Office of Naval Research Graduate Traineeship Award in Ocean Acoustics for Hadi Tavakoli Nia

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LONG-TERM GOALS

The long term goal of this research is to develop a method for probing the ocean and ocean sediment at larger depth for imaging submerged objects at high resolution. We aim to use nonlinear scattering of sound in the presence of inhomogeneities to obtain high resolution images at high penetration depth. Through the developed theory, we can tackle the problem of high attenuation of acoustic field at high frequencies in ocean sediment, and the low resolution of low frequencies on the other hand.

Another goal of this research is to formulate a unified theory and model of reverberation from ocean sediments. The reverberation theories and models are different for different environments, frequencies and angular dependencies. This fact necessitates a unified model that can be used for these parameters.

OBJECTIVES

(1) Developing a method for probing the ocean and ocean sediment based on a nonlinear theory developed for the scattering of sound in the presence of inhomogeneities.

(2) Formulating a unified theory and model of reverberation from ocean sediment.

APPROACH

Detection of buried objects in ocean sediments is hindered by the following problems: (i) high frequency, high resolution images lead to high attenuation of acoustic field in ocean sediments, (ii) low frequencies lead to much lower target strengths and poorer resolution. Through a developed theory on nonlinear scattering of sound, we tackle the above problems. The use of two incident waves differing slightly in frequency results in sum and difference frequency waves that, by appropriate choice of the incident frequencies, can achieve both higher penetration into sediment and better resolution. For objects with different geometries and acoustic properties we have shown that the the physics of the response are different [1]. Exploiting these differences is key in detecting and discriminating submerged and buried objects.

Using the seafloor reverberation measurements from Ocean Acoustic Waveguide Remote Sensing (OAWRS) experiments in 2003 and 2006, we will formulate a unified reverberation theory for the different ranges, frequencies and grazing angles used in these experiments [2]. The different frequency

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14. ABSTRACT
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bands provide a wide range of low frequency measurements to verify and potentially improve the existing low- frequency sea-bottom reverberation models.   The grazing angles for modes 1-10 (dominant modes at the measured frequencies) ranges from 2 to 12 degrees that makes it possible to obtain angular dependency of bottom scattering strengths.

We will also use the matched filter to estimate the bottom characteristics from the data obtained in 2003 and 2006 experiments. The matched filter is applied in many remote sensing systems to provide high resolution imaging. In reverberation analysis of seafloor, scattered returns from inhomogeneities are matched filtered to determine the bottom characteristics such as the coherence volume. We will the theory developed for the statistical moments of the broadband matched filtered filed simultaneously scattered from random distribution of scatterers [3].

WORK COMPLETED

A theory for nonlinear scattering of sound in the presence of inhomogeneities has been derived and will be used in detection of submerged targets at higher resolution and depth. From the equations of mass conservation, momentum conservation and state, the second-order nonlinear wave equation in the presence of inhomogeneities was derived, and a general solution was obtained in the form of a volume integral, which was evaluated for a number of canonical cases.

We showed that the second-order scattered field is comprised of three distinct physical mechanisms given two non-collinear incident plane waves, typically chosen at two different frequencies. In the mechanism, which we call "interaction-before-scattering," a propagating scattered second-order field is generated from the interaction of the object with a non-propagating second-order incident field caused by nonlinear interaction of the non-collinear incident plane waves. In the mechanism which we call "interaction-after-scattering," a second-order scattered field is generated from the nonlinear interaction of the linearly scattered incident fields. Finally, in what we call the "advective mechanism," the residual second-order displacement field of the inhomogeneity on its boundary leads to second-order radiation from a field of monopolar and dipolar sources.

The use of two incident waves results in sum and difference frequency waves that by appropriate choice of the incident frequencies can achieve both higher penetration into sediment and better resolution. For objects with different geometries and acoustic
properties we have shown that the contribution of each mechanism, and consequently the physics of the response are different. We utilize these differences in imaging and detecting submerged and buried objects.

IMPACT/APPLICATIONS

We have developed a theory for nonlinear scattering of sound in the presence of an inhomogeneity insonified by two plane waves at slightly different frequency, and have explained the mechanisms through which sum and difference frequency waves are generated. Our theory can be used in detection and discrimination of objects buried in seafloor sediments, by simultaneously using the high penetration of the incident low frequency waves and the high resolution of the sum frequency wave.

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