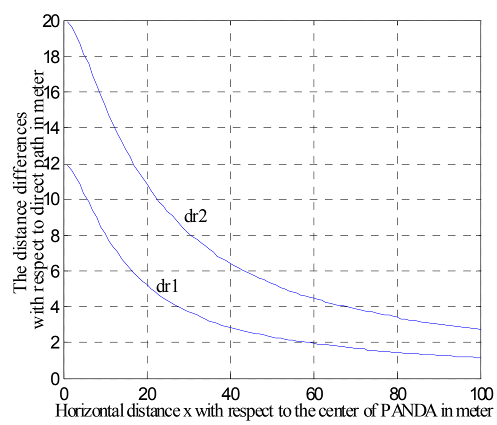


Fig. 1 Geometric description of single receiver geoacoustic inversion

Fig. 2 PANDA before deploying

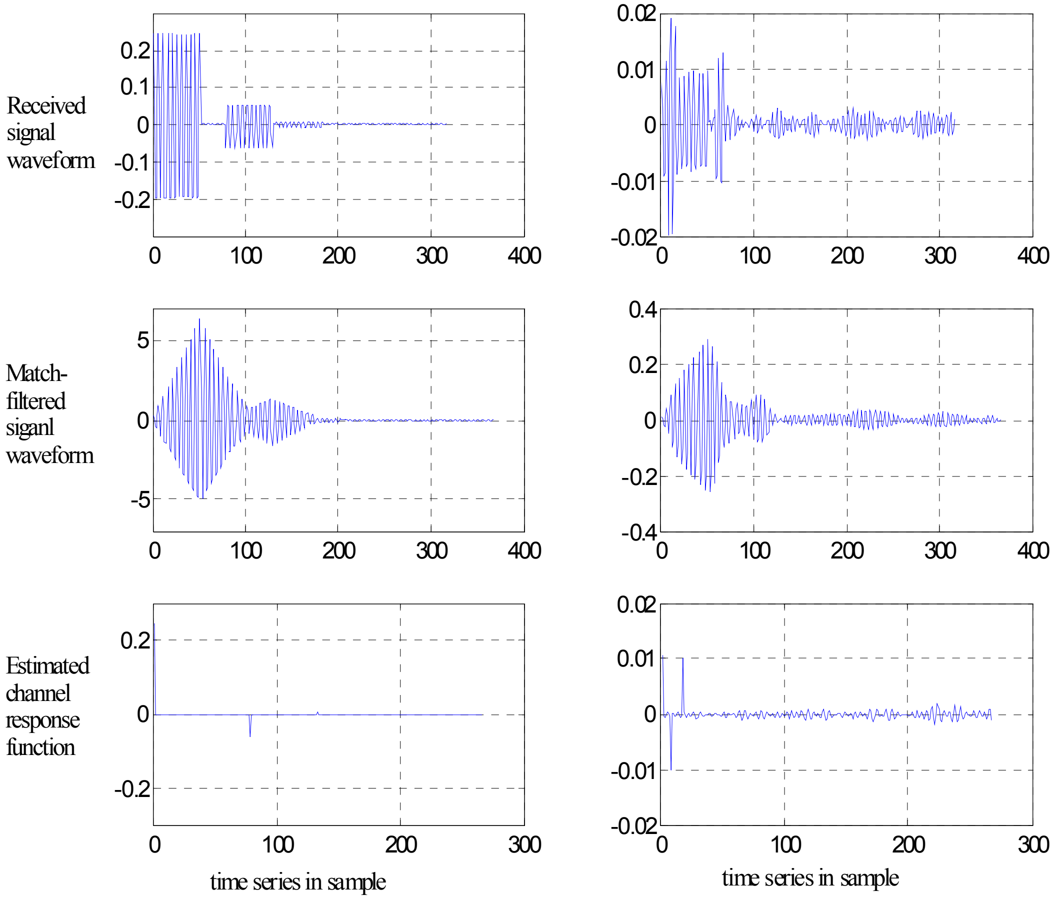


(a) Optimization of depths of the PANDA and source with *dr*=1m



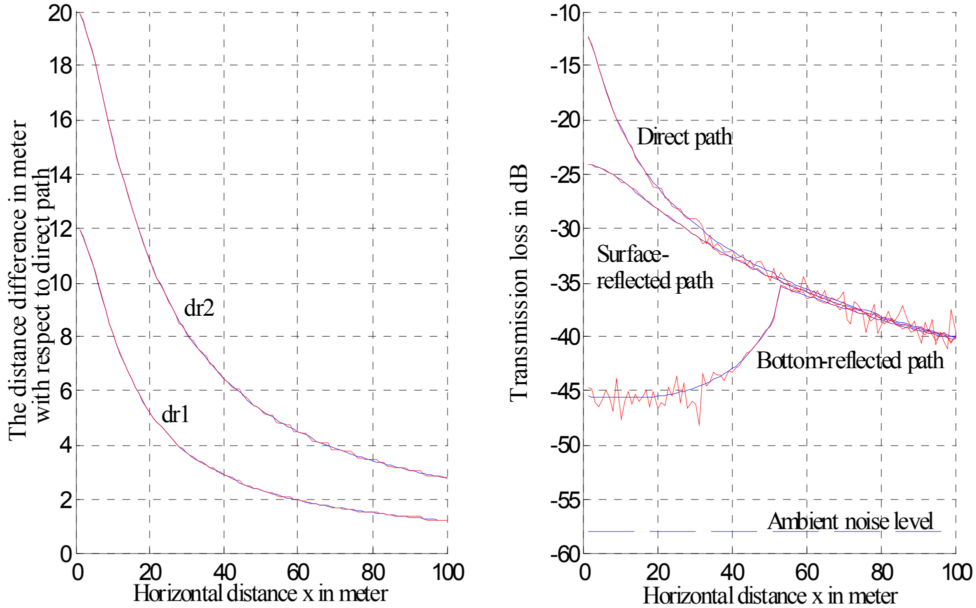
(b) The range difference example for *h1*=6m, *h2*=10m

Fig. 3 Optimization of the depths of the PANDA and source to separate direct path, surface reflected path and bottom reflected path



(a) Horizontal position x=0m (b) Horizontal position x=100m

Fig. 4 Deconvolution processing to estimate the channel response function



(a) The geometries (b) The transmission losses

Fig. 5 The theoretical and estimated geometries and transmission losses

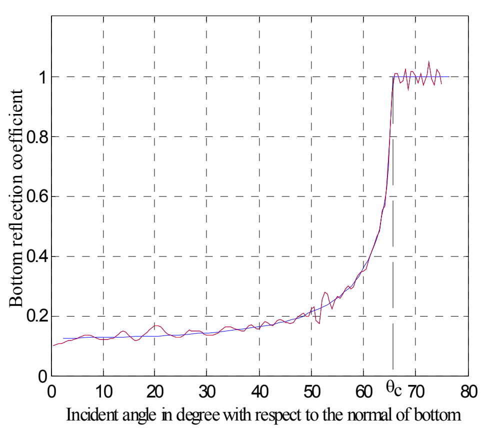


Fig. 6 The theoretical (blue) and estimated (red) bottom reflection coefficients

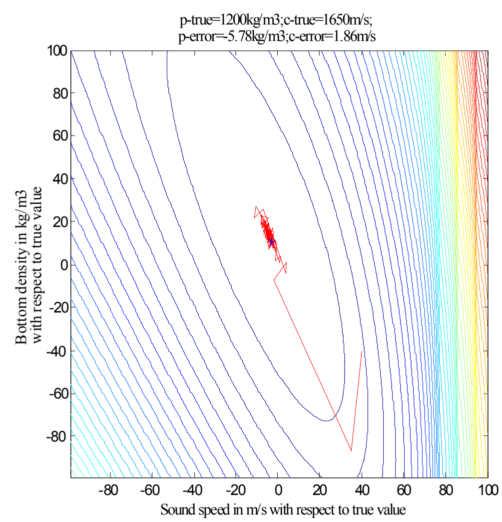


Fig. 7 Optimization processing with Newton method