Topographic Correction of GPR Profiles Based on Laser Data

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Abstract. Data obtained by GPR (Ground Penetrating Radar) are displayed as a continuous cross-sectional profile. Surface, generally, is not flat. As a result, the image becomes distorted and the depth calculated from the surface no longer represents the true and exact position of electrically distinctive layers and objects in materials. In order to get real geologic cross section, GPR data must be corrected.
This is paper discusses a new method using the color point cloud data obtained by a Vehicle-borne laser scanning system to compensate for elevation fluctuate. Elevation profile can be extracted from topographic data of survey site acquired using laser scanner, which can then be used to offset the error of GPR data. Through the discrete points in the survey line, each trace of the profile has its own elevation value showing a vertical difference from the reference profile with maximum elevation, then time shifts value of traces vertical offset versus the reference trace of profile can be obtained. At last, the results of topographic correction for radargrams that look extremely like the real geologic cross section are presented, which allows us to get a better profile interpretation and position of the objects and layers in the subsurface.

1. Introduction

Ground Penetrating Radar (GPR) is a remote sensing and non-destructive geophysical method which uses a single and short high electromagnetic pulse (1-20ns) with a center frequency from 10MHZ to 2.5GHZ. It is often used to view the subsurface of soil and rock layers and give an overall qualitative internal image of the shallow subsurface conditions and features [1]. When collecting GPR data in testing field, the terrain is often not flat. As a result, the depth calculated from the surface will no longer represent the true and exact position of electrically distinctive layers and objects in materials. Even more, it could bring many image analysis and interpretation problems if one treats an undulating surface as a flat line. There is a most striking problem that when reading the same objects from different angles at uneven relief surface and getting different depths. In order to avoid these problems, it is necessary to proceed the GPR data with topographic correction before interpretation.

There are several traditional surveying equipments for creating topographic data like total station [2], GPS or DGPS [3], accelerometers and inclinometers [4].The disadvantages of these measuring instruments for terrain data are time consumption, complicated and inefficient.

In this paper, a novel approach is showed which integrates laser scanner data for topographic correction of GPR data. The terrain data could be quickly exacted from the color point cloud of the test site. These data are synchronized with the GPR profile through some feature points along the measurement line, which can be used for its topographic correction.

2. Theoretic ground

The data acquired by GPR are presented in the form of two-dimensional images with traveled distance on horizontal axes and travel-time on vertical axes. When the surface is flat, the GPR profile is a moderate good indicator of the real terrain as shown in Figure 1. But collecting data in the roughness site, the geometry of subsurface image becomes distorted. It's hard to read the same object from different angles and could get different depths as shown in Figure 2.

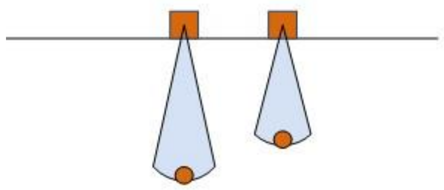

Figure 1. Collect data on the flat site.

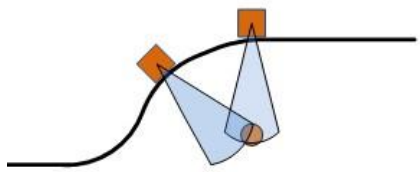

Figure 2. Collect data on the roughness site.

Once the velocity of the electromagnetic wave in the medium is determined, the depth of GPR depends on the time which indicates the signal arrives at the target and reflected back to the receiving antenna. When the terrain of the location is assumed to be plane, the distance to a target can be expressed as shown in figure 3.

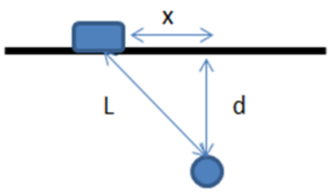

Figure 3. The distance to a target when the surface is flat.

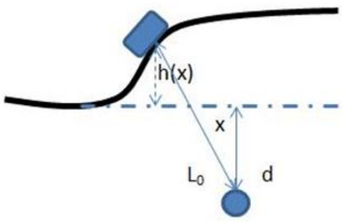

Figure 4. The distance to a target when the surface is uneven.

The length of the target can be simply calculated by formula 1,

$$L = \sqrt{x^2 + d^2} \tag{1}$$

And the GPR travel time down and back to the event source is

$$t = \frac{2L}{V} \tag{2}$$

V is the velocity of the electromagnetic wave in the medium.

While the topographic variation is too abrupt, the GPR travel time and the location of the target could be impacted. Figure 4 shows the distance to a target. Before calculating the length of the target, it needs to obtain the terrain elevation and some direction parameters.

The length of the target can be calculated by a function of the surface topographic as following

$$L_0 = \sqrt{x^2 + [d^2 + h(x)^2]^2} \tag{3}$$

If we ignore the variation of the topographic, namely assuming $L=L_0$, it could lead to erroneous conclusions .With the changes of the terrain, the distance path begin to reflect the topographic. As a result, the profile becomes distorted and could not demonstrate the accurate positioning of the target.

Most post-processing methods of the seismic wave can be applied directly to GPR data. Yilmaz provides a method of seismic aspect of 'statics correction' which used time–shift to compensate surface undulations [5]. This corrects the two-way travel time of the traces to a flat datum level some distance above the air/ground interface. The method of statics correction applied to the topographic correction of GPR data by Lehmann and Green[6]. When the reference surface is determined, usually either the lowest or the highest point in the whole survey line, each point in the measurement line has its own elevation value relative to the reference plane, and then time-shifts of each profile can be calculated by the following simple formula.

$$\Delta t = \frac{-2h(x)}{v} \quad (4)$$

Where h(x) is the elevation difference and v is the velocity of the electromagnetic wave in the medium.

3. Methodology

3.Laser scanner

Topographic data of the survey site are acquired by a Vehicle-borne laser scanning system as shown in Fig 5. The system integrates an integrated navigation system (POS/GPS), a 360 degree laser scanner and six digital cameras from Common EOS 5D mark Ⅱ. The laser scanner is used to obtain three-dimensional coordinates of target objects in the space. The Integrated Navigation System, providing the real-time position and attitude for system platform. The elegant texture information acquired by high-resolution digital camera could be processed with point cloud data. After data integration we can get point cloud data with the RGB color which is appropriate for human sight. The metric characteristics of the SSW system are shown below:

- Measure range: 5-200 m
- Rang precision: 5 mm
- Absolute accuracy: 2 cm(100m)
- Scanner field of view: 360 °
- Laser measurement rate:50- 200KHZ

Figure 5. SSW Vehicle-borne laser scanning system

Figure 6. Data acquisition by GPR

Before and after data collection, IMU (Inertial Measurement Unit) should be initialized for 10 min in an area with high precision GPS signal. Laser scanner and digital camera are only taken while the van is moving to avoid the excess of data. The synchronization of the data from different sensors of the Vehicle-borne laser scanning system is achieved using the time stamp and the PPS of GPS and IMU. It is the standard GPS time of the data acquired by different sensors. The data processing and fusing are performed using post-processing software and the final data is displayed in the form of the color point clouds.

The Vehicle-borne laser scanning system is one of the most convenient methods to get the high rate of three-dimensional coordinate data over the structure surface. Then terrain data could be exacted from the color point cloud data of the structure surface, then the precisely elevation value of the discrete points in the measurement line can be obtained.

3.2 Ground Penetrating Radar

The GPR survey was performed using a RAMAC/GPR system from MALA Geoscience. The electrical conductivity of the subsurface materials and the frequency of GPR antenna are two crucial factors to decide the depth to which the electromagnetic waves can penetrate. In low conductivity materials, deeper probing depth may be achieved. In highly conductivity materials, the depth of penetration would be reduced because the electromagnetic waves are attenuated and absorbed. A low frequency antenna gives deeper signal penetration but lower resolution. A higher frequency antenna has better resolution but shallower penetration. Taking the penetration and resolution, into account, the shield antenna with the 500MHZ center frequency was selected as the most optimum due to soil exploration. This antenna provides on the order of 6m in depth penetration and a vertical resolution of 5cm. Radargrams were obtained with trace intervals of 2 cm, time windows of 60 ns, 408 samples per trace and sampling frequency of 6700MHZ. During the survey, an odometer wheel calibrated was attached to the antenna for regulating when sending and receiving data, to get accurately the profile length (Figure 6).

Before interpretation, radargrams obtained by GPR were processed by Reflexw2D-5.0.8 software with the purpose of reducing noise ratio in raw-data and improving the quality of raw-data. This makes the GPR data interpretation easier. The order of the signal processing filters was: time-zero correction, DC-removal, automatic gain control, subtract mean trace, band-pass filtering and running average.

3.3 Data Integration

In order to synchronize the terrain data and GPR data, the measured point must be marked on the ground along the profile before the acquisition of GPR data. The integration of the GPR data and the color point cloud was achieved by field marker distributed in the measuring line. Before data acquisition, several discrete markers are placed along the survey line with 20cm intervals. The more disperse discrete points are, the more accurate the acquired terrain data. In our experiment, a total of 46 discrete points was created.

After integration of the point cloud and images attained by Common EOS 5D mark Ⅱ, we can accurately figure out the location of field markers in the color point cloud and three-dimensional coordinates of the filed marker could be extracted from the color point cloud easily be used in combination with the GPR data(Figure 7) . In most situations, the maximum elevation values of the discrete points is considered as reference point and the remaining discrete points has its own elevation value relative to the highest point[7]. In the light of the fact that wet soil test environment, an average electromagnetic wave velocity of 11.0cm/ns was supposed to the survey. The method of statics correction which uses time–shift to compensate for surface undulations could be applied and the GPR Profiles had been corrected.

Figure 6. The markers in the measuring line.

Figure 7. The color point cloud of the survey

4. Results

The GPR cross section obtained by 500MHZ shielded antenna without terrain correction is shown in Figure 8. It does not match with the real survey topography. By applying time-shift topographic compensation, the GPR cross section is displayed in Figure 9. Compared with the original GPR image in Figure 8, the GPR profiles looks very much like the real test topography shown in Figure 6. The time–shift correction makes the GPR profile more realistic and interpretable. Observing the radargrams in Figure 9 we can find that it is clearly to identify two hyperbolic reflections of tree roots and water pipes. The approach proposed us to get a better profile interpretation and position of the objects in the subsoil.

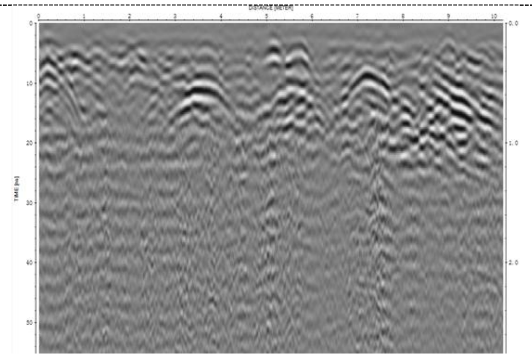

Figure 8. Original GPR profile.

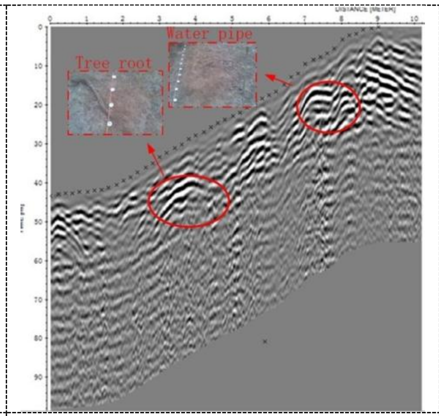

Figure 9. The GPR profile after topographic correction.

5. Conclusions

The Experimental results confirm that topographic correction of GPR images can be made with the laser data, our proposed methodology could collect data more rapidly than other one proposed in the past. The elevation data of terrain can be extracted from the color point cloud data quickly by Vehicle-borne laser scanning system. Then the correction of GPR profiles would be performed by time-shift compensation. The method is appropriate to be used in the sites with slow slope changes, when the terrain changes abrupt, the tilt correction of the antenna needed to applied.

Acknowledgments

The work of this paper is supported by the open fund from State Key Laboratory of Information Engineering in Surveying, Mapping and Remote Sensing ,Wuhan University (NO:11P02) and the National Science and technology support program (NO: 2012BAH34B01)

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