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GPR TECHNIQUE AND DATA FOR ACHIEVEMENT 4D CADASTER

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Abstract: *This article proposes to strengthen the connection of data about constructions made underground and what is built above ground for the development of the concept of multidimensional GIS. We emphasize here the importance and need to use GPR (Ground Penetrating Radar) systems for a fast and accurate acquisition of information about underground utility networks and the geological and geotechnical structure of the land, useful information for new construction investments (buildings, roads, highways, subway etc.). Also here is presented a variant of integrating this data in a GIS platform.*

Key words: *georadar, GPR, dielectric permittivity, underground utility networks, GIS.*

1. Introduction

At the moment it has become imperative to know about a plot of land, especially in urban areas, what structure has the basement and whether there are objects or utility networks buried, especially when it is to be built a new construction, with several underground levels.

In this context, the non-destructive and low-cost investigation of the land area on which it is to be built is very useful, in the feasibility project stage. Georadar referenced investigations can be an effective radiography of the subsoil structure in a short time and with a high degree of certainty, regarding the existence or not of some underground elements that can increase the design and construction costs if they are discovered and/or damaged at the start of the construction process (digging foundations or drilling piles).

The information provided by the GPR technique can greatly complement the geotechnical studies but also the cadastral information regarding the equipping of the land plot with urban networks, having a contribution also on the property evaluation criteria.

If we extrapolate, in the case of large-scale projects that have as their theme the inventory of underground utility networks at zonally level or at the level of a locality, the GPR (Ground Penetrating Radar) technique can play an essential role, especially for the fact that georeferenced data can be generated digitally, in formats recognized by GIS platforms. Utility-specific software modules already exist in most GIS platforms, which

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have defined appropriate symbol libraries and generate specific windows for entering the characteristic attributes of each type of underground utility network.

2. Working Principles of GPR

Ground Penetrating Radar (GPR) is a non-invasive subsurface imaging technique that typically uses short pulses of electromagnetic energy to "see" into the ground (see Figures 1 and 2).

GPR can have applications in a variety of environments, including rocks, soil, ice, freshwater, sidewalks and structures. Under the right conditions, practitioners can use GPR to detect underground objects, changes in material properties, and gaps or cracks.

GPR is used to map geological conditions that include the depth to the bedrock, the depth to the groundwater, the depth and thickness of the soil layer, and the location of objects such as pipes, drums, cables, and conducting archaeological investigations [1].

Fig. 1. *A GPR system components*

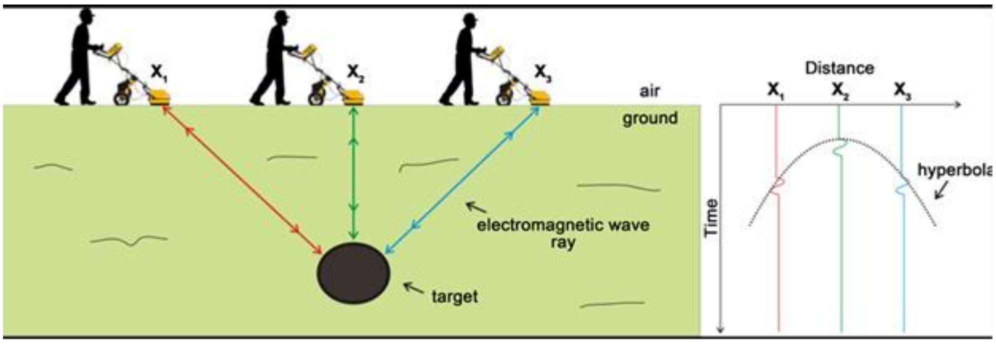


Fig. 2. *Principle of detection with GPR*

The source of the GPR system sends a set of electromagnetic waves that oscillate near a certain frequency and as these waves propagate through the ground are distorted due to the distribution of the electromagnetic properties of the ground (σ - density, μ - permeability and ε - electrical permittivity), are reflected and received by the device antenna [2], [6].

In general, the depth at which an object is in the ground can be determined by the relation:

$$H = \frac{V * t}{2}. \tag{1}$$

In principle, the speed of wave propagation is the speed of light in a vacuum "*c*", but in the ground things are different, so the speed depends on the physical properties of the environment:

$$V = \frac{c}{\sqrt{\mu \cdot \varepsilon}}. \tag{2}$$

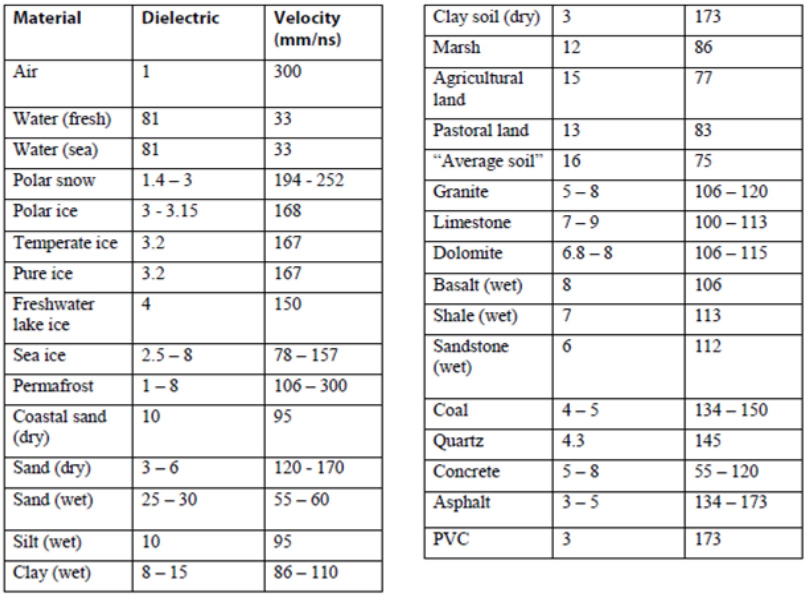
If the propagation medium is not magnetic, then $\mu = 1$, and the velocity relation can be written as:

$$V = \frac{c}{\sqrt{\varepsilon}}. \tag{3}$$

Because ε (electrical permittivity), also called the dielectric constant, depends on several parameters, such as soil compaction, lithology and water concentration, the results obtained in the calibration stage provide more detailed information about the speed of the GPR electromagnetic wave through the investigated environment. This has positive implications both for estimating the depth of the objects sought and for knowing the soil matrices [3].

The table below shows the speed dependence in relation to the dielectric permittivity for different materials.

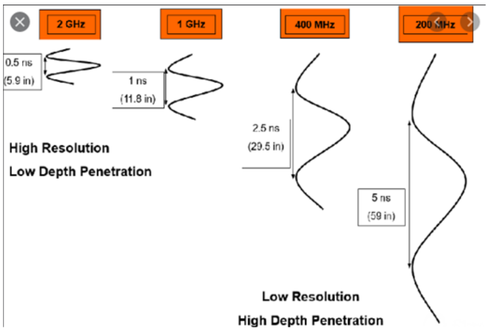
Microwave speeds in different types of soil Table 1

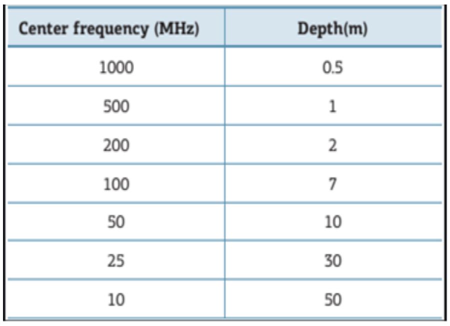


Material	**Dielectric**	**Velocity (mm/ns)**
Air	1	300
Water (fresh)	81	33
Water (sea)	81	33
Polar snow	1.4 – 3	194 - 252
Polar ice	3 - 3.15	168
Temperate ice	3.2	167
Pure ice	3.2	167
Freshwater lake ice	4	150
Sea ice	2.5 – 8	78 – 157
Permafrost	1 – 8	106 – 300
Coastal sand (dry)	10	95
Sand (dry)	3 – 6	120 - 170
Sand (wet)	25 – 30	55 – 60
Silt (wet)	10	95
Clay (wet)	8 – 15	86 – 110
Clay soil (dry)	3	173
Marsh	12	86
Agricultural land	15	77
Pastoral land	13	83
"Average soil"	16	75
Granite	5 – 8	106 – 120
Limestone	7 – 9	100 – 113
Dolomite	6.8 – 8	106 – 115
Basalt (wet)	8	106
Shale (wet)	7	113
Sandstone (wet)	6	112
Coal	4 – 5	134 – 150
Quartz	4.3	145
Concrete	5 – 8	55 – 120
Asphalt	3 – 5	134 – 173
PVC	3	173

The resolution and depth of the investigation are directly dependent on the frequency used (see Table 2 below), so when we want to detect objects at shallow depths, we set high frequencies, and for in-depth investigations we will set lower frequencies. This indicates that it is necessary to have approximate information about the targets we want to locate in the soil, from other sources [4].

Dependence of the investigation depth on the transmission frequency Table 2





Center frequency (MHz)	Depth(m)
1000	0.5
500	1
200	2
100	7
50	10
25	30
10	50

3. GPR Equipment and Data Acquisition Procedures

Underground measurement equipment covers a wide range of detection and location objectives:

- Underground utilities (cables, pipes, manholes, optical fiber and others);
- Determining the state of the transport infrastructure;
- Archeology;
- Environmental studies (area spread of contaminants or the presence of groundwater);
- Studies of the resistance structures of industrial buildings and residential buildings.

Some types of GPR equipment can be:

- RIS MF Mi-Mod system, produced by IDS Georadar [https://idsgeoradar.com/products/ground-penetrating-radar/ris-mf-hi-mod]

- Leica DS2000 GPR system [https://leica-geosystems.com/products/detection-systems/utility-detection-solutions/leica-ds2000-utility-detection-radar]

- GPR LMX200 ™ system - made by Sensors & Software [https://www.sensoft.ca/products/lmx200/overview/]

- Georadar systems Guideline MALÅ EasyLocator [https://wwwguidelinegeoc.cdn.triggerfish.cloud/uploads/2016/07/EL-HDR-Manual.pdf]

- GPR Quantum Imager Triple Frequency System - produced by US RADAR INC [https://usradar.com/quantum-imager-triple-frequency-gpr-system/]

Any GPR equipment used is normally composed of a transmitter and receiver antenna, a radar control unit and appropriate data storage and display devices.

The radar control unit synchronizes the signals to the transmitting and receiving devices in the antennas to generate a sampled waveform of the reflected radar waves. These waveforms can be filtered and amplified and are transmitted together with synchronization signals to the display and recording devices.

Using polarized antennas with two different frequencies (usually clad), will maximize the detection capability of underground objects located at different depths [5].

The measured time from transmission to reception is transformed into the depths at which the objects in the subsoil or geological layers are located, the speed of electromagnetic waves through the ground can be 60 - 175 mm / ns, depending on the electrical conductivity of the soil substrates.

If you are using a GPR system for the first time, you must first access the settings menu: UNITS, LANGUAGE, DATE&TIME, PATH, VERSION.

When you go to GPR data collection, we need to make some more settings:

RADAR - antenna type and emission rate; SCAN - set the data sampling rate, format, dielectric constant and others; GAIN - the degree of amplification of the reflected signal; POSITION - the three-dimensional position of the scan start point, correlated with the GNSS receiver attached to the GPR system; FILTERS - choosing how to filter (remove interference and noise) of the collected data.

A pre-established plan is required to investigate the area of interest. At the beginning of the recording (of the GPR profile) RUN is pressed, and at the end the data collection is stopped by pressing the RUN key, being automatically created a file that can be processed later.

Each GPR equipment manufacturer also delivers software for field data acquisition. Some of these may be:

- MALÅ Object Mapper,
- ImpulseRadar ViewPoint,
- EKKO_Project,

but, GPR-SLICE is a complete and unique software package that has a direct interface (see Figure 3) to raw field data, processes raw data, and creates a multitude of possible image presentations as well as office post-processing operations.

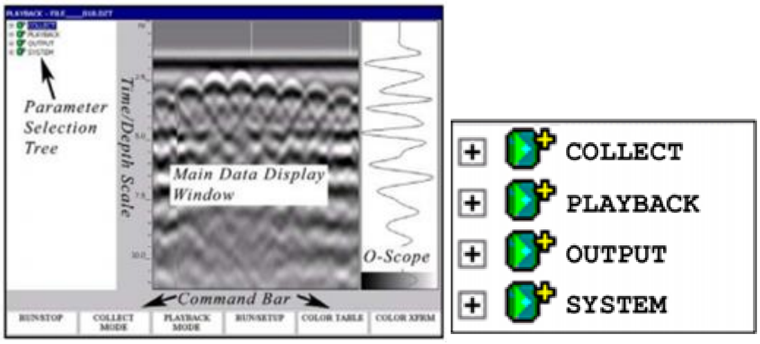


Fig. 3. *GPR-SLICE software interface*

Among the operations that can be performed with GPR-SLICE, at post-processing are found:

- Data analysis, filtering and decimation.
- Radar charts can be segmented, multiple radar charts can be concatenated, noise filtering, identification of migration zones of the reflected signal and application of filters or signal amplifiers in unclear portions.
- Bringing a topographic map in the background.
- In the 3D Visualization menu you can build semi-automatic objects in the basement (pipes, cables, gaps etc.) with the possibility of exporting in DXF format or other formats.
- 3D analysis of data volumes can be performed by viewing any vertical, horizontal or oblique sections.

All these processing results with this software can be layered, transformed into vector formats and then exported to a GIS or Google Earth.

4. Integration of GPR Data into GIS Platforms

4D engineering representations allow new collaborative digital workflows for the management and development of public works for utilities, for the benefit of city owners and administrators. For infrastructure professionals, BIM and GIS are effective 4D digital components.

As part of the ArcGIS platform, the "Utility Network" allows users to create, manage and share data on electrical, water, wastewater, gas, district heating and telecommunications assets. Esri provides database models in some of these areas. Thus, technicians will be able to track the route of the network of interest and edit information about it, easily managing billions of data on any device, anytime and anywhere, facilitating the exchange of information with those who need them (designers, specialists in network maintenance) (see Figure 4).

The "Utility Network" module of the ArcGIS platform, installed on a field device allows the specialized user to simulate intervention solutions (connecting a new pipe in a valve for example), placing network elements in the same location and viewing the effects that will appear.

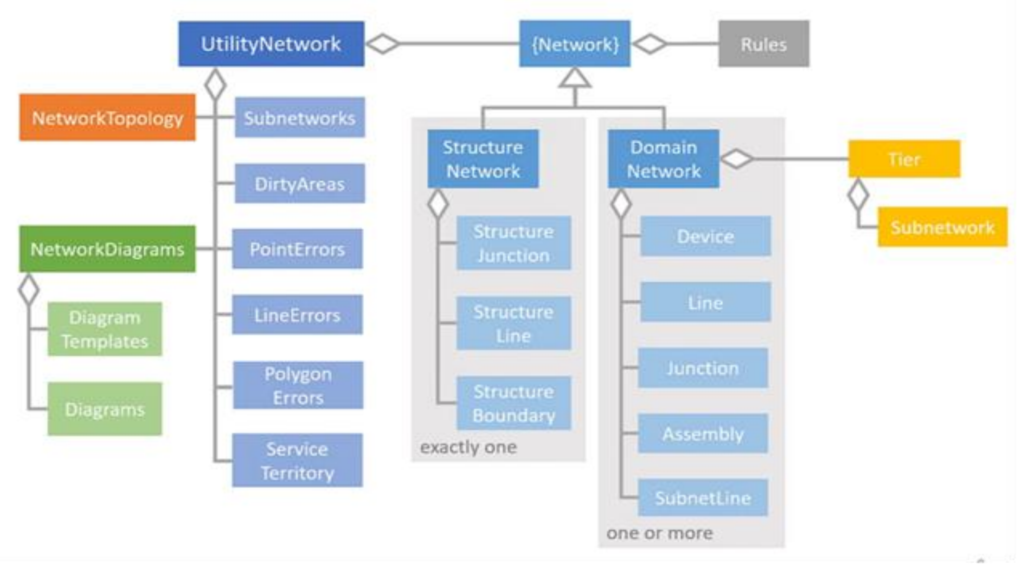


Fig. 4. *The workflow of the "Utility Network" module in the ArcGIS platform*

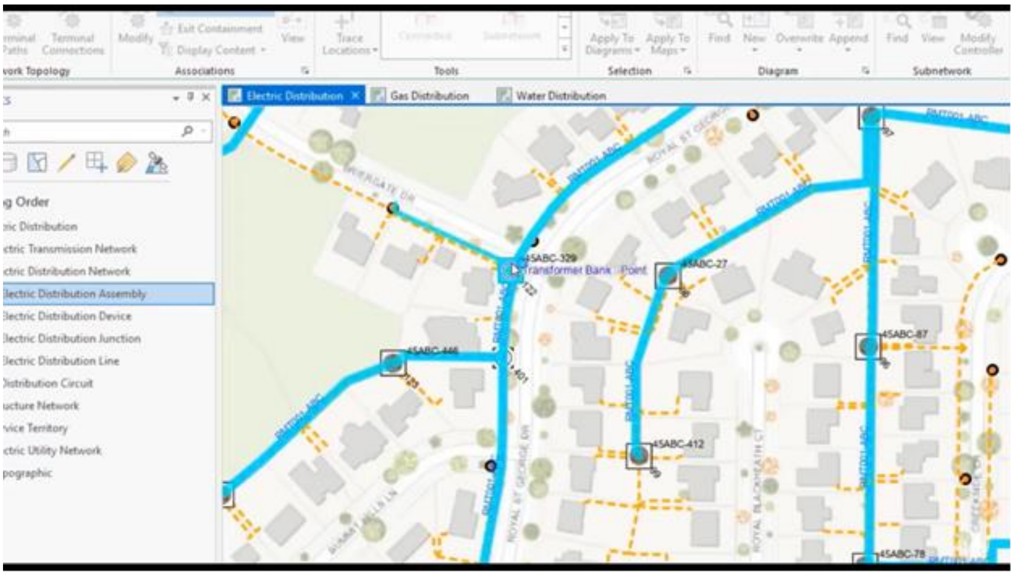


Fig. 5. *Screenshot from "Utility Network"*

The same specialist user can model attached network elements and the "Utility Network" application proposes possible solutions depending on the given situation, such as how an electrical transformer can be fixed on a certain type of pole (see Figure 5).

This technology has built-in rules and standards that protect the user from making mistakes when entering data, for example it will not be allowed to connect a high voltage cable with a low voltage one.

If previously ArcGIS users could only view utility networks geometrically, this new software module allows networks to be edited and provides tools for extracting information that characterizes the components of a network. There are templates, shortcuts and simplified workflows so that users can have increased productivity, facilitating 3D visualization.

There is the possibility to extend the functionality of this GIS platform with other modules for various purposes specific to other departments (infrastructures, logistics, finance), in order to increase the efficiency of an emergency response. By immediately transmitting the location and type of fault on the phone or tablet, it is possible to estimate exactly the necessary materials and the estimated time of the remedial intervention, in order to be able to publish the information regarding the interruption of a utility service (water off, power off, heat off).

5. Conclusions

The current requirements for a complete cadaster and a real assessment of real estate require the integration in GIS and information on underground utilities but also information on the structure and qualities of the soil.

GPR underground land investigation techniques are already being developed and there is software for processing and interpreting this category of data, which can be transformed into digital information accepted by the databases used by GIS platforms.

GIS software developers have already prepared specific modules and applications in this regard, so we can talk about a concept of multidimensional cadaster, compared to the classic 3D.

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