Computers and Mathematics with Applications ▮ (▮▮▮▮) ▮▮▮–▮▮▮

Contents lists available at ScienceDirect

Computers and Mathematics with Applications

journal homepage: www.elsevier.com/locate/camwa

A simple method for detecting scatterers in a stratified ocean waveguide

Keji Liu

Shanghai Key Laboratory of Financial Information Technology, Institute of Scientific Computation and Financial Data Analysis, School of Mathematics, Shanghai University of Finance and Economics, 777 Guoding Road, Shanghai 200433, PR China

ARTICLE INFO

Article history:
Received 17 April 2018
Received in revised form 1 July 2018
Accepted 15 July 2018
Available online xxxx

Keywords:
Stratified ocean waveguide
Inverse scattering
Simple method
Optimal computation complexity

ABSTRACT

In this paper, we have designed a simple method for the inverse scattering problem of stratified ocean waveguide. The simple approach applies the bisection technique in parallel to estimate the boundaries of inhomogeneous media from the received partial data. In addition, the algorithm only involves the matrix–vector operations and possesses the optimal computation complexity in both two and three dimensions. In practice, it is easy to carry out, robust against noise and capable of reconstructing the penetrable obstacles of different locations and shapes. We can consider the simple method as a direct and straightforward process to supply satisfactory initial positions for the implementation of any existing more refined but computationally more demanding techniques to achieve accurate reconstructions of physical features of scatterers.

1. Introduction

The direct and inverse problems of underwater acoustics have been investigated extensively in recent years [1–8], and have essential practical applications in navigational objects, identification of seamounts, submarines, submerged wreckages, mineral deposits and so on. Initially, the one-layered waveguide bounded by two horizontal surfaces is usually employed for acoustics in a finite depth ocean, the numerical and theoretical achievements can be found in [9–13]. As we know that a typical sound velocity profile consists of three layers, namely, the surface channel, the thermocline and the isothermal layer [12]. In order to maintain all the physical features of ocean environment, the horizontal stratified waveguide in [14,15] is introduced as a simple but reasonably realistic model, see Fig. 1 for the demonstration.

In this model, because of temperature and pressure constraints, the velocity of acoustic waves varies with the depth of ocean. Due to the absorption of acoustic energy by the geometric spreading (divergence effect) and the propagation medium [15], a distinctive property of the submerged acoustic model is the *propagation losses*. Furthermore, owing to the reflection and refraction of the surface, bottom and the interfaces of each two adjacent layers, sound wave propagates in a special way. All these phenomenona increase the ill-posedness of the inverse problem notably, thus the reconstruction of unknown objects in the stratified system is much more complex than that in the homogeneous one. Based on the complexity of the problem in the stratified ocean waveguide, a "complete set of data" is always required from the aspect of engineering. Unfortunately, only partial data can be employed during the reconstruction process since the "complete data" is generally not available in practice.

Nevertheless, a large amount of efficient and impressive numerical algorithms are developed for detecting scatterers in the stratified ocean waveguide, for instance, the linear sampling method (LSM) [2,16–18], the optimization method (OM) [2,19], the multilevel sampling method (MSM) [5,6,20], the direct sampling method (DSM) [7] and so on. Among all

E-mail address: liu.keji@mail.shufe.edu.cn.

https://doi.org/10.1016/j.camwa.2018.07.030
0898-1221/© 2018 Elsevier Ltd. All rights reserved.

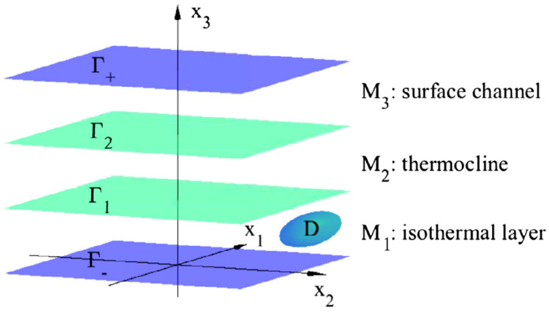

Fig. 1. The demonstration of three-layered ocean waveguide.

the existing techniques, one efficient and popular type of approaches [5–7] is based on some index functions that exhibit considerably different values for the interior and exterior of obstacles. And we are able to verify if a sampling point situates inside or outside the inhomogeneous inclusions from the indicators, and thus reconstructing their shapes and locations. However, all these algorithms have large computational burden, especially in three dimensions.

In this work, a simple method would be designed to reduce the computational burden immensely in both two and three dimensions. With the help of the indicator function, the method applies the bisection procedure in parallel to estimate the locations and shapes of scatterers in a three-layered ocean waveguide. It is worth mentioning that our method can be directly extended to solve any other inverse problems when an index function exists. In practice, the proposed algorithm can distinguish all the disjoint inhomogeneous obstacles quickly and easily. Furthermore, it is able to reconstruct objects of different features? ease of implementation and highly tolerant to noise. Moreover, the approach only applies the partial scattered data which is obtained from some curved lines of a cylinder's surface or some segments of a finite plane . As the simple method is only able to provide the approximate locations and shapes of obstacles, any existing effective but computationally more demanding algorithms (i.e. optimization process [1,2]) can be implemented in the recovered region for the further refinement of the approximation of each object as well as for the recovery of other physical features (i.e. the refractive index, density, etc.) of different media.

This paper is organized as follows. In Section 2, we will state the direct problem of stratified ocean waveguide in the three dimensions. In addition, some numerical techniques for solving the forward problem are proposed at the end of this section. Some indicator functions for the inverse scattering problem of three-layered ocean waveguide are shown in Section 3. Section 4 presents the simple method to solve the inverse scattering problem of our model. Several extensive numerical experiments are exhibited in Section 5 to evaluate the performance of the developed algorithm by the partial near-field data. Finally, some concluding remarks would be stated in Section 6.

2. The direct problem of three dimensional stratified ocean waveguide

The direct problem of our interest in the three dimensions would be exhibited in this section. We investigate a three-layered ocean waveguide of the following form

$$\mathbb{R}^3_h = \mathbb{R}^2 \times (0, h),$$

where h is the height of waveguide. The surface and bottom plane of ocean waveguide are expressed as

$$\Gamma_+ = \left\{x \in \mathbb{R}^3_h : \ x_3 = h\right\} \quad \text{and} \quad \Gamma_- := \left\{x \in \mathbb{R}^3_h : \ x_3 = 0\right\},$$

where the point x of waveguide is represented as follows

$$x := (\bar{x}, x_3)^\top = (x_1, x_2, x_3)^\top,$$

where the third coordinate axis is orthogonal to the horizontal surface. We describe the three interior layers of ocean waveguide separately as

$$\begin{aligned} M_1 &= \left\{x \in \mathbb{R}^3_h : \ 0 < x_3 < h_1\right\}, \\ M_2 &= \left\{x \in \mathbb{R}^3_h : \ h_1 < x_3 < h_2\right\}, \\ M_3 &= \left\{x \in \mathbb{R}^3_h : \ h_2 < x_3 < h\right\}, \end{aligned}$$

where h_1 and h_2 are positive constants that satisfy $h_1 < h_2 < h$. Moreover, the interface between M_1 and M_2 is denoted as $\Gamma_1 = \left\{x \in \mathbb{R}^3_h : \ x_3 = h_1\right\}$, and the one between M_2 and M_3 is shown as $\Gamma_2 = \left\{x \in \mathbb{R}^3_h : \ x_3 = h_2\right\}$. An inhomogeneous scatterer D is compactly buried in the three-layered waveguide $\mathbb{R}^3_h$, and the other part of the ocean waveguide is connected. Furthermore, the object D may sit in any place of the ocean waveguide and may possess any geometric shape. For the ease

Please cite this article in press as: K. Liu, A simple method for detecting scatterers in a stratified ocean waveguide, Computers and Mathematics with Applications (2018), https://doi.org/10.1016/j.camwa.2018.07.030.