Joint FDTD forward simulation/real data inversion for cross hole GPR processing

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Abstract

Crosshole radar data interpretation is linked to the best quality of first arrivals picking for all traces. This is particularly required for an accurate direct waves inversion algorithm. In this paper, we present a mixed validation concerning the use of MIGRATOM ray tracing code inversion applied to a geological example, and FDTD (Finite Difference Time Domain) forward simulation in crosshole configuration. To achieve this point we compare the dielectric permittivity distribution obtained thanks to MIGRATOM from raw radargrams with those calculated by a forward FDTD simulation code.

Introduction

First arrivals analysis in a crosshole acquisition leads to an evaluation of a particular dielectric permittivity. Inversion using MIGRATOM straight ray algorithm will gives distribution of dielectric permittivity correspond to the respective paths of each ray. The conductivity distribution properties is given by dispersion analysis between sources and receivers.

The aim for a complete crosshole campaign is to maximize the informations concerning the velocities, thus the more numerous the angles the more accurate the description of the medium and finally the better is constrained the inversion.

In this paper we use 2D FDTD [2], [3], [4], [5] method to simulate forward propagation of radar waves to show the difficulties in discriminating direct waves (which are used to determine first arrival lines), from refracted and reflected ones. The synthetic example presented here, after a simple bi-media, is an unfavorable configuration for crosshole acquisition because of the low ratio hole depth/distance between boreholes. The analysis on such an unfavorable example will prove that for much of radar acquisition, this approach (using FDTD forward modeling to enhance tomography inversion) is very valuable.

The algorithm is a based on the classic Yee scheme [6] with Simplified Unsplited Perfect Matched Layer (SUPML) absorbing boundary condition; further details on the implementation are described in [5].

The aim is to validate the use of FDTD algorithm for crosshole radar simulation by comparing inverted raw and simulated forward data considering the spatial domain of validity of MIGRATOM [1] inversion algorithm.

FDTD crosshole simulation

The FDTD-SUPML algorithm [5] is used for the TM polarization 2D case. Let’s consider a simple two layered media fig 4-a.

Figures 1 show snapshots (at 50, 60, 80,85 ns) of the wave propagation for a 100MHz emission located at 2 meter depth in the bottom media with null electrical conductivity. Obviously, a simple bi-layered media of few meters dimensions reveal a lot of waves front – fig 1 –a and -b:

- Refracted wave on media1/Air interface
- Direct wave in media 1
- Reflected wave on media1/Air interface
- Reflected wave of W on media1/media2 interface
Refracted wave of $v$ on media1/media2 interface
Refracted wave of $w$ on media1/media2
Direct wave in media2
Reflected wave on media1/media2

The distance between drillings (6 meters) and the ratio of the relative dielectric permittivity chosen are not proper conditions to a crosshole acquisition. The capacity of FDTD forward modeling to discriminate properly all front waves, validates such an approach for classic ground geometry. Furthermore, we notice that multiplying the acquisition at the reception makes much easier the visual interpretation: a spatial over sampling (fig 2) at the reception could be of great interest if difficulties arise when refracted, reflected and direct waves arrives at similar times, compared with a classic acquisition – fig 3 (~20 cm for 100MHz antennas)

Case study: Kerbernez (Bretagne, France)

The acquisition (Multiple Offset Gather) was done between two vertical drillings distant by 4.7 meters and respectively 18 (RX) and 12 (TX) meters depth. The antennas used are 100 MHz, while both spatial steps (emission and reception) is 50 cm. That corresponds to 864 traces.

The geology consists in fractured granite, filled with clays, which explain the heterogeneity of the velocity fig 5-a, obtained after inversion. During the inversion process, the whole set of rays calculated in the whole grid are not homogeneously distributed.

Straight inversion of raw data (fig 5-a) lead to a distribution of velocity that could be converted to relative dielectric permittivity.

Conclusions

FDTD method is well adapted to simulate crosshole radar acquisition in the aim of optimizing the technique of acquisition; for example by defining the proper sampling for the reception or for the emission. Furthermore, the attenuation through conductivities could be evaluated using trial and error with the FDTD algorithm, and open the way to FDTD inversion for both dielectric permittivity and electric conductivities.

References

Figures Captions

Fig 1 –a: snapshot of wave front at 50 ns for an emission in the second media situated at 2 meters depth. Three wave fronts 1, 2, 3 correspond respectively to $u$ the refracted wave on media1/Air interface $v$ the direct wave in media 1 $w$ the reflected wave on media1/Air interface $v$

Fig 1 –b: snapshot of wave front at 60 ns for an emission in the second media situated at 2 meters depth. Wave fronts 4, 5, 6, 7, 8 correspond respectively to $x$ the reflected wave of $w$ on media1/media2 interface $y$ the refracted wave of $v$ on media1/media2 interface $z$ the refracted wave of $w$ on media1/media2 $\{u \text{ the direct wave in media2}\}$ the reflected wave on media1/media2.$y$

Fig 1 –c: snapshot of wave front at 80 ns for an emission in the second media situated at 2 meters depth.

Fig 1 –d: snapshot of wave front at 85 ns for an emission in the second media situated at 2 meters depth.

Fig 2 -a: Time depth representation (same simulation as fig 1) for an emission situated at 2 meters depth for the geometrical model fig 4-a without electric conductivity.

Fig 2 -b: Time depth representation for an emission situated at 2 meters depth for the geometrical model fig 4-a with attenuation. We distinguish the refracted waves (a)-(d)-(e), the reflected wave (b), and the direct waves (c)-(f)

Fig 3 –a: Visualization of traces each 20 cm from fig 2 –a, as it will be for real acquisition. Direct waves are still distinguishable in non-lossy media.

Fig 3 –b: Visualization each 20 cm of Fig 2 –b, as it will be for real acquisition. Direct waves are not distinguishable anymore because of the attenuation, and picking of first arrivals is tricky.

Fig 4 -a: Geometrical model for crosshole simulation: a bi-layered media, with a 1.5 meters thickness for the first media. The drillings are both of 4 meters depth, and separated by 6 meters.

Fig 4 -b: Velocities obtained from the inversion of traces simulated without attenuation (19*19 traces) every 20 cm using MIGRATOM straight ray algorithm. We have a correct correspondence with the initial model fig 4 –a.

Fig 5 -a: Velocity obtained from the inversion of Kerbernez crosshole data with MIGRATOM straight ray algorithm.

Fig 5 -b: Velocity obtained from the inversion of the forward simulated crosshole data (using the permittivity distribution obtained by real data inversion) with MIGRATOM straight ray algorithm with the same parameters acquisition of Kerbernez data. The difference in the velocities is due the absence of conductivity in the simulation, and first picking errors.

Fig 5 –c: Map of reliability on a grid of 10 (depth discretization) by 5 (distance discretization) cells used for the inversion of both real and simulated data (Fig 5 –a and –b)