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FAST ACOUSTIC IMAGING FOR A 3D PENETRABLE OBJECT IMMERSED IN A SHALLOW WATER WAVEGUIDE*

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Abstract

The paper is concerned with the inverse problem for reconstructing a 3D penetrable object in a shallow water waveguide from the far-field data of the scattered fields with many acoustic point source incidences. An indicator sampling method is analyzed and presented for fast imaging the size, shape and location of such a penetrable object. The method has the advantages that a priori knowledge is avoided for the geometrical and material properties of the penetrable obstacle and the much complicated iterative techniques are avoided during the inversion. Numerical examples are given of successful shape reconstructions for several 3D penetrable obstacles having a variety of shapes. In particular, numerical results show that the proposed method is able to produce a good reconstruction of the size, shape and location of the penetrable target even for the case where the incident and observation points are restricted to some limited apertures.

Mathematics subject classification: 35R25, 35P25, 76Q05, 65M30, 81U40.
Key words: Oceanic waveguide, Penetrable object, Inverse problems, Indicator sampling method.

1. Introduction

The inverse domain problem of determining the shape of an unknown object from the knowledge of some scattered far-field patterns has drawn considerable attention in recent years due to its importance in many areas of science and technology. It is well-known that this inverse problem is not only nonlinear, but also severely improperly posed in the sense of Hadamard [1]. This means that the numerical solution of such an inverse problem is considerably difficult due to the fact that small perturbations of the far-field pattern can induce large errors in the determination of the shape of the obstacle. During the last two decades, various computational schemes have been developed for solving the inverse domain problem, such as nonlinear optimization or Newton-type iteration techniques [2], linear or indicator sampling methods [3-7], but such efforts focused primarily on the numerical solution for the inverse domain problem in a free space. More to the point, recent works on imaging penetrable objects in free-space, half-space and waveguides, some potential methods such as MUSIC-type algorithms and topological derivative based imaging inhomogeneities of small diameter look like very valuable [8-11], At the same time, analysis of resolution and stability with respect to measurement as well as medium

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noise of the imaging algorithms were performed there. On the other hand, Multistatic imaging of extended targets has been studied in [12].

As well known, the seas occupying more than two-thirds of the surface of the earth are places where a great variety of natural and man-made objects (such as sea mounts, mineral deposits, submarines, sunken vessels, leaky pipelines, submerged wreckage and navigational obstacles, etc.) are located. Acoustic waves are considered as the best tool to identify these objects due to its good propagation in water. Therefore, the inverse domain problem of identifying size, shape and location of an unknown object immersed in a water-filled guide from the scattered far-field information of known acoustic waves has received fairly considerable attention due to its considerable archeological, history and geophysical interest.

Some earlier schemes for solving the inverse domain problem by an impenetrable object in a shallow water waveguide are rather computer-intensive due to the fact that all of them are based on both some nonlinearized iterative techniques and some approximations to the solution of associated direct problem during the inversion[13-15]. Another scheme in this area is the so-called ICD method which is achieved by employing the intersecting canonical domain(ICD) approximation procedure to invert the field in a numerically more efficient manner[16-18]. However, the ICD method has a main disadvantage of being only applicable for the case of a cylindrically axisymmetric object.

It should be emphasized that in these schemes mentioned above, the prior knowledge of what kind of boundary condition on the unknown object is required. However, in practice, the prior information is not available. In order to avoid such an inherent defect in the previously mentioned schemes, a generated dual space indicator method[19-21] was introduced for imaging an impenetrable obstacle having any shape in a shallow water waveguide, which is achieved by the observation that the combination of the measured scattered field can approximate the waveguide Green's function very well when the source point of the waveguide Green's function is inside of the obstacle, but not so well when the source point is outside of the obstacle.

The paper is concerned with the inverse domain problem of the identification of a 3D penetrable object immersed in a shallow water waveguide with perfectly reflecting boundaries. This concern is motivated by the fact that in practice, the scattering object often is a penetrable inclusion, whose material properties differ from those in the surrounding fluid. To our knowledge, no investigation has been reported for the acoustic imaging of a 3D penetrable obstacle placed in a shallow water waveguide.

An indicator sampling method is introduced for solving the inverse penetrable obstacle problem in a shallow water waveguide, which belongs to a further development of a new group of fast acoustic imaging schemes for the inverse domain problem in a free space, good examples of which are found in [5-7]. The main contributions of the indicator sampling method are that its computational speed is rather fast, its implementation is computationally simple and it is no need for a priori information about the scattering object. However, the numerical solution for such an inverse domain problem in a shallow water waveguide does pose particularly challenging difficulties due to the filtering out high-spatial-frequency components of the scattered wavefield with range and the propagation of only finitely many modes[16].

The paper is organized as follows. In Section 2 the basis of the indicator sampling method is analyzed and presented for fast imaging a 3D penetrable object in a shallow water waveguide. In Section 3 the good efficiency of the proposed method is confirmed through a few numerical examples for several 3D penetrable obstacles having a variety of shapes from synthetic far-field data. The last section gives some conclusions and remarks.