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# A Direct Inversion Method to Remotely Measure the Concentration Profile of Suspended Sediment Using Acoustic Backscatterance

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## 1. Introduction

The use of acoustics to measure the concentration profile of suspended sediment become increasing common. Field studies have shown the usefulness of remotely measuring the suspended sediment concentration with high spatial and temporal resolution. Techniques that allow for the conversion of the backscattered acoustic intensity into suspended sediment concentration have been developed concurrent with instrumentation.

When a short pulse of acoustic wave energy propagates through suspended sediment, it continuously send back a part of its energy scattered by sediment particles. The returned acoustic wave is not a pulse but a continuous wave train, that is a continuous stream of returned pulses. The time delay between transmission and a certain point of the returned wave train is proportional to the distance from the sensor to the sediment particles. The envelope of the returned wave train contains information on the characteristics of the ocean water and the sediment particles in suspension along the sound path.

The acoustic measurement of suspended sediment concentration requires an inversion technique that accounts for all the acoustic scattering and energy loss mechanisms. The backscattered acoustic intensity at any particular range is affected by the entire concentration field through which the sound travels. thus the inversion generally involves successive iteration along the sound path. The present study introduces an explicit solution to acoustic backscatter equation, and compares it with iterative solution.

## 2. Near Field Concentration

The relationship between the sediment concentration C at distance r is described in the following acoustic backscatter equation (ABE)

$$AC(r) = V(r)^2 r^2 \exp \int_0^r 4\left[\alpha_w + \alpha_s C(r')\right] dr' \qquad \text{(ABE)}$$

where A, $\alpha_w$ and $\alpha_s$ are determined in laboratory calibration of the transducer with specific sediment sample. V is the voltage measured at the transducer.

The difficulties of the inversion mainly arise from the two facts: firstly, the ABE is nonlinear and implicit, and secondly, the boundary condition is not prescribed. Specifying the boundary condition is equivalent to finding the near field concentration. The transmitter of acoustic pulse is usually a circular plate of finite radius. It does not radiate like a point source at short distances. This region is called near field. The acoustic wave field is very irregular, and the interaction between sound and suspended particles is somewhat complicated to be formulated in an analytical equation.

In the field application, the usual purpose of acoustic profiling is to measure the suspended sediment concentration near the ocean bed which is in the acoustic far field. The boundary point is put in the far field but very close to the near field limit. Without considering the details of the consideration in the near field, the suspended sediment concentration at the boundary point is calculated with the far field ABE assuming that the concentration is uniform from the transducer to the point. this method proved successful in the laboratory with uniform concentration of sand up to 3.5 g/l.

## 3. Far Field Concentration

### Iterative Solution

The nonlinear implicit ABE is converted in a discrete form and solved iteratively with the near field concentration as an input. The sediment concentration at the following points through the sound path are also solved iteratively in a successive manner.

### Direct Solution

By taking logarithm of ABE, solving for V(r), and taking derivative with respect of r, we get the following Bernoulli type nonlinear ordinary differential equation

$$C' + \left[ -4\alpha_w - 2\frac{rV' + V}{rV} \right] C = 4\alpha_s C^2$$

The above differential equation has the following analytical solution

$$C(r) = \frac{V(r)^2 r^2 \exp(4\alpha_w r)}{\gamma - 4\alpha_s \int_{r_1}^{r} V(r')^2 r'^2 \exp(4\alpha_w r') dr'}$$

where $\gamma$ is an integration constant which is determined by the sediment concentration at the boundary point $r_i$.

The inversion times for the different methods are compared using a uniform concentration profile with superimposed random fluctuations. The direct method is approximately 1000 times faster than the iteration method when solved with an i486-based computer The inversion range and the spatial resolution were 123-600 mm and 3 mm, respectively. The iterative solution was obtained with the Matlab command 'fsolve'.

## 4. Conclusions

The newly found explicit solution to ABE reduces the computation time significantly during the inversion process. This is of practical importance because the size of an acoustic data set is usually quite large. The inversion process is reliable if the scattering coefficients and the near field concentration are known accurately.

The near field effect can be included in the inverted quantities by calculating the boundary condition with the far field ABE and under the assumption of uniform near field concentration. This method proved successful in the laboratory with uniform suspended sediment concentration up to 3.5 g/l.

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