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Using georadar systems for mapping underground utility networks

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Abstract

The transport infrastructure development in big cities leads to design underground road passages for fluidity of traffic. Under these conditions it is necessary to divert the underground utilities routes. Also, the construction of new metro sections is an alternative to public transport from the surface. New modern office and residential buildings, as well as new commercial complexes, require new underground utility projects.

In these circumstances, design studies require investigations about underground utility networks, in order to avoid the damage in execution operations of new construction foundations works. These investigations allow the design of metro lines and metro station avoiding major waterways, sewers, gas or electric cables, or design first the deviation project for these underground utility networks. Georadar systems together with advanced positioning surveying, assisted by specialized software, allow fast mapping, non-destructive and precise, very useful to designers for types of construction mentioned above. This system becomes a necessity in terms of urban agglomerations in growing today [6].

This article refers to modern systems Ground Penetrating Radar (GPR), to software for taking over of field information and to post-processing software that lead to obtaining 3D georeferenced digital map products, integrated into a GIS [1].

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Keywords: Ground Penetrating Radar; depth of investigation; hyperbola; tomography; digital map;

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1. Introduction

The exact knowledge of the positions and routes of the pipelines and underground cables, which constitute the utility networks in the localities, has become a necessity in the design and execution processes of all kinds of constructions.

As a rule, utilities networks are located under the street networks. Thus, when rehabilitating a street or avenue is done, it is intended to avoid the destruction of these existing networks if they are kept in operation, and when they are replaced, for the economic efficiency of the works, it is necessary to know the route and the laying depth.

Extending the subway routes in big cities, involves excavating works at least in areas where the subway stations are designed with exits to the surface, that impose carrying out some of the deviation routes works of sewer, water, gas, etc., utility network which are buried under the streets of major cities.

An effective investigation and accurate of these underground utility networks is provided by GPR systems, which are based on modern microwaves transmission and reception technologies, on software for automatic data acquisition and on specialized software for processing and interpretation of this information [3].

The possibility of correlating GPR data with data provided by GNSS positioning systems or total stations can lead to high-quality 3D modeling products of the studied area, easily integrated into a thematic GIS (Geographic Information System).

2. Operating principles of GPR systems

The GPR compact system transmits electromagnetic pulses into the ground and measure the time "t", time elapsed between the emission and the reception part of the signal returned by reflection (Fig. 1.).

Knowing the propagation speed through the ground, we can determine the depth to the target object from the soil.

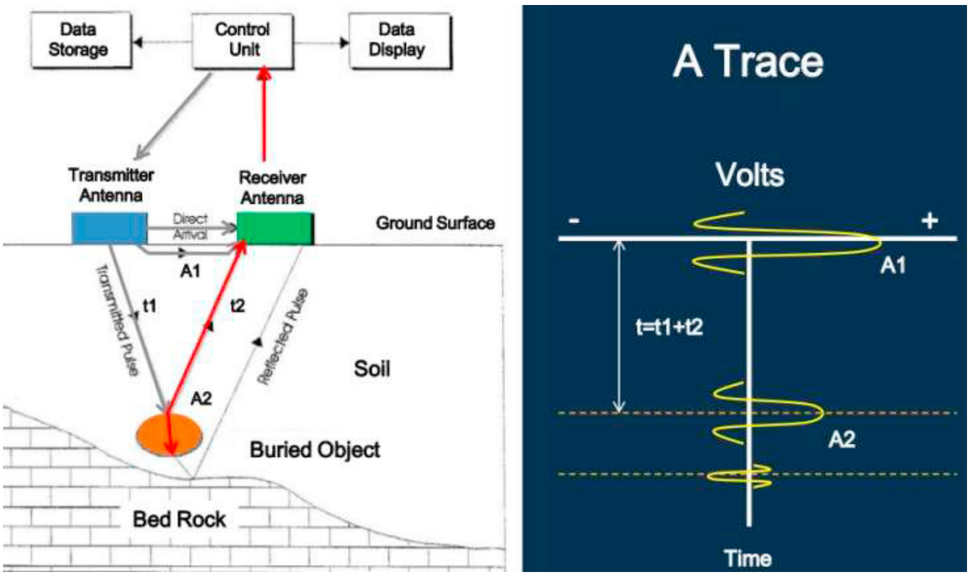

Fig. 1. Principle of waves propagation in soil. [11]

If radar impulses cross different materials on their way to the "target" we want to record, the speed of these pulses will change depending on the physico-chemical properties of the materials they are crossing. Thus, materials with different dielectric properties will result in different reflection and refractive velocities of the respective waves.

Different antennas allow different radar signals to be emitted. High frequencies allow for high resolution at the expense of the depth of investigation. Conversely, when the frequency is low, the depth of investigation increases, but the resolution decreases.

Depth investigation "d" is also controlled by the soil nature prospected whose absorption characteristics (radar waves) are variable.

$$d = \frac{t}{2} \times V_m \quad (1)$$

$$V_m = \frac{c}{\sqrt{\varepsilon_r}} \quad (2)$$

where c - is the wave propagation speed in free space (3×10^8 m/s), Vm – is the wave propagation speed in soil and ε_r – is the relative permittivity of the soil.

The relative dielectric permittivity ($\varepsilon_r = \varepsilon/\varepsilon_0$) is a magnitude that characterizes the polarization state of the material and it is dimensionless and in size between 1 (for gases) and thousands or even tens of thousands in the case of ferroelectrics (for example, absolute permittivity of vacuum (air) is $\varepsilon_0 = 8.854 \cdot 10^{-12}$ F/m, of water is $\varepsilon = 80$ F/m, of send is $\varepsilon = 4$ F/m, of concrete is $\varepsilon = 6 \div 20$ F/m, etc.).

Depending on the field of use, the depth at which we want to make the investigation or objects of interest are located and the dimensions of these objects, will choose the type and frequency GPR antenna (see Table 1. and Fig. 2., Fig. 3., Fig. 4.).[9]

Table 1. Correlation between antenna frequency and depth of investigation.

Operating frequency (MHz)	Maximum scanning depth (m)	Minimum size of scanned objects (cm)
80	14	25
160	10	15
450	6	6
760	3	4
1200	1,5	1,5
1600	1	1
2300	0,6	0,5


Fig.2.Real-time location – OPERA DUO.[9] Fig.3.Localization and mapping – RIS MF.[9] Fig.4.Intensive mapping – STREAM EM system. [9]

The GPR STREAM (Subsurface Tomographic Radar Equipment for Assets Mapping) EM system is a dual-polarized double-polarized dual-frequency with high productivity that allows data collection for all underground utilities in a single pass at speeds of up to 18 km / h, so the closure of some streets is not necessary.

At this GPR STREAM EM there are two antenna matrices. The front ones are 200 MHz and form the DML (Detect Main Line) matrix with vertical polarization designed to detect parallel conduction paths and the rear ones are on the 600 MHz frequency and form the DCL matrix (Detect Connection Line) with horizontal polarization to detect transverse paths in the direction of travel. [7]

This complex GPR system can acquire information on 38 channels (30 on DML matrix and 8 on DCL matrix) that can be correlated and compatible with positioning information provided by a GPS or a total station.

3. Taking and viewing data in the field

For georadar mapping is recommended to use other information sources to obtain a set of data from existing maps and plans until a visual localization of networks placement, their depth, diameter and direction of advancement through manholes.

It is possible to estimate the size of the investigated area, the characteristics of the targets, the design of preliminary scanning routes, the provision of accessibility (traffic permits, presence of parked cars, access to private premises, etc.), selection of the appropriate frequency, calibration routes, adjustment of the soil perimeter system (electrical conductivity and relative dielectric permittivity), after which the actual data is acquired.

GPR system recorded data can be viewed on site, on the field computer and can show as follows [4]:

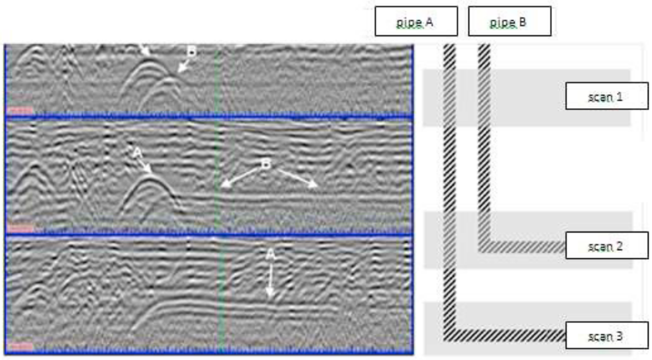

Fig. 5. View on the field.

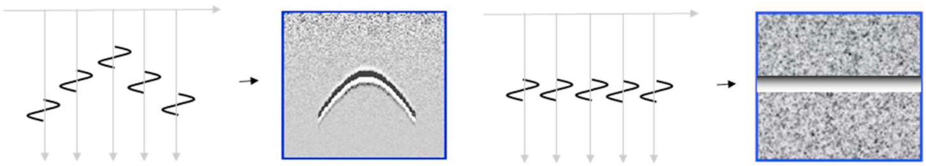

Fig. 6. Locate a pipeline perpendicular and along to the investigation path.

For street junctions, where there is an agglomeration of pipelines at different depths, it is recommended to design an investigation grid and use both low and high frequency antennas simultaneously.

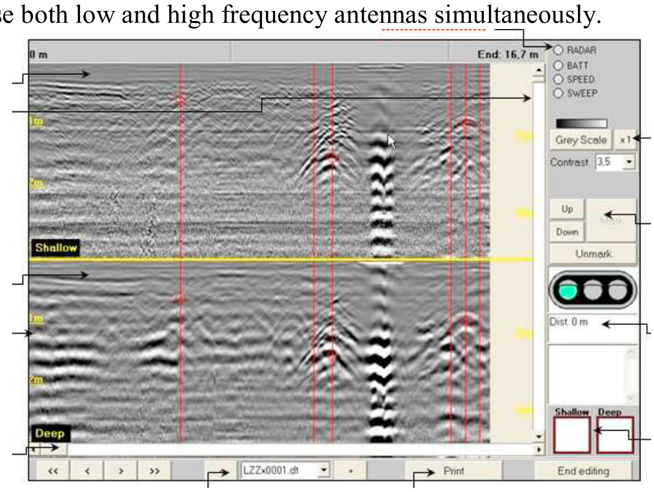

Fig. 7. Field computer screen. [12]

During data acquisition, both radar views can be viewed on the field computer display when both antennas (600 MHz and 200 MHz respectively) operate, the two sections being separated by a horizontal yellow line. To mark the presence of a parabola on the screen during acquisition (generated by the presence of a pipe or cable), the GPR system moves back in the opposite direction to the acquisition direction, this temporarily suspends the recording and produces a red line on the display.

It is obvious that these aspects may have an impact on productivity with GPR, also taking into account the effort of processing and further analyzing a large set of data, which can last at least twice as much as the time required for data acquisition.

A recent innovation of land acquisition and analysis software is the hyperbolic representation of reflected waves with automatic markings of their spikes ([2], [8]), the position of the pipes can be easily recognized to obtain a 2D map of the scanned area.

The automatically detection algorithm of hyperbolas (HADA) allows GPR data visualization like a tomography, being comprehensible to the operator who can perform some settings to achieve optimal tomography [5].

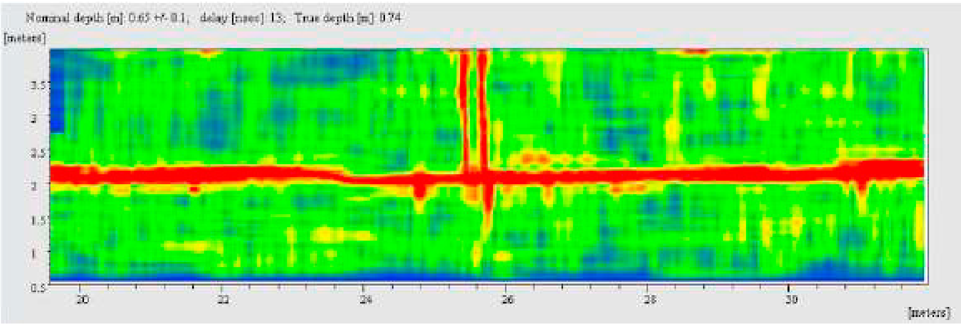

Fig. 8. A tomography. [5]

The operator can mark the lines detected on this tomography, find visible and intersections of the underground networks on a single screen capture, reducing the time needed for data analysis, and these software tools can increase productivity up to 4 times.

4. Post-processing of GPR data

Each manufacturer of GPR detectors delivers or recommends specialized software for analysis, post-processing, and modeling to get graphical products that are easy to understand and used by the beneficiary.

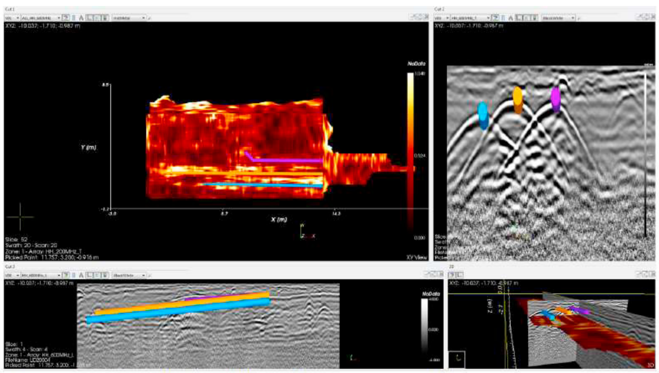

Fig. 9. Screen from the GRED HD3 Software [1].

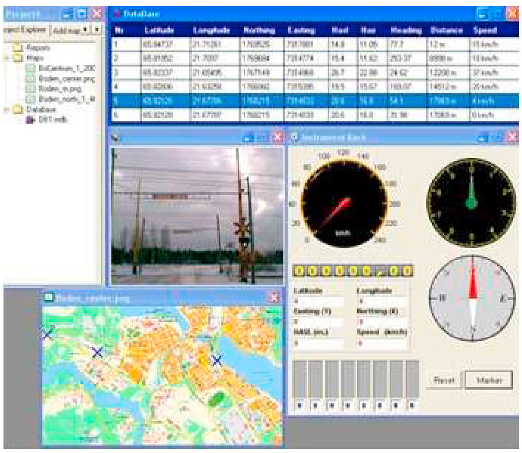

Fig. 10. Screen from the GeoPointer X Software. [10]

The high-resolution post-processing GRED HD3 software is developed by IDS (Ingeneria dei Sistemi) in Italy and is dedicated to viewing GPR data using powerful 2D and 3D processing algorithms. This software can integrate captured information with GPS or total station, the results being compatible with CAD and GIS systems.

You can simultaneously view 4 windows:

- Plan XY
- The YZ plan
- Plan XZ
- 3D View, XYZ

Another software used to process GPR data is GPRSoft ™, an affordable and easy-to-use solution for displaying, post-processing, and interpreting GPR data. With an intuitive interface, it allows you to focus your attention on the target underground network. GPRSoft ™ has full data file support from all major GPR manufacturers and is constantly reviewing the formats used in the application to meet the latest changes to this technology (sample formats: GSF Geoscanners Survey Files, GOF Geoscanners Object Files, DT IDS Files, DZT GSSI Files, DAT Data Files, RD3 MalA Files, SEG-Y Segy Files, DT1 SensorsSoftware DT1).

GeoPointer X is a GPR post-processing software that combines GPS coordinates, positioning on the map, images and much more from a geophysical study in a single system. It's an easy way to document investigation areas.

GeoPointer X brings new possibilities in the way geophysical data is analyzed, not only data in the geophysical tool is available, but also an entire set of data about the location of the survey can be viewed. GeoPointer X provides a real possibility to link GPR data with a database that describes the site if other data were collected. In other words, combining geophysical survey data and data stored in GeoPointer X, it is possible to see both sides of the surface.

By combining GPR system with a Topcon IPS2 LIDAR or a mobile system for 3D mapping IPS3 HD, through a single pass can be collected both sets of information that can generate a single three-dimensional CAD drawing, with elements on the ground and underground.

Fig. 11. A mobile mapping system combined with GPR system. [9]

Data analysis will reveal the features available under the surface of the soil along with an image of the surroundings above the soil surface. These linked data give us a better idea of the survey site and its position. The gathered information can be used while writing reports or detailed descriptions of that site.

4. Georadar graphics products requested by the beneficiaries

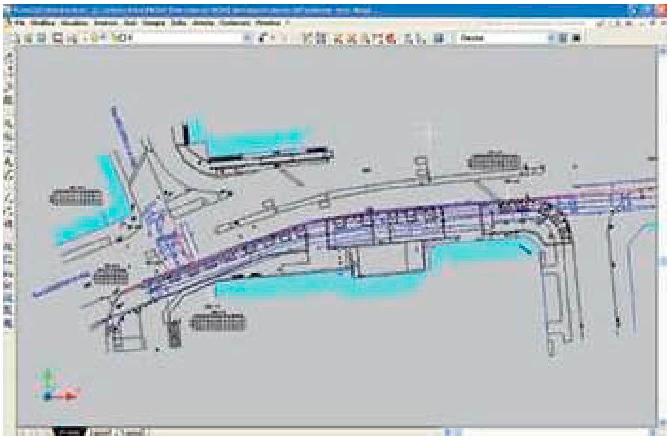

Fig. 12. Representation on thematic plan. [9]

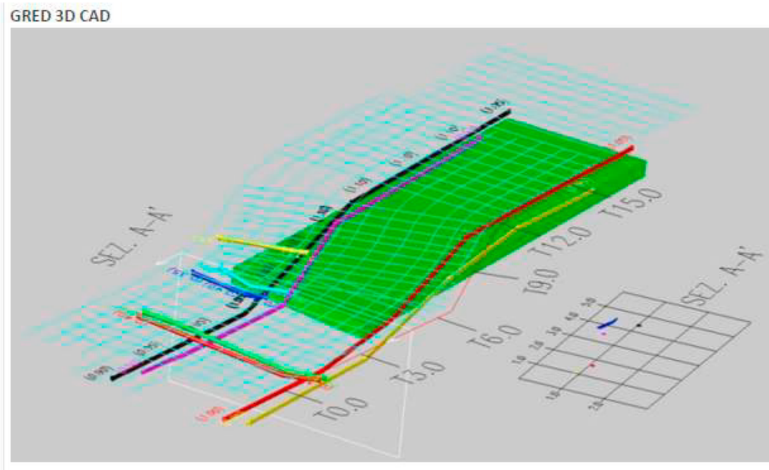

Fig. 13. Three-dimensional CAD representation. [12]

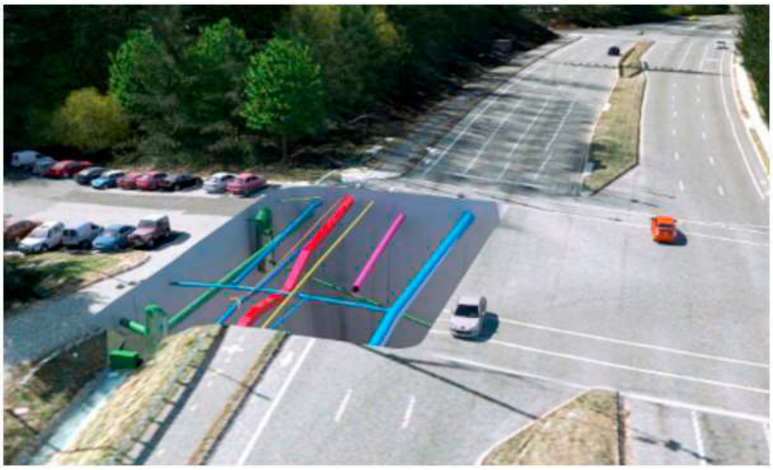

Fig. 14. Virtual-realistic image. [13]

6. Conclusions

The georadar technology offers high-quality technical solutions to the most common problems in the field of construction in all aspects (tracing, making three-dimensional models of the land, natural hazard analyzes, tracking the movement of massive constructions - bridges, bridges, Major architectural importance, etc., as well as the realization, mapping and extension of underground public networks) and therefore becomes more and more used.

Integrated GPR equipment with already widely used technologies (GPS equipment, total stations) bring innovation to the field of geodesy, enabling large-scale works with all the necessary equipment. GPR equipment can be used on both small areas of land, sporadically, as we have seen before (OPERA DUO and RIS MF Hi-Mod), as well as for large areas, where it is necessary to accurately map existing public networks in the basement (STREAM EM equipment).

Due to the technology used, which is based on the detection of buried objects by measuring the time elapsed between the emission and reception of the radar wave by an antenna of a certain frequency, different resolutions are obtained. Thus, depending on the frequency of an antenna, the equipment can provide information about the depths of the larger or smaller depths, but a very important contribution to data acquisition is the physical component of the soil. The most important effect is the soil degree saturation with water, as well as its dielectric constant (conductivity). The maximum penetration depth of the emitted wave depends on the wavelength used and the dielectric constant of the investigated environment (see table 1).

Regarding the way of viewing and processing the information obtained using the georadar, the post-processing of the information is obtained from the acquisition software. In this way, "water in-situ" water losses can be detected, but certainly the most reliable detections are made after the information provided by the equipment is introduced into the specialized software component in order to eliminate the redundant information and the "noise" produced by the presence of the various buried objects that do not make the purpose of the work done (underground holes, buried metal objects, non-excavated excavations, etc.).

That is why a very good knowledge of the used equipment as well as of the specialized software component is necessary in order to obtain the results with the necessary accuracy depending on the specifics of the work done.

As far as the mapping of underground utilities is concerned, connecting the georadar to GPS equipment creates the possibility of positioning in local or national system for their reference.

According to these considerations, the GPR technology represents a real progress in achieving a systematic record of underground utility networks, which is extremely useful for the speed wherewith develop the infrastructure of human settlements which are in perpetual expansion.

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