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РАДИОТОМОГРАФИЯ И СВЕРХШИРОКОПОЛОСНОЕ ЗОНДИРОВАНИЕ

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3D TOPOGRAPHIC MIGRATION OF GPR DATA ACQUIRED ON UNEVEN SURFACES

High resolution subsurface imaging reconstruction using a non-destructive probing technique is very important issue in many fields of applications. The Ground Penetrating Radar (GPR) has been shown to be an efficient subsurface imaging tool. The 3D GPR image reconstruction is useful to identify the depth, shape and size of subsurface targets from which the end-user can easily extract quantitative results. The GPR migration process is very important to collapse the wide diffraction from a target and recover and focus it into its true shape and position. 3D topographic migration of GPR data directly from uneven surfaces with obvious topographic variations was successfully performed using the diffraction stacking migration algorithm. The coordinates and topographic information of each GPR trace were obtained from the Rotary Laser Positioning System (RLPS) that provides millimeters accuracy of positioning information after improving the synchronization with the GPR system.

Keywords: *Subsurface imaging, 3D GPR, iGPS, migration, topographic correction.*

1. Introduction

High resolution subsurface imaging reconstruction using a non-destructive probing technique has many important applications, for example in engineering, environmental, geology, and archaeology. The Ground Penetrating Radar (GPR) has been shown to be an efficient subsurface imaging tool due to its low cost nondestructive capability of detecting both metal and non-metal objects, and is in theory faster than conventional geophysical methods [1]. The 3D GPR image reconstruction is useful to identify the depth, shape and size of subsurface targets from which the end-user can easily extract quantitative results. The main requirement that must be fulfilled to collect a GPR dataset that can be successfully transformed into a realistic 3D image is expressed by the Nyquist sampling theorem. The GPR migration process is very important to collapse the wide diffraction from a target and recover and focus it into its true shape and position. However, the topographic variation of the ground surface where the GPR survey took place is one of the most important factors that greatly contribute to the distortion of the GPR reflections and negatively affect the migration result. Synthetic GPR studies have demonstrated the inadequacies of the conventional GPR migration procedures when surface gradients exceed 10 % or much greater than 6°[2]. We performed 3D topographic migration of GPR data directly from uneven surfaces with obvious topographic variations. The coordinates and topographic information of each GPR trace were obtained from the Rotary Laser Positioning System (RLPS) that provides millimeters accuracy of positioning information after improving the synchronization with the GPR system.

2. Migration Algorithm for 3D GPR Topographic Migration

The diffraction stacking migration algorithm has been implemented to conduct the 3D topographic migration and it is a very convenient and straightforward method, which is commonly used for seismic data processing. This approach is an integral solution of the wave equation. This technique is a relatively straightforward method and illustrates well the general principle of migration. Consider a 3D data set $b(x,y,t)$ recorded in the data plane. Each point in the migrated image $Q(x,y,z)$ is the result of a summation of the recorded amplitudes in the data-plane along a diffraction hyperbola, whose curvature is governed by the medium velocity and the depth of the point to be migrated. If there is an object in the apex of the diffraction hyperbola, the amplitudes will add. If not, the summation of the non-coherent data along the diffraction hyperbola tends to zero.

Suppose the data $b(x,y,t)$ is recorded with a monostatic GPR by moving the antennas on the ground in the $xy-$ plane, taking a measurement $b(x_i, y_k, t)$ at position $(x_i, y_k, 0)$ with $j = 1,2,..,J$ and $k = 1,2,..,K$. The migrated image $Q(x,y,z)$ is then calculated by:

$$Q(x,y,z) = \sum_{j=1}^{J}\sum_{k=1}^{K} b(x_j, y_k, \frac{2R_{j,k}}{v}) \qquad (1)$$

Where $R_{j,k}$ is the distance between the measuring position $(x_i, y_k, 0)$ and the point (x, y, z) that is to be migrated, v is the propagation velocity in the medium. The time $\frac{2R_{j,k}}{v}$ represents the total travelling time from the transmitting antenna to the point (x, y, z) and back. To obtain the point in the migrated image, the summing must be performed along the migration template. This must be repeated for all GPR surveyed points. The three-dimension migration template can be calculated using this equation:

$$z_0 = \sqrt{(\tau_n v)^2 - (x_f - x_n)^2 - (y_f - y_n)^2 - (z_f - z_n)^2}\ . \tag{2}$$

The next step is the summation of the measured signal along the calculated three-dimension migration template using the equation below:

$$S(\boldsymbol{r}_f) = \sum_j S\left(t = \frac{2\left|\boldsymbol{r}_j - \boldsymbol{r}_f\right|}{v}\right). \tag{3}$$

Where t is the travel time, v is the wave velocity and the multiplying two indicates that the signal travels twice the distance; from the antenna to the target, and back from target to antenna.

3. Experimental Data and Results

An experiment was carried out in the sandpit of our GPR laboratory after changing the ground surface topography by creating a small mound on the top of the targets (Fig. 1).

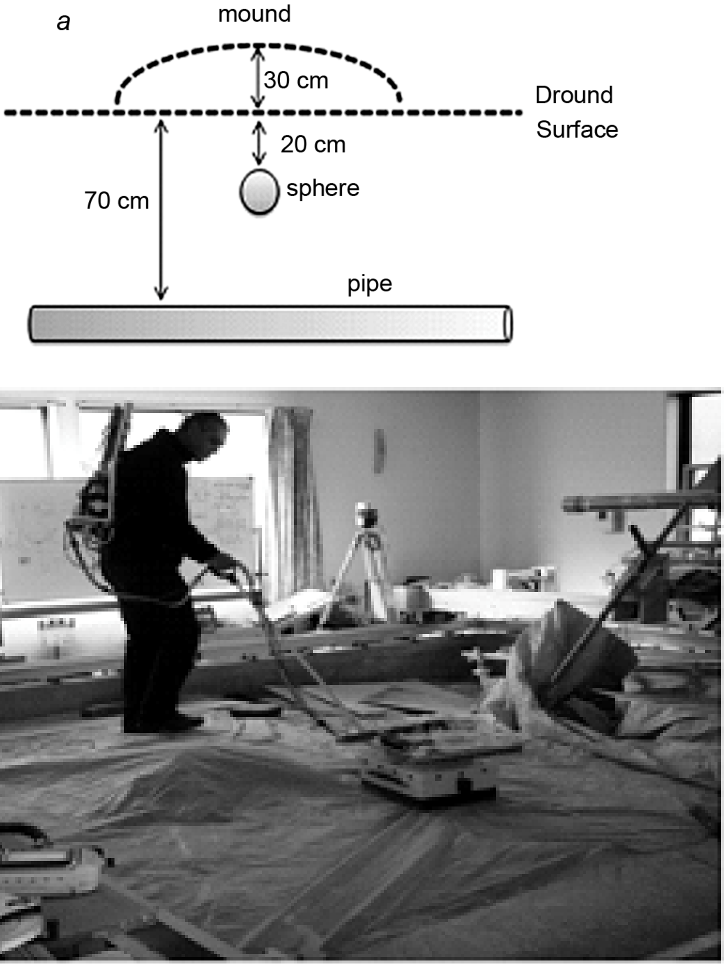

Fig. 1. Sketch of the two targets and their depths (*a*) and 3D GPR experiment (*b*)

A metallic sphere with a diameter of 15 cm and a metallic pipe with a diameter of 5 cm and a length of 100 cm were used as targets at different depths 20 cm and 70 cm respectively. The 500 MHz RAMAC

GPR shielded antenna was used to scan 1 x 2 m survey area with around 10 cm inline spacing. The data sampling of the GPR was triggered by time using trace time interval of 0.05 second and recording the x, y and z coordinates of each trace using the RLPS positioning system. The migration grid was defined as 5x5 cm and the propagation velocity of electromagnetic waves was chosen as 0.14 m/ns based on the sand condition in the sandpit. Both targets were detected clearly after processing the GPR data (Fig. 2). Successful 3D topographic migration results were obtained with high resolution subsurface images, which validate our processing method.

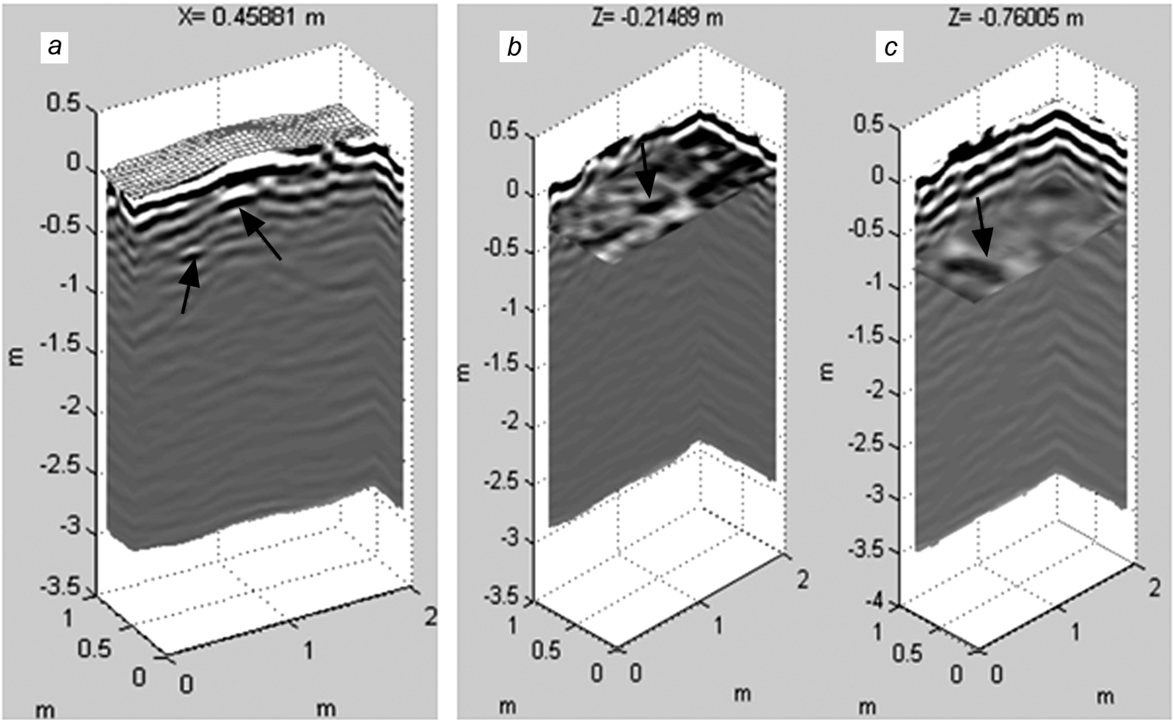

Fig. 2. Y scan shows the topographic migrated pipe (deep) and sphere (shallow) (*a*) and depth slices of the sphere (left) and pipe (right) (*b*)

REFERENCES

1. Doolittle J.A. and Collins M.E. // J. Appl. Geophys. – 1995. – V. 33. – P. 101–108.
2. Lehmann F. and Green A.G. // Geophysics. – 2000. – V. 65. – No. 3. – P. 836–848.

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