Topographic Correction of GPR Profile Based on Odometer and Inclinometer Data

Vitalii Prokhorenko, Volodymyr Ivashchuk, Sergiy Korsun, Sergiy Musiyachenko, Vladyslav Borodavka
Transient Technologies LLC
Kyiv, Ukraine
pvp@viy.ua

***Abstract*— Usually, data obtained by ground penetrating radar (GPR) are displayed as a rectangular 2D picture (profile), vertical and horizontal axes of which are proportional to depth and traveled distance, respectively. Surface, generally, is not horizontal, that leads to distorted view of irregularities in the GPR profile. To eliminate these distortions a topographic correction is used. Topographic data can be obtained by laser leveler, total station, GPS and similar equipment. Further this information is used for topographic correction of the GPR data.**

This paper provides method of topographic correction based on information about traveled distance and tilt of antenna unit at each point of measurement. These data are measured by odometer and inclinometer, respectively. The information is obtained simultaneously with the GPR data and is connected with each trace of the profile. Algorithm of traces vertical offset calculation relatively the first trace of profile and accuracy of topographic correction are discussed. The results of topographic correction of profile acquired by VIY3-300 GPR are presented. This inexpensive solution improves performance characteristics of GPR and reduces time required for GPR profiles processing and their interpretation.

Keywords-ground penetrating radar; GPR; topographic correction; elevation; antenna tilt

I. INTRODUCTION

Acquisition of topographic data is one of the most time-consuming aspects of Ground Penetrating Radar (GPR) survey. To be useful, GPR data have to be matched with terrain.

Topographic data can be obtained using traditional surveying equipment: laser levels [1], Total Station [2], GPS [3] or DGPS [4]. To refine the GPS data was used LIDAR also [7].

The next, very time-consuming task is to synchronize the topographic and GPR data. It is simplified when geodetic and GPR data acquisitions are made simultaneously. To measure antenna coordinates and GPR signals at the same time self-tracking laser theodolite [2] or real-time kinematic GPS [5, 6] were used. However such systems are quite complex and expensive.

We propose a method for topographic correction, based on measuring of traveled distance and slope of antenna during the GPR sounding. Odometer and inclinometer determine the traveled distance and antenna tilt, respectively. These data are synchronized with the GPR profile and can be used for its topographic correction.

II. TOPOGRAPHIC CORRECTION OF GPR PROFILE

Typically, the data obtained by GPR are presented in the form of rectangular two-dimensional images (profile or B-scan), vertical and horizontal axes of which are proportional to the depth and traveled distance. In general, test site is rough. Therefore the GPR profile is not consistent with the surface geometry. To correct these distortions topographic correction is used [8].

The simplest way of topographic correction consists in taken into account antenna elevation relative to the initial point. It is performed by vertical displacement of each trace of the profile in accordance with the topographic data [9]. The length of the profile, however, remains equal to traveled distance.

During GPR survey the antenna is located on the ground surface and, in general, tilted and rolled relative to the horizon. The next step consists in the correction of the antenna tilt when the GPR profile is displayed. The tilt can be, for example, is calculated from the GPS data [10].

Further development is in 2D-correction, when taken into account both tilt and roll of the antenna [6, 11]. This method is used with 3D GPR survey.

Consider the test site model that represents hill with buried cylindrical object. The distance from the surface to the object is the same for all points of the route (Fig. 1).

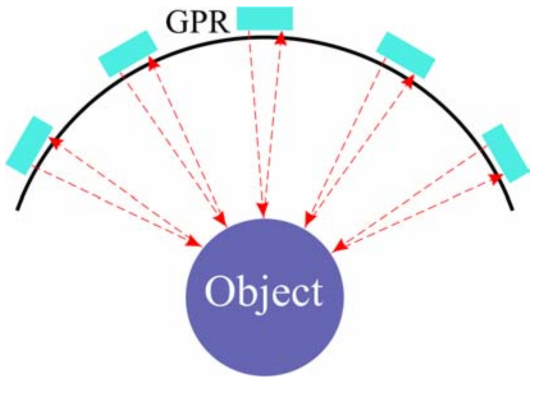

Figure 1. Test site model

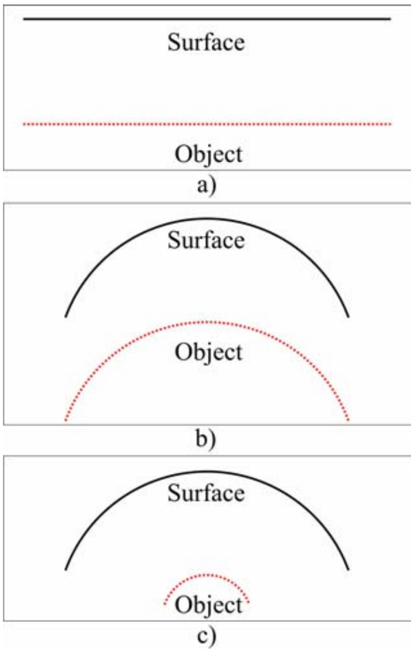

Figure 2. Topographic correction of the GPR profile: without correction (a), elevation correction (b), elevation and antenna tilt correction (c)

Length of the GPR profile without correction is equal to traveled distance and greater than geometric dimensions of the test site. The object is represented as a horizontal line (Fig. 2a).

Topographic correction of the elevation agrees shape of the GPR profile with the surface, but the object is displayed as a curve parallel to the surface (Fig. 2b).

When elevation and antenna tilt are under correction the GPR profile reflects geometry of the surface and the object more accurately (Fig. 2c).

III. ODOMETER PLUS INCLINOMETER

In general, topographic correction requires measurements of traveled distance, as well as antenna tilt, roll and azimuth angle (Fig. 3).

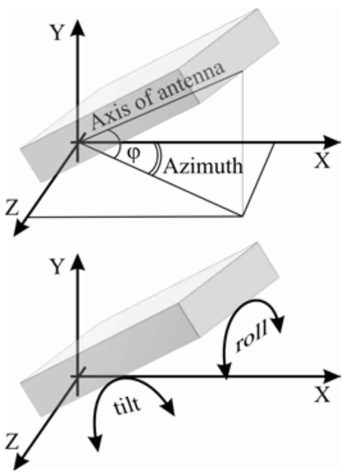

Figure 3. Orientation of the GPR antenna

Let the longitudinal and transverse axis of the antenna coincide with the axes X and Z of the inclinometer, respectively. Rotation around the X axis corresponds to the antenna roll, around the Z – antenna tilt, and around the Y – azimuth. Since the GPR profile for topographic correction is always located in the XY plane, the azimuth can be omitted

If the inclinometer is based on the accelerometer, antenna tilt and roll are calculated. Output signals of the accelerometer (G_x, G_y, G_z) are proportional to orthogonal projections of the gravity vector G. Taking into account that between the longitudinal and transverse axes of the antenna and the gravity vector G there is an initial shift of $\pi/2$, these projections can be written as follows:

$$G_x = G \cdot \sin(\varphi),$$

$$G_y = G \cdot \cos(\varphi) \cdot \cos(\psi),$$

$$G_z = G \cdot \cos(\varphi) \cdot \sin(\psi),$$

$$G_x^2 + G_y^2 + G_z^2 = G^2. \quad (1)$$

Where:

φ is antenna tilt in a range from $-\pi/2$ to $\pi/2$,

ψ is antenna roll in a range from $-\pi/2$ to $\pi/2$.

Therefore the antenna tilt and roll are calculated as:

$$\varphi = \arcsin(G_x / G),\ \psi = \operatorname{atan}(G_z / G_y). \quad (2)$$

Consider the GPR, which executes survey, measurement of antenna tilt and traveled distance simultaneously. Let the n-th trace is assigned to the traveled distance $D(n) = n \cdot \Delta D$ and antenna tilt $\varphi(n)$. Assume that the antenna position is changed slightly between neighboring traces of the GPR profile.

Elevation H(n) and horizontal projection L(n) are calculated in a mode of piecewise linear approximation. The initial conditions (GPR at the starting point) are: $D(0) = H(0) = L(0) = 0$, $\varphi(0) = \varphi_0$.

In the case of rectilinear movement ($\varphi(n) = \varphi(n-1)$) the elevation H(n) and horizontal projection L(n) are calculated by the formula of rectangular triangle:

$$H(n) = H(n-1) + \Delta D \cdot \sin(\varphi(n-1)),$$

$$L(n) = L(n-1) + \Delta D \cdot \cos(\varphi(n-1)). \quad (3)$$

Consider the curvilinear movement (Fig. 4) when antenna tilt varies ($\varphi(n) \neq \varphi(n-1)$).

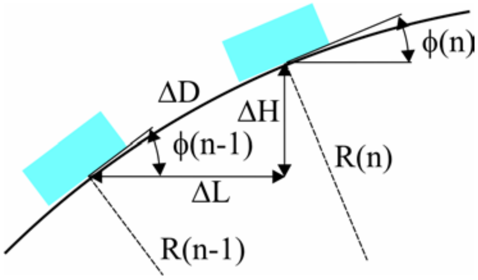

Figure 4. Movement along a curvilinear trajectory

In a simplified case average angle between adjacent traces can be used. Elevation H(n) and horizontal projection L(n) are calculated as follows:

$$H(n) = H(n-1) + \Delta D \cdot \sin((\varphi(n) + \varphi(n-1))/2),$$

$$L(n) = L(n-1) + \Delta D \cdot \cos((\varphi(n) + \varphi(n-1))/2). \quad (4)$$

Accuracy of calculating of H(n) and L(n) depends on the angular difference between adjacent traces. Calculation error increases with the difference between the length of arc and chord. To improve the accuracy we can use the feature that two neighboring traces can be placed on an arc of radius R = R(n-1) = R(n). The radius is related to angles and traversed way the following relation:

$$\Delta D = R \cdot \Delta\varphi. \quad (5)$$

Where φ is in radians.

Then,

$$H(n) = H(n-1) + R(n) \cdot (\cos(\varphi(n)) - \cos(\varphi(n-1))),$$

$$L(n) = L(n-1) + R(n) \cdot (\sin(\varphi(n)) - \sin(\varphi(n-1))),$$

$$R(n) = \Delta D / |\varphi(n) - \varphi(n-1)|. \quad (6)$$

Topographic correction based on odometer and inclinometer data is as follows. Elevation of the zero level of the GPR profile is calculated with traveled distance and antenna tilt angle. Traces of the profile are converted from time to distance scale considering wave speed in the media. A blank profile with increased dimensions is created. Each trace is transformed from linear form into sector one using mask of radiation pattern of the antenna. Then, taking into account tilt angle, traces are located on the appropriate place of zero level perpendicularly to it. Overlay of the traces forms topography corrected profile (Fig.5).

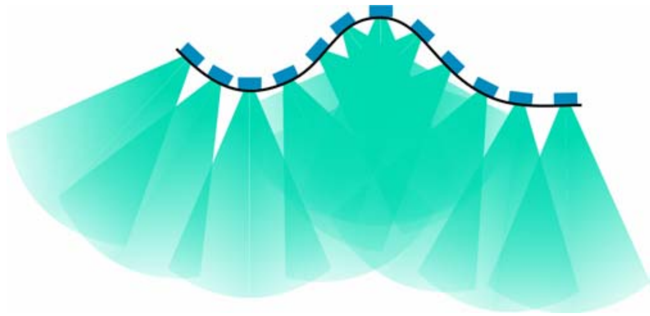

Figure 5. Topographic correction based on elevation, tilt and radiation pattern information

IV. Experimental Results

Verification of the topographic correction method was carried out with VIY3-300i GPR. The GPR is equipped with inclinometer based on MMA7260Q three-axis analog accelerometer of Freescale Semiconductors. It is mounted on the synchronizer board. Output signals of the accelerometer is converted to digital code by 10-bit ADC and added to GPR data for every trace. Traveled distance is determined by VO-20 measuring wheel which controls the GPR data acquisition also. Distance between traces in the profile was set to 125 mm.

To obtain correct topographic data the inclinometer has to be calibrated before sounding. The calibration was carried out in two steps. First, normalization of the accelerometers was executed. For this purpose the antenna unit was rotated along longitudinal and transverse axes in order to determine amplitude of the gravity changes. Then correction of angular error caused by nonparallel position of the accelerometer relative to the ground surface was carried out. This was done by measuring tilt of the antenna unit at opposite directions. Accuracy of angular measurements after calibration was about 20 minutes.

Test site was a steep slope of an artificial channel (Fig. 6). The height of the slope measured by Leica DISTO D3a laser distance meter with built-in inclinometer was 5.58 meters. The GPR was dragged perpendicularly to slope into upward direction. As a result of topographic correction the slope height was 5.67 meters. Accuracy of height measurement was better than 10 centimeters for traveled distance around 30 meters.

Original GPR profile is shown in Fig.7. Corrected profile is shown in Fig. 8.

V. Conclusions

Test results confirmed that topographic correction of GPR profiles can be made with inclinometer and odometer. Acquired data (traveled distance, tilt and roll) allow providing complete correction that also takes into account the GPR location on the surface and radiation pattern of the antenna.

With this method topographic and GPR data are acquired simultaneously. Correction of the GPR profile is performed immediately after finishing of the survey. Accuracy of the method is sufficient for its application in the GPR surveys. The method is suitable for use in sites with limited visibility, including enclosed areas, slopes and tunnels, forests, etc.

Further development of the method of topography correction based on odometer and inclinometer data involves improving of calculation algorithms and corrected profile representation.

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Figure 6. Test site

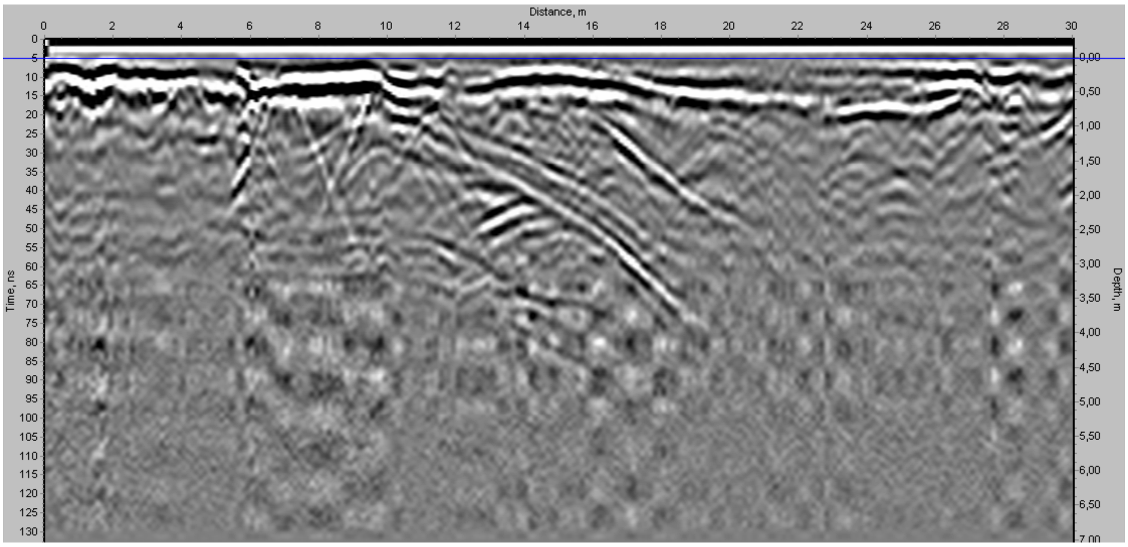

Figure 7. Original GPR profile

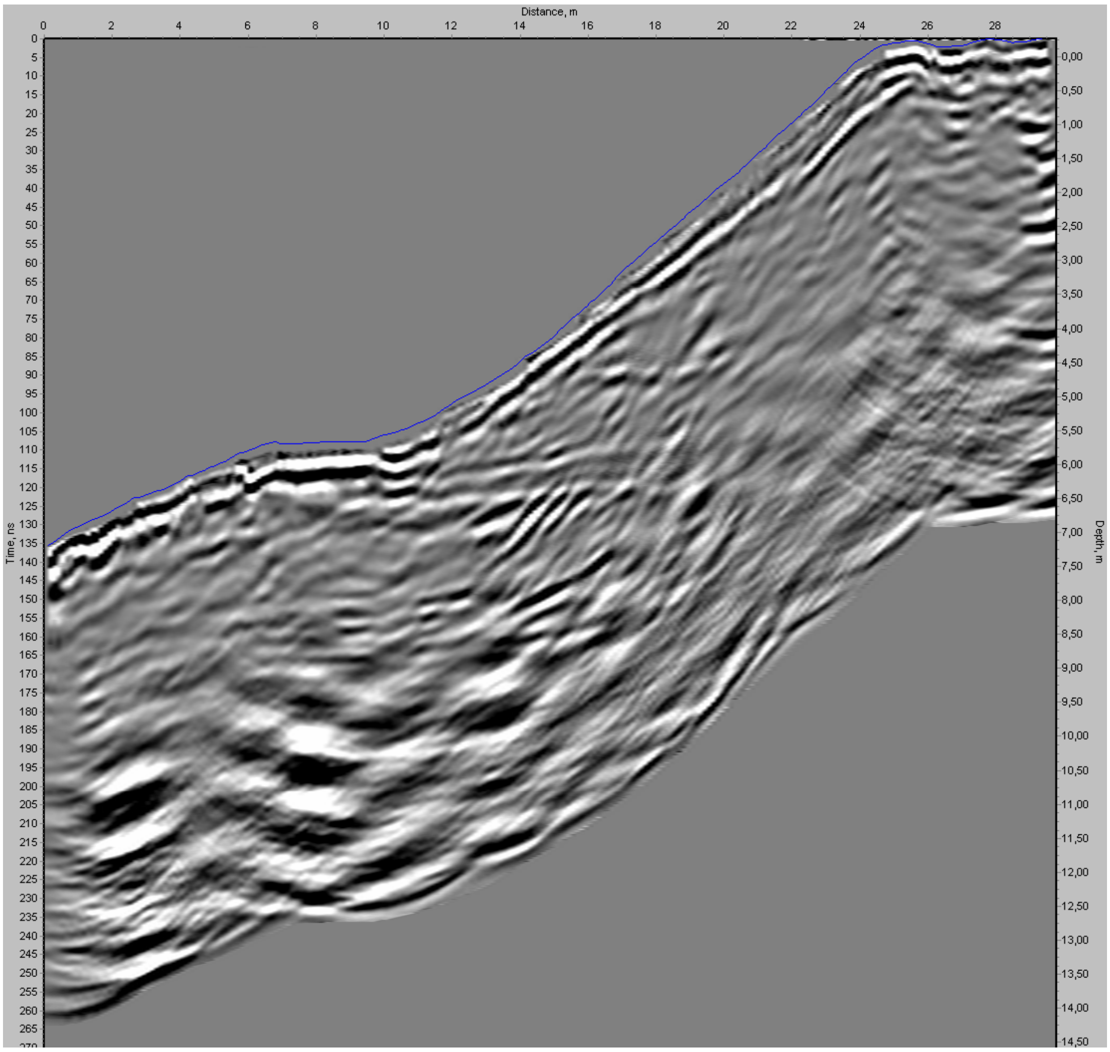

Figure 8. The GPR profile after topographic correction