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EXAMPLES OF USING GROUND PENETRATING RADAR AND GPS TECHNOLOGY FOR DETECTION OF UNDERGROUND UTILITIES

RISTIĆ Aleksandar, PETROVAČKI Dušan

UNIVERSITY OF NOVI SAD, FACULTY OF TECHNICAL SCIENCES, DEPARTMENT OF AUTOMATIC CONTROL

ABSTRACT

This paper describes modern, non-invasive data acquisition methods in underground utility detection. The work presents the possibilities of connecting data acquired with a Ground Penetrating Radar with GPS data and the joint use of these technologies through various examples. Also, the basic parameters, methods and their influence on the acquisition speed and data quality are defined.

1. INTRODUCTION

The Ground Penetrating Radar (GPR) is a device used for non-invasive scanning and precise detection of underground utilities. The GPR can be equipped with a GPS (*Global Positioning System*) rover, which is used for measuring spatial coordinates of the projection of the pipeline route on the site surface. Measurement of pipeline parameters with GPR and GPS measurement coordinates on the site surface are with centimetre accuracy. This measurement accuracy satisfies geodetic mapping laws [1].

When the survey cart moves on the site surface the transmitting antenna sends polarised, high frequency electromagnetic (EM) waves in the ground. Because of different existing inhomogeneties in the ground, e.g. soil layers, underground utilities, stones, gravel, cavities and other anomalies, part of the EM waves is reflected from the dielectric boundary between different materials and the other part is refracted and goes to the deeper layers. The decribed process is repeated until the EM waves become too weak. Reflection of EM waves from the dielectric boundary is the consequence of differences in the electric and magnetic properties of materials of infrastructural objects and soil layers.

Time necessary for the propagation of EM waves from transmit antenna to the boundary surface and its reflection back to the receiver antenna is defined as a two way travel t_R [ns] time. The GPR measures t_R, and finally calculates the relative depth of the underground object. Because each location has its specific soil structure, ε_R has to be recalculated for each site. Usually, the GPR recalibration method is used on site. This method is based on a GPR scan of an underground object with known depth [2].

Maximum penetration depth in pipeline detection is usually 3.5 to 7m (400MHz and 200MHz antenna, respectively). Vertical resolution in pipeline detection is usually 3 to 7cm (400MHz and 200MHz antenna, respectively).

Pipeline parameters are detected by 2D and/or 3D scans of the site. Complexity, type of pipeline network and amount of data determine which method is used for scaning.

A regular hyperbola shows up on the scan when ortogonally crossing above the pipeline axis. When the antenna trajectory is along the pipeline axis, the hyperbola is distorted into a straight line.

2. THE EFFECT OF THE MATERIAL AND ITS TYPE OF UNDERGROUND UTILITIES ON THE REFLECTION'S SHAPE

The shape of the hyperbola and the type of peaks (maximum or minimum) depends on the material of the utility [3]. By analysing the above data, it is possible to define the type and material of the utility. Figure 1 shows hyperbolas with various characteristics, measured on different locations in Novi Sad. By analysing the shape of the hyperbola, we can identify the type of the object: cable or pipe. Light segments of the hyperbola indicate positive peaks, while dark parts indicate negative peaks. If the positive peaks is the highest, it indicates a cable or a pipe filled with a liquid. The highest negative peaks indicate empty pipes. Figure 1A shows the reflection from an electrical cable, about 35mm in diameter. Figure 2B shows the reflection from a filled metal pipe, whose diameter is 100mm. Figure 2C shows the reflection from an empty concrete pipe, diameter 150mm. Figures 2C and 2D show the comparative view of an empty metal pipe and an empty PVC cable with an optic cable. Both pipes have a diameter of 110 mm.

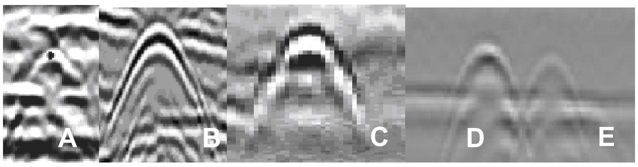


Figure 1. *Type and material detection of utilities*

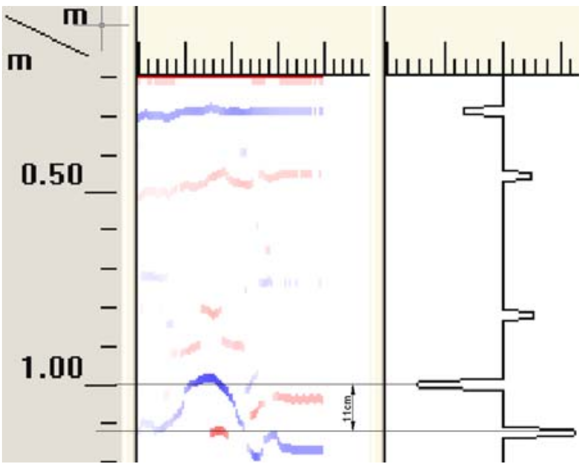


Figure 2. *Optical cable in PVC pipe*

It is obvious, that the electric cables differ from empty PVC cables the most, and also that it can be difficult to differentiate reflections of concrete and PVC pipes. We also determined, that metal utilities have better reflections than those made of non-metalic (concrete, PVC) [4]. This difference is caused by various reflective capabilities of metals and non-metals. Metals reflect the most of EM waves, while PVC is transparent for EM waves. This allows us to detect metal cables in PVC cladding. Figure 2 shows a processed scan of an optic cable in PVC cladding, diameter 110 mm.

Figure 2 shows a radar scan with marked positive and negative peaks. The negative peak shows the depth of the PVC pipe (h=1.00m), while the positive peak the depth of an optic cable (h=1.12m). PVC pipes have standard diameters, so it is possible to determine their diameters indirectly.

3. THE LONGITUDINAL SCAN

If the antenna moves along the pipeline axis – the longitudinal scan transforms the hyperbola into a straight line. Metal objects have weak reflections cause by minimal radar cross-section of longitudinal scans. Empty non-metal pipes (concrete, PVC, ceramics) have opposite polarisation, which cause negative peaks and good quality of longitudinal scans. Figure 3 shows the longitudinal scan of a PVC pipe in length of 12 meters (diameter 200 mm) taken in Novi Sad. It also illustrates the parameters which can be estimated: pipe inclination, length, junctions, reductions, etc.

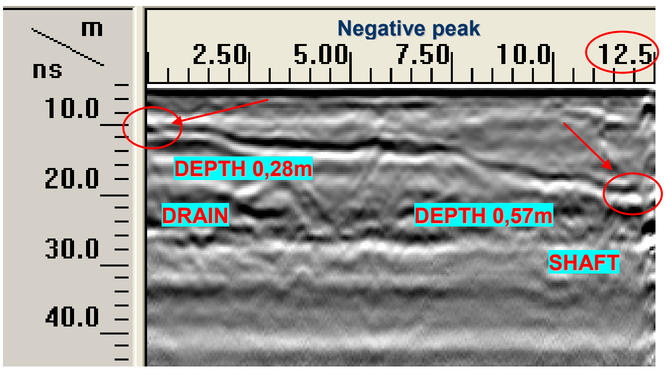


Figure 3. *Scan along PVC pipe*

4. SOIL STRUCTURE ANALYSIS

The detection and mapping of existing, or planned utility routes, it is important to estimate the level of groundwater and leakages [5]. Figure 4 shows a radar scan of the soil with a clearly marked groundware depth. It was scanned in an industrial area in Novi Sad.

Pipeline leakages form cavities and voids. Analysing the scan taken above a leakage, it is possible to determine the depth and shape of the anomaly [6]. Figure 5 shows the radar scan of an anomaly caused by pipeline leakage. This can be used as the basis for preventive analyses of road structures. Alternative method of determining the location of a leakage is to determine the change of the soil's dielectric constant or the shape of the EM reflection. [7].

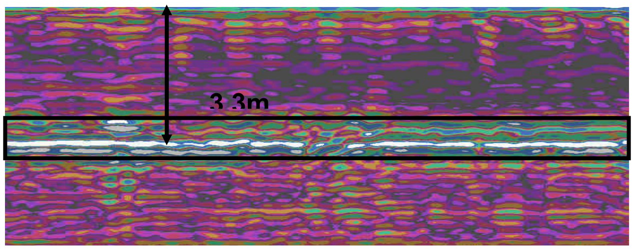


Figure 4. *Detection of groundwater level*


Figure 5. *Void and pipe leakage detection*

5. SCAN PROCESSING SOFTWARE

RADAN (*RAdar Data ANalyzer*) is a software package used for displaying, filtering and processing the radar scan. Data display is usually in *Linescan* format, where the color variations (or grayscale variations) indicate the values of positive and negative reflection amplitudes. Basic filtering functions are the horizontal (H) and vertical (V) *high-pass* and *low-pass* filters, deconvolution and migration. *High-pass* filters remove sistematic noise, while *low-pass* filters remove high frequency noise. The soil modifies the emitted EM waves, by partially absorbing high frequencies. High frequency emissions cause multiple reflections (*ringing)*. Multiple reflections overlap information coming from deeper layers. Deconvolution removes the effects of multiple reflections, and reconstructs the sequence of layers on the radar scan. Migration compresses the hyperbolical reflection into a single point, and positions it in the real position of the detected object. Beside filtering, object positions and depths can also be corrected on slopes. Variations are caused by topographic effects and by the fact that the antenna always emits the waves normally to the surface.

RADAN includes a number of functions for increasing the visibility of low amplitude features and to generate clearer data displays for reports. Beside these time domain functions, (two-way travel time and wave amplitude), it also has spatial filtering and Hilbert transformation functions, which process data in frequency domain (frequency and phase).

The Interactive interpretation modul decomposes the scan into layers with positive/negative amplitudes. The results can be exported to Microsoft Access. The scan can be automatically scanned for hyperbolic reflections, based on finding positive/negative peaks [8].

Functions for 3D visualization connect a number of sequential 2D scans (figure 6). Space between these scans is interpolated. Each horizontal layer is a *time slice*. Time slices contain data from all scans which were taken at the same moment. By analysing these time slices it is possible to detect linear objects (usually pipes). This can be done manually or automatically. The results can be exported to an AutoCAD 3D document [8].

Also, 2D radars scans can be synchronized with GPS coordinates measured on the surface, and shown on a three dimensional view [8].

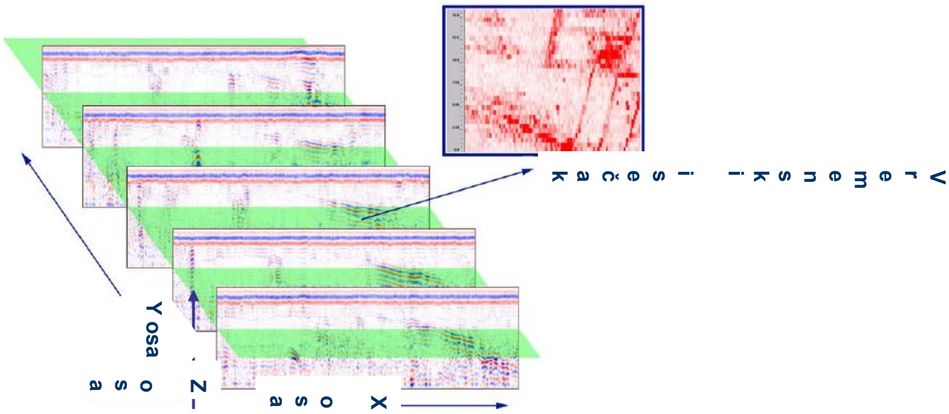


Figure 6. *3D scan generation rules*

6. PIPELINE ROUTE MAPPING EXAMPLE

One of the realised projects was the mapping of a regional pipeline route in Apatin and neighbouring villages. The project included the mapping of 12 km of pipeline route. Part of the route lies in urban environment, but the bigger part goes through suburban environments between villages near Apatin. All detected parameters measured by GPR were recorded as attributes in a georeferenced AutoCAD document.

Pipes were of different materials (PVC, Poliester, metal segments in shafts), different diameters (from ϕ125mm to ϕ350mm) and on various depths (from 1m to 2.5m), depending on terrain configuration and water flow direction. Shafts were placed on every 1 to 1.5 km along the route. The acquisition process was finished in 3 days.

The scans were recorded with a GPR antenna, with a central frequency of 200MHz. Maximum penetration depth of this antenna is about 7m. It is possible to use antenna with central frequency of 400MHz (max. penetration depth 3.5m). The second antenna is less robust because of a number of potential sources of obstacles (rugged, uncleansed terrain, gaps, cavities, deflections).

Spatial coordinates of all characteristic points on surface were measured with a GPS rover *Trimble 5800* using RTK (*Real Time Kinematic*) method with VRS (*Virtual Reference Station*) [9]. VRS software simulates reference stations near rover positions, thereby increasing the precision of the measured GPS coordinates. A network of base stations covers the region Vojvodina [10], enabling the measurement of GPS coordinates with a precision of 1cm. Real time differential corrections were received through GPRS (*General Packet Radio Service*). Rover Trimble 5800 has centimeter accuracy and is categorised with geodetic device accuracy.

All measured points are on a georeferenced map, with corresponding pipeline parameters recorded with GPR. Pipeline route situation view includes software defined distances of straightline pipe segments. Figure 7 shows attribute data table. AutoCAD document serves as a georeferenced graphical database, holding information about the pipeline. All data can be exported to other applications like Microsoft Excell, or Access.

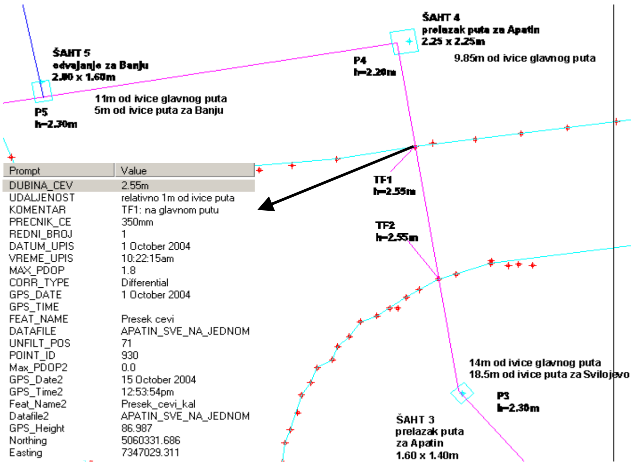


Figure 7. *Georeferenced graphical view with database*

7. FUTURE PIPELINE ROUTE SCAN EXAMPLES

2D GPR method can be used for complete scanning of future pipeline routes, in order to prevent possible damage and collision with existing utilites. Two projects in different locations were finished in Novi Sad with analyses complete future route for new concrete sewer collector 3x3m and a water pipeline ϕ500mm. Scanning of the future route for a sewer collector detected 25 new undergound utilities and verified 47 objects from an old utility map. Figure 8 shows shape and position reconstruction of hotwater pipes with diameter 400mm. These pipes are in protecting concrete duct.

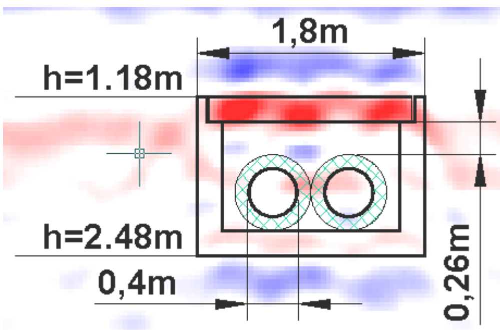


Figure 8. *Pipeline location and depth reconstruction from scan*

Scanning of future route for water pipeline detected 20 new undergound utilities and verified 24 objects from an old utility map. Beside that, on the second location GPR detected level of underground water table at 3.5m. The recorded data was used in deciding where future pipeline routes will be positioned.

8. 3D GPR SCAN OF A CROSSROAD EXAMPLE

Figure 9 shows a crossroad in Novi Sad. The emphasis was put on the atmospheric sewer junction under the crossroad. Crossroad coordinates measured with GPS rover Trimble 5800. This coordinates are used for crossroad map generation [9]. On figure 9 is marked GPR working area and scan sequencies. Space between scans is 1m.

Figure 10a shows final result of the 3D processing exported into AutoCAD (Figure 10b). The radar scan was processed with GSSI RADAN 6.0 software.

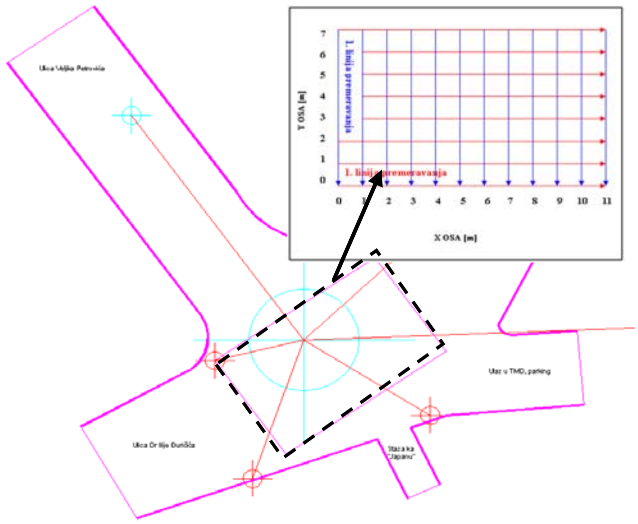


Figure 9. *Georeferenced view of cross road in Novi Sad with marked working area*

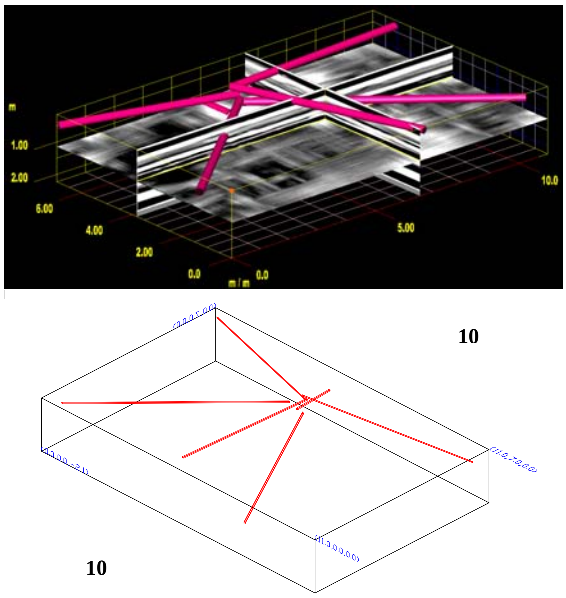
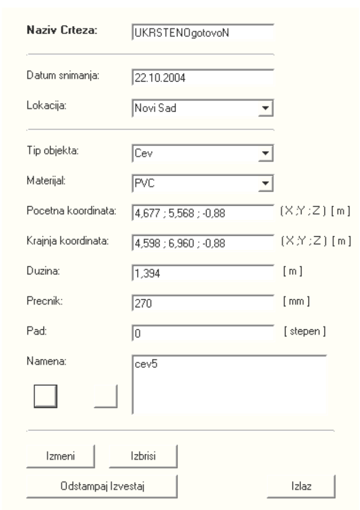


Figure 10. *Pipe location below the cross road after processing*

9. APPLICATION FOR AUTOMATED DATA EXTRACTION FROM RADAR SCAN



The extraction, calculations, editing, filtering and storage of relevant data, and report generation is done with an application developed in Visual Basic. The application extract data from AutoCAD through ActiveX, stores it in an Access database and creates MS Word reports. Figure 11. shows one of the forms of this application, used for data review and report generation. Visual Basic application, speeding up the analyses and reducing the involvement of the human factor.

Figure. 11. *Data extraction and processing*

The collected and calculated information form a complete geographical information system (GIS) for the analyzed site. More information, about soil structure and attributes could be included in this model.

10. CONCLUSIONS

This paper presents the practical possibilities of a ground penetrating radar. The basic parameters, methods and their influence on the acquisition speed and data quality are defined. Integration of GPR with GPS technology also explained by examples. Data processing was partly automated using Visual Basic application. Hardware improvements of this method include new antennas with different frequencies, antenna arrays or antennas with stepped frequency. Future software improvements should include higher automated data extraction, data processing and data display with reducing the influence of human factor.

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