4aUWa3. Data-based sensitivity kernel in a highly reverberating cavity

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Our goal is to acoustically localize medium inhomogeneities, (i.e., scatterers) in a very complex medium without having to resort to constructing an accurate propagation model. Instead, we use a data-based sensitivity kernel approach to characterize medium changes in this complex medium which, in this study, is a highly reverberating cavity. The efficacy of the method is confirmed in an experiment with a moving aggregate of ping-pong balls inside a fish tank of 5.6m-diameter and water depth of 1.05m in the ~10KHz frequency regime; acoustic sources and receivers are on the periphery of the tank. Using a sensitivity kernel constructed from field data for scatterers at a sparse set of known positions, we demonstrate that we can localize other scatterers at unknown positions.

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INTRODUCTION

The main focus of this paper is to utilize a data-based method to localize changes in a very complicated medium without the use of a propagation model, and a sensitivity kernel (SK) analysis (Sarkar et al., 2011) provides a solution to this problem. Sensitivity kernel is used to define a relationship between a change in the acoustic field and a local change in the medium property. In underwater acoustics, it has been used in travel time tomography (Skarsoulis and Cornuelle, 2004), for a local change in density (Marandet et al., 2011) or sound speed (Roux et al., 2011), surface scattering in a waveguide (Sarkar et al., 2012). In this paper, we perform sensitivity kernel analysis experimentally, in a fish tank, which determines the perturbation in the acoustic field as a function of a local perturbation at a scatterer position. The sensitivity kernel is obtained by measuring the difference of the scattered field with and without the scatterer inside the fish tank. This difference in between the two field is then used to localize scatterers at any position within the (sensitivity kernel) measurement region.

EXPERIMENTAL SETUP

Experimental geometry

An experiment is performed inside a fish tank of 5.6m-diameter and water depth of 1.05m on an aggregate of ping-pong balls (Figure 1). The source and receiver sensors are located on a sensor cable of which diameter is 5.2m, and the depth of the sensors vary between 0.2 - 0.8m. In total, 24 sensors are used for signal acquisition, with 8 sources, of which inter-element spacing is approximately 2m, and 16 receivers, of which inter-element spacing is approximately 1 m. In this experiment, the scatterer is an aggregate of 4 ping-pong balls, which are identical with a 4cm-diameter. The SK region, where we observe changes in the medium, is a 13x13 grid with 10 cm grid spacing, at the center of the fish tank. This is the region where the scatterer is moved from one position to another until the completion of sparse set of 169 grid points. Here for the sake of the reader, we will call measurements at the grid points as known positions. Five more measurements are performed when the scatter is in between the grid points, which we will call as unknown positions.

![Figure 1](image.png)

**Figure 1:** a) Experiment was performed inside a fish tank of 5.6m-diameter and water depth of 1.05m on an aggregate of 4 ping-pong balls. Set-up includes 8 sources of which inter-element spacing is approximately 2m, and 16 receivers of which inter-element spacing is approximately 1 m. The source and receiver sensors are on a cable of which diameter is 5.2m, and the depth of the sensors vary between 0.2-0.8m. b) A two period pulse is generated at source 1 while time series composed by the echoes from the reverberations into the tank are recorded on all 16 receivers, and same pulse is transmitted using all the other sources, respectively. One round of signal acquisition completes itself in 5 seconds, which we call as one shot.
Signal acquisition

Signal acquisition is performed with and without the scatterers inside the tank. First type of the measurements gives us unperturbed field, where the recorded echoes have been reverberated by the fixed boundaries of the tank. Second type of the measurement gives us perturbed field, where the recorded echoes now also includes echoes reverberated by the scatterer. A differentiation of unperturbed field from perturbed field will be used for localization purposes.

A two period pulse is generated at source #1 (Figure 1.b for source and receiver geometry) while time series composed by the echoes from the reverberations into the tank are recorded on all 16 receivers, and same pulse is transmitted using all the other sources, respectively. Pulses used in this experiment consist of 10kHz and 20kHz center frequency simultaneously with a sampling frequency of 100 kHz. In this work, we show results from data with a bandwidth of 6-14 kHz.

Sensitivity Kernel Analysis

Derivation of Unperturbed Field

SK analysis requires the difference of unperturbed field and perturbed field to keep track of the changes in the medium. Therefore, obtaining a good unperturbed field is an important step in a SK problem. We can derive unperturbed field using three different methods. The first method includes an average of two unperturbed field measurements; one before and one after SK experiment. The second method is to implement a moving average of perturbed field. That is, for each target position, unperturbed field is obtained using average of ~20 successive target positions; e.g. for position 50, an average of [40 : 60] positions were used. While first two methods are known, third method has been found during this work and it is an elegant way of obtaining the unperturbed field. In this method, for each source-receiver pair we form a data matrix, $G_u$, which consists a set of whole or part of the time series of [1:174] positions and we perform a Singular Value Decomposition (SVD) on matrix $G_u$. The first singular value gives us the unperturbed field, whereas the rest of the singular values represent the subtracted field. In Figure 2, we have shown perturbed field, and unperturbed field obtained using moving average. As it is seen, both fields are quite similar to each other. However, one can see the subtle difference between the two by looking at the subtracted field in Figure 3.a. Notice that the amplitude and arrival times are only due to the scatterer. Figure 3 also shows the comparison of subtracted field using SVD and moving average.

Localization without using a model

Localization of scatterers involves the difference of perturbed field and unperturbed field. Here, we show an amplitude-based sensitivity kernel method. Amplitude of subtracted field for each source-receiver pair at a particular position of the scatterer is calculated, and a data matrix $G$ is formed. Solving the problem for position $P_n$

$$[A] = [G] [P]$$

gives us the location of the target. Here, we only show the localization results of the target at unknown position as localization of the target at known positions is only a matching problem. The method works very well for single and multi-target localization. Figure 4 shows localization results for a) a single target b) multi-target.
FIGURE 2: Comparison of perturbed and unperturbed field for source#1 and receiver#5.

FIGURE 3: Subtracted field (perturbed-unperturbed) comparison for source#1 and receiver#5, target position [40:143] a) using SVD b) using moving average.

CONCLUSIONS

Experimental data, obtained in a highly reverberating fish tank, were analyzed using a data-based sensitivity kernel method. Experiment involved two type of measurements; with
scatterer and without scatterer inside the tank. The inhomogeneities in the medium, due to scatterers, were detected by subtracting unperturbed field from perturbed field. Amplitude of the subtracted field is used to localize the scatterers at known and unknown positions. The method works very well for localization of a single scatterer at unknown positions. Multi-targets at unknown positions were also localized successfully with a resolution less than the single-target localization.

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