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Book Review

Review of "Marine Acoustics: Direct and Inverse Problems", J.L. Buchanan, R.P. Gilbert, A. Wirgin, Y.S. Xu. SIAM, Philadelphia (2004) (348pp., Paperback), ISBN: 0-89871-547-4

A typical example of a direct (or forward) problem in marine acoustics is the calculation of acoustic pressure due to a submerged source of known position and frequency, for a known water depth, known seabed parameters and so on. Conversely, for an "inverse problem" the pressure field is measured (i.e., known) and the information contained therein is used to infer some *unknown* parameter of the forward problem. The unknown parameter might be the position of a submerged or buried object to be located, or the properties of the ocean or its boundaries. The book is aptly named, as the reader will find in it the solution to a number of such direct and inverse problems pertinent to undersea acoustics. What is not obvious from the title (abbreviated henceforth as *Marine Acoustics*) is that there is particular emphasis on problems relating to the interaction of sound with the seabed. This focus on the seabed makes *Marine Acoustics* primarily applicable to problems involving either a low acoustic frequency (less than 1 kHz) or a calm sea surface.

Chapter 1 of *Marine Acoustics* starts with a brief overview of previous publications relevant to the book's theme, including an extensive list of references. It continues with a thorough mathematical description of the mechanics of continuous media. This description includes a derivation of the linear wave equation in a solid elastic medium and the associated boundary conditions. An introduction to forward and inverse problems related to the solution of this wave equation is presented at the end of the chapter.

Chapters 2–5 consider successively more complex ocean environments, starting with a highly idealized situation, with isovelocity water and perfectly reflecting boundaries. For this simplified environment, the forward and inverse problems are described, respectively, in Chapters 2 and 3. These two chapters are of a highly mathematical nature, as is Chapter 6, in which the authors 'derive a mathematically rigorous treatment of poroelastic materials using the methods of homogenization theory'. The remainder of this review concentrates on Chapters 4–6, where most of the interesting physics can be found.

In Chapter 4, the isovelocity assumption is dropped, and a five-parameter solid elastic seabed is introduced. The five parameters are the compressional and shear wave speeds, the corresponding attenuation coefficients and the mass density. The forward propagation problem is described, and this chapter includes some numerical inversion results for the five seabed parameters. In other words, a search is carried out in a five-dimensional parameter space in order to identify the set of five parameters that, when fed into a forward prediction, best match the (synthetic) measured pressure field.

This is an important and non-trivial optimization problem. An exhaustive search over such a large space is usually not an option, and instead many and diverse search algorithms have been devised to explore the parameter space in an efficient manner [1].

Some of these methods are deterministic and some are random. Some of them are "local" methods, meaning that they consider possible solutions in a limited region in the vicinity of a specified starting point, and others are "global" ones that attempt to explore the entire parameter space. All of them require a means of quantifying the "goodness of fit", and this is done by defining a "cost function" or "objective function" [2], whose value is small when the predicted pressure field resembles the measured one and large otherwise.

The intended audience for this book includes 'engineers and scientists working in ocean acoustics, military scientists interested in submarine detection and long-range underwater communications, and geophysicists

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involved in locating underwater oil fields'. It is our view that a scientist or engineer working in these fields would need to ask the following questions:

- What are the advantages and disadvantages of the various search strategies?
- Having selected a search strategy, what is the best choice of cost function?
- How do we know when we have found a solution that is good enough for a given purpose?
- How can we deal with the possible existence of local minima, with a low value of the cost function, but with incorrect parameter values?
- How can we use the information stored in all of the trial solutions to learn something about the landscape in which we are searching?
- Are there any established statistical tests that we can apply in order to determine convergence?
- How should we deal with the possibility of errors in our predictions or in our measurements?

Many of these questions are inter-related, and we suppose that none of them has a simple answer. We were disappointed not to find a more comprehensive discussion of them in the text describing the 5-parameter inversion. We also found the layout of the tables of results on page 193 confusing, a point which we return to below.

Chapter 5 is similar to Chapter 4, except that the seabed is modelled as a porous medium with a solid frame plus interstitial pore fluid. The widely used Biot–Stoll poroelastic model, which requires a total of 11 variables to parametrize the seabed, is described in considerable detail.

The introduction to Chapter 5 argues that the study of propagation over a seabed comprising a thin sediment layer over a hard solid substrate can often require a solid seabed model. The important role of thin layers is indeed demonstrated by several publications [3–5], but the example chosen from the classic article by Hughes et al. [3] involves a *thick* sediment layer, and does not illustrate this effect. Nevertheless, *Marine Acoustics* shows that for this case an improved match with the measured data can be obtained using a poroelastic model for the seabed. The improvement is achieved by means of a manual search, examining the behaviour of the predicted field while varying one of the 11 Biot–Stoll parameters, keeping the remaining 10 parameters fixed. An automated search algorithm, such as is used in Chapter 4, is not applied to this case.

Wave equations for an elastic medium are introduced in Section 5.2. Section 5.3 introduces the theoretical background for Biot theory and the derivation of the required parameters, and discusses numerical parameter values for five different sediments, with particular reference to the work of Stoll and the depth dependence of the elastic parameters resulting from over burden pressure. Section 5.4 considers harmonic solutions of the Biot–Stoll wave equations, introduces analytical consideration of depth dependence, discusses values for wave attenuation and dispersion and derives solutions for propagation in a poroelastic waveguide or layer. Section 5.5 presents the Green function solution for the problem of a point source in the ocean above a multiply layered poroelastic sediment and the results of calculations of transmission loss.

Of relevance to Chapter 5 is the "grain-shearing" model recently developed by Buckingham [6,7]. The reader should be aware of the existence of this competing theory, which predicts different dispersion relations to those of the Biot–Stoll model. The Biot–Stoll theory considers a fluid medium whose motion is constrained by the presence of a rigid frame. In Buckingham's theory, the rigidity modulus is zero, and the motion of individual particles is impeded instead by inter-granular friction.

Chapter 6 is concerned, among other things, with asymptotic methods. Section 6.1 introduces WKB and perturbation methods. Section 6.2 considers the homogenization of an idealized porous medium consisting of a periodic packing of pores into cells. Section 6.3 considers the corresponding time-varying solutions. Section 6.4 is concerned with a periodically rough interface between the poroelastic seabed and the water column with the aim of obtaining effective parameters for the rough seabed surface.

Although Chapter 6 should be related to Chapter 5, the authors of Chapter 6 do not concern themselves with connections between them and it is left to the reader to find any. In particular, it would have been helpful to note that Biot-type equations can result from homogenization in Chapter 6 itself rather than in the preface. The so-called numerical example in Section 6.5 of the rough surface analysis seems very far from reality. Moreover, it is somewhat irritating that, in any case, the reader has to refer to an authors' paper to see the numerical results. Despite being cited in the Introduction (p. 8) among the impressive total of 492 references in the book, the potentially relevant work by Williams et al. [8] is not mentioned anywhere in Chapter 6.

Chapters 5 and 6 continue the historical divide between underwater and other acousticians interested in porous media acoustics. A particular opportunity that arises in connection with rigid-frame porous media is missed. The authors cite gravel and sandstone as underwater media that might be modelled as rigid and porous. On the other hand most air-filled porous solids can be modelled in this way. The considerable developments in expressing and understanding the Biot viscosity function and the associated parameters by Johnson [9] and Allard [10], among others, are not mentioned. Also the structure constant of Biot theory is known more widely as *tortuosity* and is a physically meaningful and independently measurable parameter [10].

The presentation of the book, and especially of some of the tables, is poor. For example, the units of important physical parameters too often go unstated, making much of the material unnecessarily difficult to interpret. Cryptic abbreviations for sediment types such as ‘‘FS’’ (for ‘‘fine sand’’) and ‘‘SC’’ (for ‘‘silty clay’’) are used, for example in Table 5.2, where there is plenty of room to write these descriptions out in full, as is done in Table 5.6. There is a strange use of the word ‘media’, which is plural in Latin, on p. 274 viz. ‘a rigid porous media’. The reason for the normalization factor on pp. 218 and 219, although a good one, is not stated until several lines after it is introduced. Finally, a particularly confusing example concerns the above-mentioned tables on p. 193. Each table presumably contains the inversion results for one of the three sediment types that are considered. Although four columns' worth of data is included in each one, only three columns are used. The data from the missing fourth column seem to be presented in a separate *row*, above each table. Furthermore, some of the remaining table entries appear shifted to the right by one column.

The notation was a further source of irritation. We give two examples. Firstly, the hyperbolic sine function is sometimes denoted sinh x and sometimes sin hx. Or does the latter notation actually mean sin(hx)? The second example relates to the use of Landau's order symbol meaning ‘‘of order x’’. In addition to the usual $O(x)$, the notations, $o(x)$, $0(x)$ and a curly script version on page 293, are all used in *Marine Acoustics*. Do these four symbols have different meanings—Landau himself [11,12] makes a distinction between $O(x)$ and $o(x)$—or is this an error that has slipped through the proof-editing? A text aiming at a high level of mathematical rigour needs to avoid ambiguities of this nature.

Marine Acoustics is written by mathematicians, so it not unexpected that few words are devoted to the physical or engineering motivation for its contents. Such discussion is limited essentially to the Preface and the Introduction. The back cover claims that the first chapter contains all of the physics ‘‘necessary for understanding the book’’ by its intended audience of, among others, engineers and scientists working in ocean acoustics. The book provides a rigorous mathematical basis for the subsequent formulation of numerical forward and inverse problem solvers. Moreover, the discussions of Biot theory and of values for the Biot parameters offered in Chapter 5 should be of wide interest and we expect to find use for this comprehensive review. However, we suspect that the target audience of engineers and scientists will find the majority of Chapter 6 to be intensely mathematical and to offer little physical insight.

To sum up, there are parts of this book, mainly in Chapters 1 and 5, that we have grown to appreciate despite the complaints about presentation. The inclusion of a more comprehensive discussion of possible inversion strategies and of the interpretation of inversion outcomes would enhance the value of Chapter 4. We see little practical application for Chapter 6. The more mathematical sections (Chapters 2 and 3) are heavy going and these we leave for others to judge. They are clearly sign-posted, so it is easy for the reader to skip them if preferred, as we have done.

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