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GPS AND REMOTE SENSING TECHNOLOGIES APPLICATION FOR MAPPING OF MID-PRESSURE GAS LINE NETWORK

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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 (GPR) with GPS (Global Positioning System) data and the joint use of these technologies in the mapping of underground mid-pressure gas line network. Also, the basic parameters, methods and their influence on the acquisition speed and data quality are defined.
Keywords: Remote sensing, Global Positioning System, Ground Penetrating Radar, Pipeline route

1. INTRODUCTION
No dig utility mapping technology is important in data acquisition for computation, modeling and control of underground infrastructure systems. Classic mapping technologies (excavation, old maps) cannot follow the dynamics of development and repair of pipelines. Our work has shown that the use of GPR in combination with GPS is a more reliable method. A direct consequence of the classical approach is an expensive, uncoordinated process of establishing new pipelines accompanied with damage to existing utilities. Low quality information about condition and operation of, for example, city water supply system implicitly affects the flexibility of that system. This can be seen on the difference between the amount of processed and distributed water. Participants in the process of digital spatial data production, maintenance and management, as well as numerous users, who base their work on using spatial information, have the need to increase their efficiency. One of the ways to do this is the implementing the geo-information system. Considering the fact that spatial registers are extensive, the processes of producing data in digital form, maintenance and management are very complex tasks.

2. PHYSICAL CONCEPTS OF GPR WORK
The Ground Penetrating Radar (GPR) is a device used for non-invasive scanning and precise detection of underground utilities. GPR is composed of a receiver and transmitter antenna, a control unit with Win CE OS, battery supply and a survey cart. Survey cart is a tricycle equipped with incremental encoder. The incremental encoder is used for precise positioning of the center of the antenna above a pipeline route. The GPR also has a marker which is useful for marking interesting details on a radar scan. The GPR can be equipped with a GPS (*Global Positioning System*) rover that is used for measuring spatial coordinates of the projection of the pipeline route on the site surface. The GPS rover can measure coordinates either independently or synchronized with the GPR scan. In the second case, the GPS rover measures all points on the scanned trajectory, or just the start and end

coordinates. Synchronized work implies direct communication between GPS rover and the GPR device. Measurement of pipeline parameters with GPR and GPS measurement coordinates on the site surface are with centimeter accuracy. This measurement accuracy satisfies geodethic-mapping laws [1]. Figure 1 shows the schematic picture of the GPR equipment, its functional parts and the connections between them.

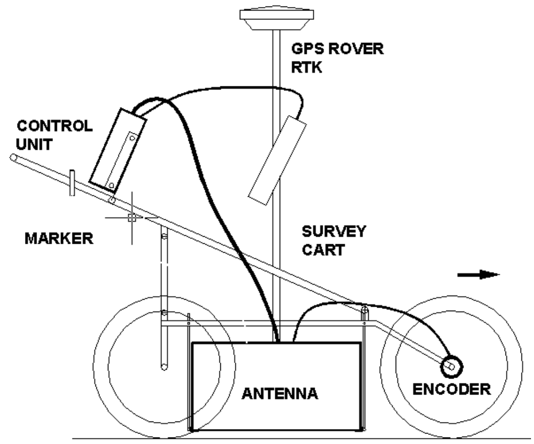

Figure 1. Functional parts of GPR

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 described 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 [2].

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 (dielectric permitivitty) 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 [3]. 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) [4]. Methodology of radar scan generation is shown in Figure 2. A radar scan is a spatial section of the working area. The antenna's linear trajectory is shown on X axis, and Y axis shows the two way travel time t_R i.e. the relative depth z from the surface to the underground object. The distance between transmit and receive antenna is very small. Because of this, the distance from transmit antenna to boundary surface is approximately equal to the distance from boundary surface to the receiver antenna. The distance from antenna to the underground object continuously changes. Distances $r_0, r_1, ... r_N$ are projected ortoghonally on the movement axis, see points x_{-N} ... x_0 ... x_N (see middle section of Figure 2.). By sequentially connecting the ends of these segments, a geometrical hyperbola is formed.

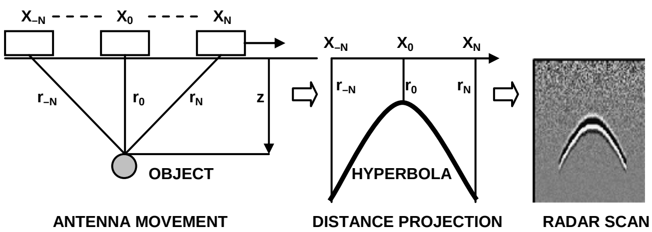

Figure 2. Radar scan generation

All points on the scan include reflected wave amplitude data. Points on top of the segments have peak amplitude value. The peak on the shortest segment r_0 (antenna center is above the pipe axis) is highest (positive or negative). This value is criteria for scan searching and determination of location and depth of underground utility.

Transmit antenna radiates a conical EM wave beam with a bandwidth β=35°÷45°. Based on these facts, it is not necessary for the center of the antenna to be above the underground object to detect it. Figure 2 shows an ideal one pipe radar scan in a homogenous soil layer. Antenna moved ortoghonally to the pipeline axis. In real conditions scan is with different noises and hyperbolical reflections, caused by other infrastructural objects. This can be eliminated by postprocessing.

3. GPR PARAMETER ACQUISITION METHODS

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. 2D scanning is useful for quick underground utilities location. The first step is the recalculation of ε_R based on a scan of an underground object with known depth. Orthogonal scanning is used to determine pipeline depth and direction. To determine pipeline direction, at least two scans are needed [4]. A regular hyperbola shows up on the scan when ortogonally crossing above the pipeline axis. In that case, rules explained in figure 2 are satisfied, and the reflected wave amplitude is maximal because of maximum radar cross section. When antenna crosses at a sharp angle above the pipeline axis, the hyperbola has a totally different shape which is no longer hyperbolic. In an extreme case, when the antenna trajectory is along the pipeline axis, the hyperbola is distorted into a straight line [4]. Detection of pipe materials (metal or non-metal pipe) is possible by measuring differences between reflected waves (reflection strength) [4]. Taking this into account, 2D scanning is useful in determining depth, directions in the horizontal and vertical planes, pipe inclination, pipe length, fluid/void ratio, changes of pipe diameter, pipe material, detection of pipe leakage, pipe radius estimation etc. Pipe radius estimation requires additional software processing because it depends on hyperbolic reflection geometry. In 3D scanning the software connects a number of 2D scans in a predefined sequence, hence creating a 3D model of the site. It overcomes the obvious limitations of the common form of GPR data display, which is a 2D vertical cross-section. Voids between the 2D scans are filled with software interpolation methods. The 3D display has the advantage of looking at the entire survey site at once. Technology of 3D scanning is useful for complex processing. This is especially important in areas with multiple intersecting, dipping or layered targets (pipes, rebar, etc.) that may be hard to identify on single radar profiles. Postprocessing software RADAN is used for filtering, normalization and transformation of raw signals. RADAN has special functions for applications that require linear feature and hyperbolic signature recognition [5].

4. MID-PRESSURE GAS LINE NETWORK MAPPING EXAMPLE

One of the realized projects was the mapping of a regional mid-pressure gas line network in the city of Novi Sad done for the Serbian National Gas Company. The project included the mapping of 44 km of gas line network and additional elements of infrastructure like shafts, air-signs, markers, stations for gas measuring and flow regulation, cathode protection, gas outlets etc. One part of the route lies in urban environment, but the bigger part goes through suburban environments near Novi Sad. All detected parameters measured by GPR and GPS were recorded as attributes in a geo-referenced AutoCAD document. All network gas line pipes were made from metal, with different diameters (from ϕ25.4mm (1" diameter) to ϕ508mm (20" diameter)) and on various depths (from 0.2m to 4.2m), depending on terrain configuration and gas flow direction. Shafts, markers, signs, gas outlets, cathode protections were placed on characteristic points along the route (cross-sections of gas lines, beside every station for gas measuring and flow regulation – for all network users, certain places for future users, special sections of gas line route). The acquisition process was finished in 30 days. The scans were recorded with a two GPR antennas. The GPR scans were verified with RD4000 [6]. It is transmitter - receiver system, in which electrical connection leads are plugged into the transmitter and attached directly to the pipeline, and the circuit is completed by connection of receiver to a ground stake (typically at 90º degrees to the pipeline). Parameters, which are measured from GPR scans are, exact gas line directions in all planes and gas line depth. Also, GPR scans are used for detection of isolated faucet (future users and gas line sections), exact location where the gas line crosses beneath certain streets and railroads, parallel gas line routes, crossings with other underground utilities, specific displacements of gas line route and finally software estimation of characteristic gas line diameter which will be discussed in detail in the next section. Spatial coordinates of all characteristic points on the surface were measured with this GPS equipment: high precision (~1cm) GPS equipment (rover Trimble 5800 using RTK (Real Time Kinematic)). The measured coordinates have to be corrected to achieve even higher precision. Corrections come from a network of permanent base stations with fixed positions, and can be acquired in real time or offline [6]. Real time corrections (RTK- Real Time Kinematic) can be received through GPRS or from a GSM modem. Offline PPK (Post Processing Kinematic) corrections can be downloaded from the website of the Center for geo-information technologies and systems [7]. A network of base stations covers the region Vojvodina since December 2004, and cover the all territory of Serbia since December 2005, enabling the measurement of GPS coordinates with a precision of 1cm [7]. Since there are no specified transformation parameters for the survey location, it was necessary to calculate them by measuring and processing certain geodethic points of state survey. Considering this, eight points inside and on the border of the survey location were measured. After that, seven datum transformation parameters were calculated. Figure 3 shows the survey area, gas line route and position of calibration points. All measured points and gas line routes are on a geo-referenced orthophoto map in scale 1:1000, with corresponding gas line parameters recorded with GPR. The AutoCAD document serves as a geo-referenced graphical database, holding information about the gas lines. In order to provide quick data review, all characteristic elements of traffic infrastructure are vectorized. Complete additional gas line infrastructure elements are cathegorised in separate layers (shafts, air-signs, markers, stations for gas measuring and flow regulation, cathode protection, gas outlets etc). Shafts and stations for gas measuring and flow regulation are measured and represented in corresponding scale. For most of measured points relative distances from fixed object (like houses, roads, lamp posts, fences, pavements, etc) are also given. Specific parts of gas line route (specified above) are clearly marked on geo-referenced map. All data was exported to Microsoft Excel datasheets and MS Access database.

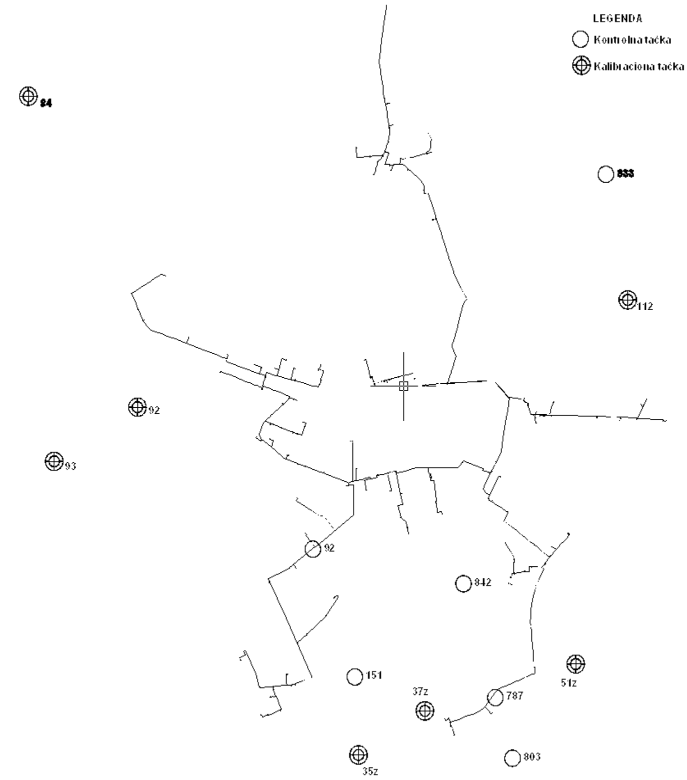

Figure 3. Georeferenced graphical view of gas line route

5. CONCLUSION

The aim of this paper is to show the parameters and methods of data acquisition, which were developed for the mapping of mid-pressure gas line network in the city of Novi Sad. The project included the mapping of 44 km of gas line network and additional elements of infrastructure. Underground pipe parameters were recorded with a two type of GPR antennas. Spatial coordinates of all characteristic points on the ground surface were measured together with high precision GPS equipment and additional information from a network of permanent base stations. All detected parameters measured by GPR and GPS were recorded as attributes in a geo-referenced AutoCAD project.

6. REFERENCES

[1] Geodethical Institute of Serbia: Pipeline Cadastre Regulations, Belgrade, 1999. (in Serbian)
[2] Petrovački D., Ristić A.: Principles of using Ground Penetrating Radar and GPS technology for detection of underground utilities, ETRAN conference, Budva, S&M, 2005. (in Serbian)
[3] Daniels D.: Surface penetrating radar, The Institution of Electrical Engineers, London, GBR, 2004.
[4] Ristić A., Petrovački D.: Examples of using Ground Penetrating Radar and GPS technology for detection of underground utilities, ETRAN conference, Budva, S&M, 2005. (in Serbian)
[5] GSSI: Radan 6 User Manual, North Salem, USA, 2004.
[6] http://www.radiodetection.com/
[7] http://gpsweb.ns.ac.yu/