Real-time geoacoustic inversion of broad band signals in deep water

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SHORT ABSTRACT: *This paper describes the development of a real time geoacoustic inversion tool devoted to broad band signals. The aim of this tool is to automatically infer geoacoustic bottom characteristics from transmission sound field pressure measurements in a deep ocean medium. The first part of the article is devoted to the direct problem. It describes the functionalities of the real time propagation simulation tool and its automatic connection with measurements parameters. Then the paper deals with an inversion method based on recent works on the subject in the scientific community. Finally real-time architecture and some concrete results obtained with in-situ data in the gulf of Oman are presented.*

Keywords: *Geoacoustic inversion, real time, underwater acoustic propagation, deep water, broad band.*

RÉSUMÉ COURT: *Cet article décrit le développement d'une méthode d'inversion géoacoustique temps-réel. L'objectif est d'inférer de façon automatisée les caractéristiques géoacoustiques de l'océan par grands fonds, à l'aide de signaux acoustiques large bande transmis dans l'océan entre une source et une antenne voisines de la surface. La première partie de l'article décrit le problème direct, et plus particulièrement les fonctionnalités du simulateur de propagation temps-réel développé, avant d'expliciter la méthode d'inversion mise en place. On présente ensuite l'architecture temps-réel mise en place et des résultats concrets obtenus sur des données prélevées dans le golfe d'Oman.*

Mots-clés: *Inversion géoacoustique, temps-réel, propagation acoustique sous-marine, grands fonds, large bande.*

1 INTRODUCTION

The work presented here follows studies and research conducted by EPSHOM/CMO in the geoacoustic inversion domain during the last ten years [1] [2]. The novelty resides here in both real time methods and the focus on a deep-water configuration. This new research orientation is guided by operational interest in sonar performance assessment. The inverse method developed is able to infer some bottom parameters from a small package of bottom reflected rays whose characteristics are measured.

The three first parts of the article describe a measurement campaign in the gulf of Oman, propagation simulations and the automatic connection between them, allowing identification. Then the paper deals with an inversion method, based on recent works on the subject in the scientific community and more specifically in EPSHOM/CMO [2]. Finally real time architecture and some concrete results obtained with in-situ data in the gulf of Oman are presented.

2 ACOUSTIC MEASUREMENTS

A measurement campaign was conducted in the gulf of Oman in 2002. A drifting vertical array (surface buoy) is made of 11 hydrophones sampling the first 100 meters. The acoustic source is towed at 100 m. The propagation range is between 20 and 60 km, crossing the convergence area. Four transects have been recorded localized above different sedimentary type bottom areas. The ray trajectories admit grazing angles from 15° at the beginning of the transects, to 5° at the end. The emitted signal is made up of broadband pulses, typically between [300 Hz, 1 kHz], with a recurrence of one minute.

3 ACOUSTIC SIMULATION PROPAGATION

Fluid sediments and multi-layered bottoms have been taken into account in the acoustic propagation simulator RAYSON [3] [4]. Automatic computation based on impulse responses for different bottom types is operational. Calculations are done for the 11 hydrophones and for a bottom relative to different kinds: rocks or fluid sediment with porosity. The fluid sediment model is that of Hall and Watson based on the porosity value [5] [6].

A real time simulation modulus of RAYSON, developed to take care of time-varying channels, was used to model underwater acoustic communication. Physical parameters characterize time varying channels by integration of static parameters (kind and form of sea surface or sea bed) and variable ones (celerity, receiver motion…). This software is suitable for testing all configurations (provided ray propagation is available) and is able to deal with time variant impulse response. Is has been used to model IR's received on the drifting antenna..

4 IDENTIFICATION. COST FUNCTION

Specific software has been developed to examine and compare measurements and simulations of impulse response signals. The aim was to allow automatic superposition of the two signals. This is a necessary step for both multi-sensor fusion and real time approaches. The software accepts as input time 'Y/M/D h:m:s' and is able to extract experimental and environmental parameters relative to that time, to launch the corresponding simulation computations and to show the following outputs, for each of the 11 hydrophones:

- Measured impulse response
- Simulated impulse response

Our work first focused on the way to infer bottom characteristics in real time from acoustic transmission measurements. The aim was to show feasibility of the automatic real-time inversion chain. For that purpose we have worked with a simple cost function and inversion method. A second stage will be then, once feasibility has been proven, to improve both. The cost function used in the inversion method is defined by the normed quantity

$$\frac{\int_{t_1}^{t_2} |f(t)-r(t)|^2 \, dt}{\int_{t_1}^{t_2} |f(t)|^2 \, dt} = \frac{\| f-r \|_{L_{2(t_1,t_2)}}}{\| f \|_{L_{2(t_1,t_2)}}} \tag{1}$$

where : f(t) is the measured impulse response
r(t) is the simulated impulse response

5 INVERSION METHOD

The inversion is realized with a matched Impulse Response method, based on exhaustive exploration for the parameter couple (D, T) , where D is propagation range and T is bottom-type among rocks or fluid sediment as defined by the porosity P. The two parameters are inverted simultaneously. Two stages are necessary:

- The first stage consists of propagation range inversion. This phase cannot be done by a complex inversion method like Simplex because evolution of the impulse response versus D is not a monotone function. Output is $\underline{D}$, which is an approximate value of D.

- The second stage is devoted to bottom-type inversion. During this phase, the value of D is refined to D, and the bottom type T is determined. For this a simplex algorithm is used.

It is interesting to note that if the bottom-type number is less than 100, matched IR works well and is just limited by the eigenrays computation time. On the other hand, for a number of bottom types which exceed 100, it becomes more attractive to improve the inversion method by the use of a more sophisticated method, like the Simplex method for example. This remark validates the interest of implementing this algorithmic architecture for small quantities of bottom types with a basic inversion method. Since the algorithms are in place and respect real-time constraints, the next stage consists of improving the inversion routines and increasing the search domains.

6 RESULTS ANALYSIS

The inversion method was run over real data. Results fit well to in situ-observations in the case of a homogeneous medium assumption (stratified bottom), and the inverse method gives a mean value of the porosity. When we try to improve the method, working in an evolving subbottom environnement, results are interesting, but they do not fit exactly to the expected environment. First of all, analysis of inversion results shows a problem of identification between simulated and measured data. Looking forward, the inversion method has been tried and tested over synthetic data representing the same configurations. For those cases we have used a real time propagation simulator, which predicts the signal received on each hydrophone of the antenna when it is drifting,and when the boat is moving. This has allowed us to identify problems due to the Doppler effect resulting on both boat and antenna displacement.

7 CONCLUSIONS – PERSPECTIVES

This work constitutes a first step in the development of a real time geoacoustic inversion devoted to broad band signals and deep water environments. It shows that the data contain information which looks relevant, and proves the opportunity to infer in real- time, from a small group of bottom reflected rays, some bottom parameters. The results could display well the notion of an equivalent medium, characterized here for a grazing angle interval [5°, 15°]. The novelty of these works remains more in the themes than in the methods used. Data inversion over a transect is here fully processed, using methods validated and used until now only in case of shallow water. The deep water problem is harder to solve because there is less observable information. The main difficulty is due to the complexity of processing all the data before the inversion calculus. A specific interest of the developed method lies in using a real time modulus to simulate the propagated signals, and so to lead to some operational recommendations concerning the way to proceed for Rapid Environment Assessment. This method also shows the feasibility of respecting constraints of time consumption that are required in REA applications.

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