

Determination of Parameters of Subsurface Layers Using GPR Spectral Inversion Method

Zhong-lai Huang and Jianzhong Zhang

Abstract—A step-by-step spectral inversion algorithm is proposed in this paper to estimate the thickness, depth, permittivity, and conductivity of layered media from ground-penetrating radar (GPR) signals. Due to the distinct GPR spectral responses to media parameters, different attributes of the spectra are used to estimate, separately, one or several parameters within each step. Such estimated parameters are then used as starting values in a nonlinear optimization problem for the inversion of all parameters simultaneously from the whole GPR spectral data. The cost function of the optimization problem is defined as the difference between the modeled generalized reflection coefficient spectrum of subsurface layers and the actual one. The optimization problem is solved by using a modified stochastic hill-climbing (SHC) algorithm. The method is applied on synthetic data of a wedge model and real data from two highway GPR detections. The results show that the step-by-step spectral inversion method can reduce the ambiguity of the inversion and improve its accuracy and efficiency.

Index Terms—Generalized reflection coefficient, ground-penetrating radar (GPR), layered media, spectral inversion.

I. INTRODUCTION

THE ground-penetrating radar (GPR) has been widely applied in civil engineering and geophysics for the characterization of subsurface structures [1], [2], buried objects [3]–[5], and medium dielectric properties [6]–[8]. In this paper, we focus on layered media concerning which a lot of works have been done so far. Kao *et al.* created a new multilayer model and used the common-middle-point method of seismic exploration to estimate the thickness and dielectric constants of highway pavements [9]. However, the echoes of reflective layers need to be distinguishable in the time domain. Huang and Yi used a parameter calibration method to estimate the permittivity and thickness of pavements, but a drilled core must be provided for *a priori* information [10]. Patriarca *et al.* established an objective function in the frequency domain with Green's function to invert layer thicknesses and dielectric parameters [11]; however, when too many parameters are involved, *a priori* information of the target layers must be given to make accurate estimation.

For GPR detection in a lossy medium, with increasing antenna frequency, the vertical resolution of the GPR data will

increase, but the penetration depth will decrease because of the attenuation of the GPR wave. In some applications of GPR, such as contaminant mapping [12] and fluvial sedimentology [13], the antenna frequency must be sacrificed to reach the penetration depth required, and the vertical resolution of the GPR data will be limited. In addition, since the target region is usually unknown, the antenna frequency chosen in the field measurement may be too low to identify potential thin layers involved in the region. In these situations, when thin layers are encountered, signal processing methods and algorithms should be necessary to improve the resolution of GPR imaging and to estimate thin layers.

Spectral inversion is a seismic method that uses *a priori* information and spectral decomposition to improve images of thin layers whose thicknesses are below tuning thickness, which is defined as a quarter of a wavelength. Puryear and Castagna formulated the method to invert frequency spectrum for layer thicknesses [14]. The method has strong adaptability for thin layers. In this paper, we present an improved spectral inversion method for GPR data. Based on the characteristics of electromagnetic (EM) wave propagation in layered media, we define a generalized reflection coefficient at each interface between two electric layers and use the coefficients to establish a cost function for spectral inversion, which includes parameters of layer depth, thickness, and dielectric properties. Through analysis of the relationship between the parameters and the reflection coefficient spectrum, a new step-by-step method of GPR spectral inversion has been proposed, which greatly helps improve inversion accuracy and convergence speed.

Problem formulation, including derivation of the generalized reflection coefficient and the establishment of the cost function, is given in Section II. The details of the new spectral inversion method are explained in Section III. The method is applied on synthetic data from a wedge model first and then on two real GPR data of highway pavements. The results are presented in Section IV.

II. PROBLEM FORMULATION

A. Generalized Reflection Coefficients

Consider an L -layer model as shown in Fig. 1, where ϵ , σ , and μ are the permittivity, conductivity, and magnetic permeability of the medium, respectively. Each layer is linear, homogeneous, and isotropic. The propagation constant $\tilde{\gamma}$ can be written as [15]

$$\tilde{\gamma} = \alpha + j\beta \quad (1)$$

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Model-based Depth Imaging Stuart Fagin, 1998 This is an informal review of the principle techniques and issues associated with prestack depth imaging The intended audience for this book would be those seismic interpreters processors managers and explorationists who require basic familiarity with the technology that has so greatly expanded the range of geologic structures that can be successfully imaged The emphasis of the book is on velocity model building techniques that are the key to successful depth imaging **Petroleum Abstracts**, 1993 **Thermie**, 1998 **Seismic Waves in**

Laterally Inhomogeneous Media Ivan Psencik, Vlastislav Cerveny, 2013-03-07 This special issue contains contributions presented at the international workshop Seismic Waves in Laterally Inhomogeneous Media V which was held at the Castle of Zahr dky Czech Republic June 5 9 2000 The workshop which was attended by about 60 seismologists from 16 countries was devoted mainly to the current state of theoretical and computational means of study of seismic wave propagation in complex structures The special issue begins with papers dealing with the study and the application of the ray methods Problems such as coupling of quasi shear waves or smoothing of models for effective ray computations are dealt with Applications of the ray methods in seismic exploration are presented Further directional wavefield decomposition phase space path integral and parabolic equation methods are discussed Attention is also devoted to attenuation and scattering problems and to seismic inversion problems **Seismic Inversion** Gerard T. Schuster, 2017-07-01 This book describes the theory and practice of inverting seismic data for the subsurface rock properties of the earth The primary application is for inverting reflection and or transmission data from engineering or exploration surveys but the methods described also can be used for earthquake studies Seismic Inversion will be of benefit to scientists and advanced students in engineering earth sciences and physics It is desirable that the reader has some familiarity with certain aspects of numerical computation such as finite difference solutions to partial differential equations numerical linear algebra and the basic physics of wave propagation For those not familiar with the terminology and methods of seismic exploration a brief introduction is provided To truly understand the nuances of seismic inversion we have to actively practice what we preach or teach Therefore computational labs are provided for most of the chapters and some field data labs are given as well *Expanded Abstracts with Biographies*, 2002 Fossil

Energy Update, 1986 **Brinkman's catalogus van boeken en tijdschriften**, 1992 With 1901 1910 1956 1960 Repertoium is bound Brinkman s Titel catalohus van de gedurende 1901 1910 1956 1960 Title varies slightly **Brinkman's cumulatieve catalogus van boeken**, 1989 *Geophysics Today* Sergey Fomel, 2010 In celebration of the 75th year of publication the Geophysics editorial team invited a collection of papers written by well recognized experts in various areas of exploration geophysics These invited papers not only form part of the present book but they also appear in the September October 2010 special section of the journal Geophysics Today A Survey of the Field as the Journal Celebrates

its 75th Anniversary complements this special section with an additional group of papers drawn from Geophysics to address areas beyond the invited articles The result is a snapshot of the state of the art in the field as Geophysics passes its three quarter century mark This book is Geophysical References Series No 16 **Technical Programme and Abstracts of Papers** European Association of Exploration Geophysicists. Meeting, **Journal of Seismic Exploration** ,1997
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