THE GEORADAR METHOD: AN ASSESSMENT OF EFFICIENCY OF SUBSURFACE CONDUITS POSITION DETERMINATION ON SELECTED TEST FIELDS*

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SUMMARY

The paper presents results of georadar positioning of a set of subsurface conduits, together with an assessment of efficiency of their detection. The measurements on test fields were performed with the RAMAC/GPR georadar, produced in Sweden by the Mala GeoScience Company. Numerous radargrams were properly processed with an optimal filtering sequence, aimed at production of a readable image of the detected conduits. The results were assessed also from the efficiency point of view of the subsurface structure detection method. The phenomenon of signal polarization, which helps to distinguish metallic and plastic conduits, is also discussed. Elements of surveying and computational procedures, leading to completion of content of digital thematic maps by the georadar sensing integrated with GPS positioning, are also given.

1. INTRODUCTION

The important feature of the georadar method is the simultaneous determination of horizontal position and depth of subsurface objects and structures, including subsurface conduits. This simultaneity of coordinate determination allows some basic assessment of the georadar method, including:

- **an assessment of efficiency of the detection method,**
- **an assessment of horizontal position accuracy of the detected objects,**
- **an assessment of depth accuracy of the detected objects.**

The paper presents results of georadar sensing of a bundle of subsurface conduits, together with an assessment of efficiency of their detection. The conduits, placed on different depths and with different spacing, formed a test field, prepared especially for investigation purposes. An assessment of georadar sensings performed at other, chosen test fields, is also included. It should be noted, that in general the accuracy of horizontal position determination of the detected objects, and that of their depth, are different. The accuracy of depth is shaped by influence of external factors, like geoelectric parameters of the penetrated strata, frequencies of the antennas, and parameters set in the instrument at the beginning of the field work.

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2. CHARACTERISTICS OF THE TEST FIELD AND SCOPE OF THE SENSINGS

The experimental surveys were, in majority, performed on a test field, which contained nine steel or PVC pipes of known position and various diameters (Fig. 1). Horizontal distances between neighboring, almost parallel pipes were about 1 m, with the exception of pipe R5, which was placed in a skew position. Depths of the upper surfaces of pipes were between 0.21 m and 1.25 m (Table 1). Some pipes were sloping, what made their depths vary in cross-sections. Georadar sensing was performed along three parallel cross-sections with 0.5 m spacing, generally perpendicular to the pipes. The Fig. 1 shows the positions of the pipes, while Table 1 contains their depths in particularprofiles.

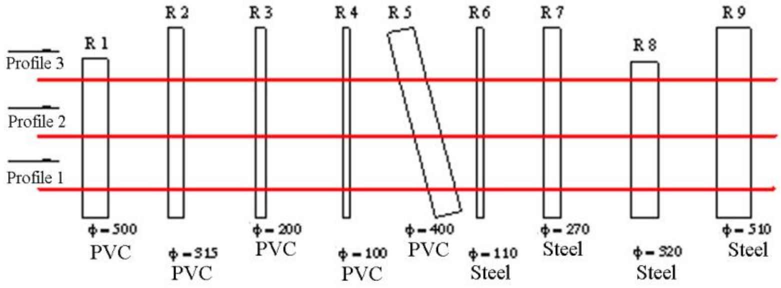


Fig. 1. Sketch of the test field and measured profiles.

Table.1. List of depths of pipes buried in the test field.

d_z [m]									
	R 1	R 2	R 3	R 4	R 5	R 6	R 7	R 8	R 9
Profile 1	0,21	0,49	0,52	0,54	0,44	0,60	0,55	0,55	0,23
Profile 2	0,22	0,46	0,53	0,77	0,66	0,84	0,53	0,46	0,27
Profile 3	0,14	0,42	0,53	0,94	0,75	1,00	0,52	0,47	0,25

The 500 MHz antenna was used in the test, as it is the most popular antenna for engineering surveys reaching down to not more than 4m depth, where voids, ducts or other solid objects are searched for. The time window parameter was set to 48 ns, what theoretically, even in case of very low velocity of the wave in the ground (0.05 m/ns), allowed penetration of the medium down to the depth of 1.25 m, within which all the test field pipes were buried. The tracks were recorded at 3 cm intervals.

3. BASIC STEPS OF RADARGRAM PROCESSING

The basic steps of processing of radargrams collected with the georadar sensor are:

- **selection of proper colour scale for the radargram,**
- **setting of the horizontal and vertical scales of the radargram,**
- **filtering of the radargram picture.**

Proper selection of colours and their scale, containing usually more than ten shades of different intensity, allows proper visualization of elements portrayed at the radargram. In case of conduits, they are best recognizable when the panchromatic palette is used.
The horizontal scale of the radargram is given usually in metres and represents length of the profile, along which the antenna moved. The vertical scale allows determination of depth of the object searched for and is given in units of length or time.

The filtering procedure is aimed at elimination of measurement noise and collection of the proper content from the image. All interpretation and measurements on radargrams were performed with the program ReflexW (Sandmeier 2001).
The following step in preparation of the radargram for further processing consisted in a certain set of filtering procedures, which were to suppress the noise appearing in the image. The noise obscures the detected objects and structures, and sometimes makes them even invisible in a raw radargram. Multiple filtration procedures were applied and finally these were chosen, which produced best results for further interpretation. The following sequence of filters was finally applied:
from the 1D domain:

- filter eliminating low frequency components of the image (subtract-mean),
- filter eliminating the direct current factor (subtract-DC- shift),

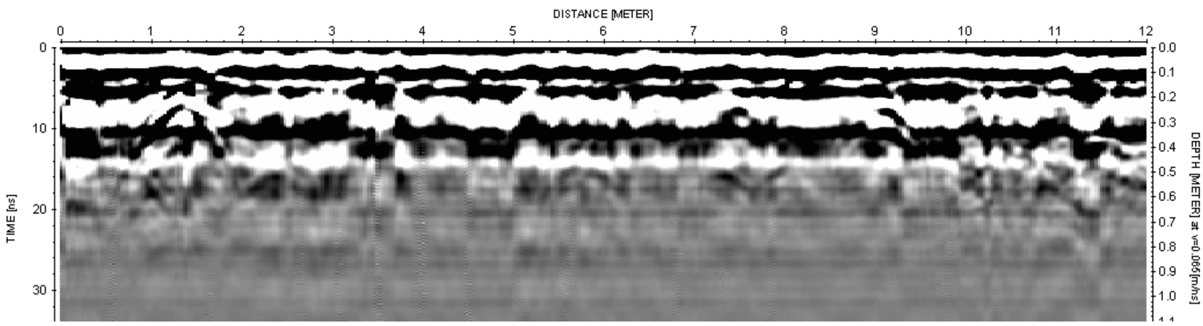
from the 2D domain:

- background (mean trace) removal filter

enhancement filter:

- gain function.

No further filtering procedure improved readability of the image significantly. The listed above procedures are suggested for application when images collected during search for subsurface conduits or other solid objects are to be interpreted. The results of application of particular filters are shown on Fig. 2.
The filter eliminating low frequency components has decisively improved the readability of the radargram. The next filter had no visible influence, as it used to normalize the signal thanks to the reduction of the direct current (DC) factor. But on the radargram one can still see effects of presence of a constant factor disturbing the data in the horizontal direction, what results in the form of parallel lines visible along the entire length of the radar image. This effect was eliminated by the filter which removed the so called mean trace. As a result of the whole procedure a highly readable radar image was obtained, and in the final touch it was treated with a gain function which amplified the signal in time.



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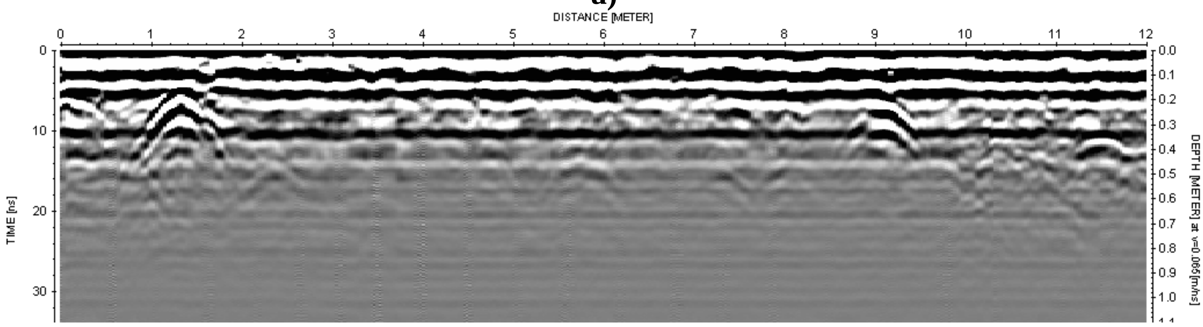

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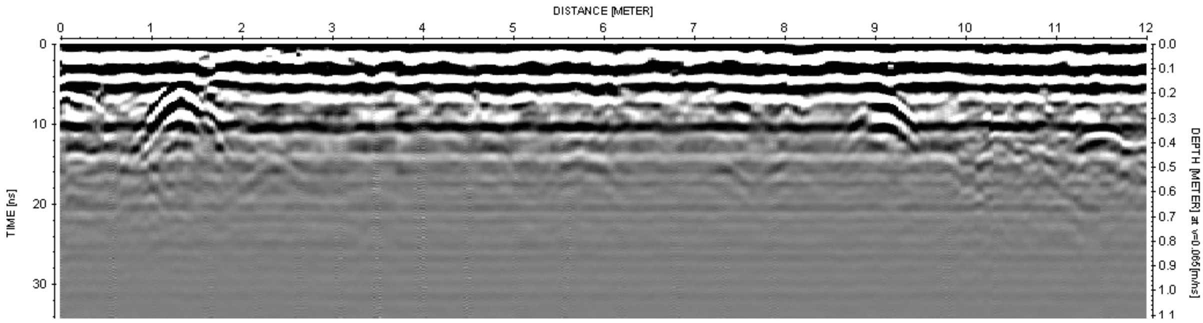

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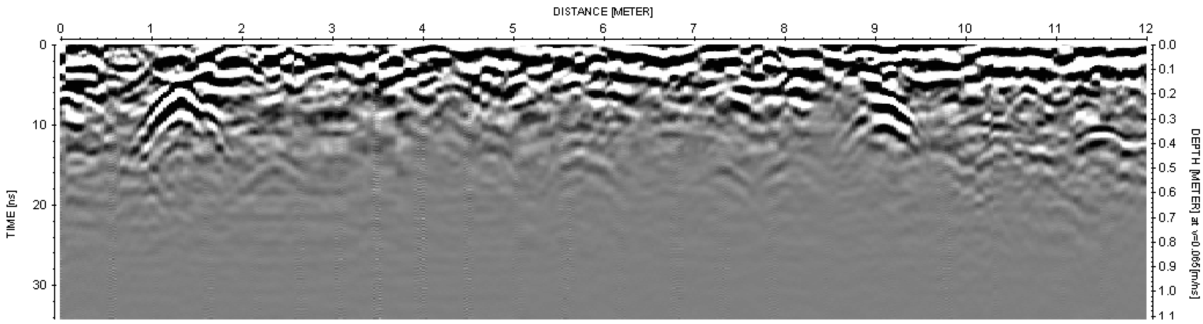

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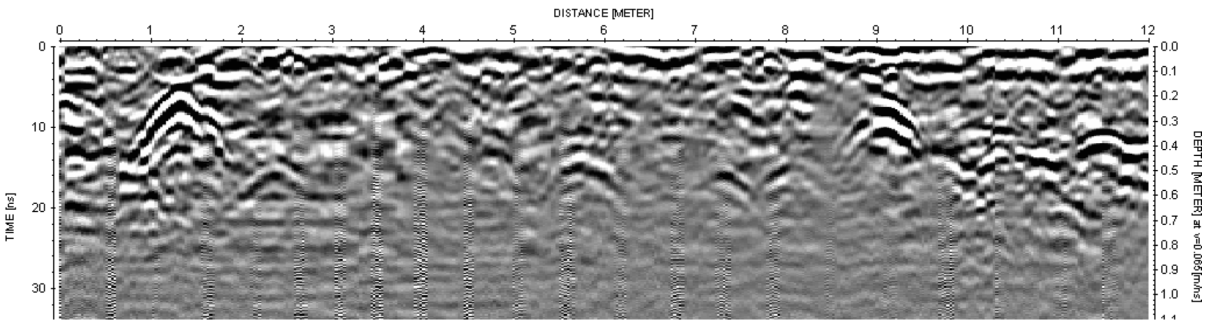
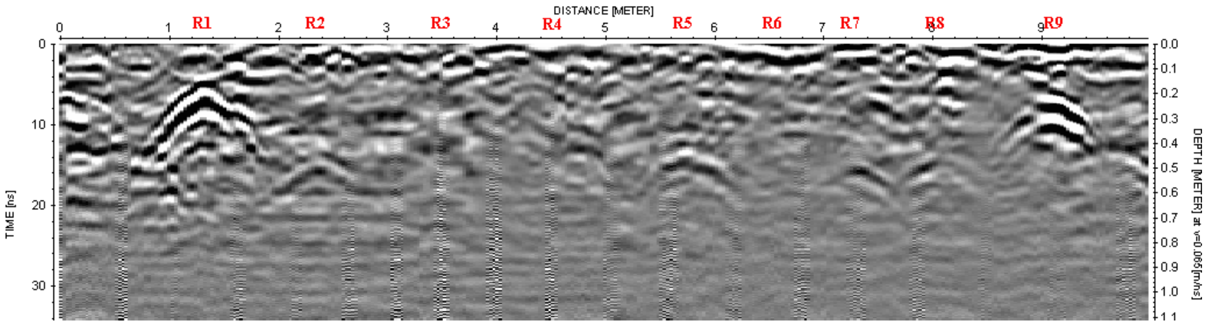


e)

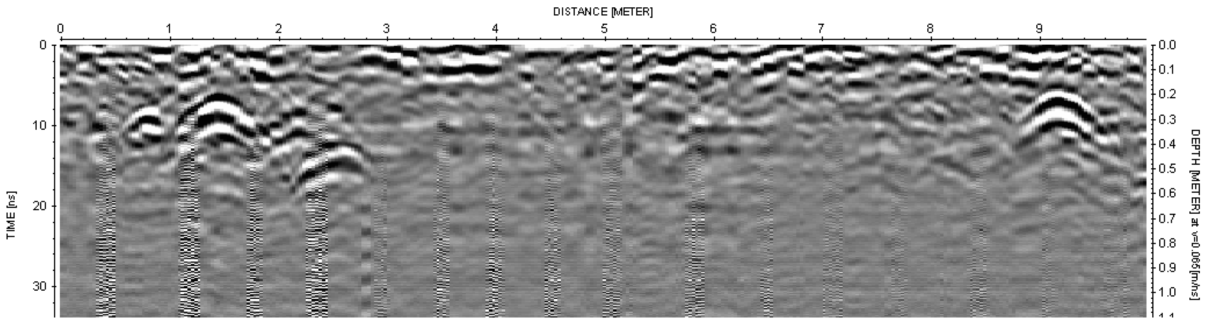
Fig. 2. The radargrams of the profile 1 after consecutive steps of filtration
a) raw radar image with 0 set on the time axis, b) filtration eliminating the low frequency components of the image, c) filtration eliminating the constant DC factor, d) background removal, e) signal amplification in time.

4. INTERPRETATION OF FILTERED RADARGRAMS AND EFFICIENCY ASSESSMENT OF THE METHOD

The filtration procedures described in the paragraph 3 produced final radargrams for all profiles. The radargrams are shown on Fig. 3. On the horizontal axis of the profile 1 there are marked known positions of particular pipes.



a)



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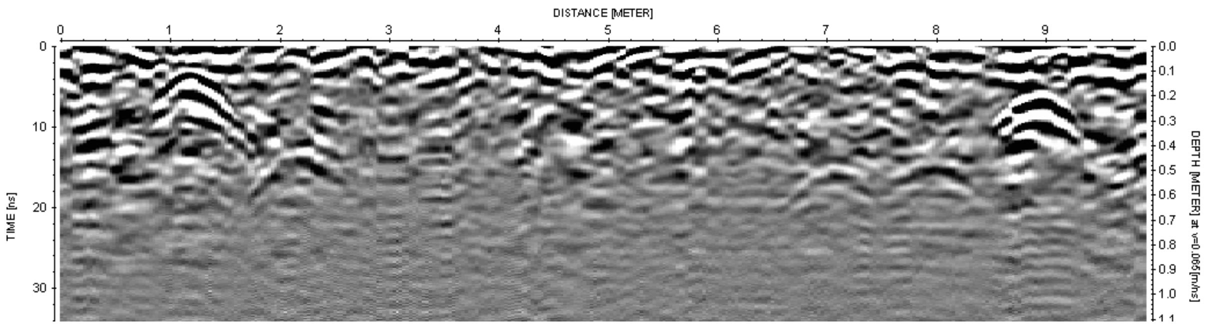

c)

Fig. 3. The radargrams after filtration: a) profile 1, b) profile 2, c) profile 3.

The georadar sensings performed in the test field (Fig. 1) and the obtained results as shown on the preprocessed radargrams (Fig. 3) reveal, that only some of the pipes could be detected. They are as follows (Ortyl 2007):

1) **PVC pipe of ϕ = 500 mm, located at the depth of ~ 0.25 m,**
2) **PVC pipe of ϕ = 315 mm, located at the depth of ~ 0,50 m,**
3) **PVC pipe of ϕ = 400 mm, located at the depth of ~ 0,45 m,**
4) **steel pipe of ϕ = 270 mm, located at the depth of ~ 0,50 m,**
5) **steel pipe of ϕ = 320 mm, located at the depth of ~ 0,45 m,**
6) **steel pipe of ϕ = 510 mm, located at the depth of ~ 0,25 m.**

The georadar sensor applied was unable to detect:

1) **PVC pipe of ϕ = 200mm, located at the depth of ~ 0,50 m,**
2) **PVC pipe of ϕ = 100mm, located at the depth of ~ 0,50 m,**
3) **steel pipe of ϕ = 110mm, located at the depth of ~ 0,45 m.**

The PVC pipe 5R of 400 mm diameter (Fig. 1), buried in strongly inclined position, became undetectable despite its significant diameter, when its depth reached 0.66 m or more.

Conduits of similar diameters, though made of different material, show equal detectability when buried at the same depth, what shows, that the type of material has no significant influence on intensity of their representation in the radar image. But the PVC and steel pipes show different polarization of the reflected signal as recorded in the radargrams.

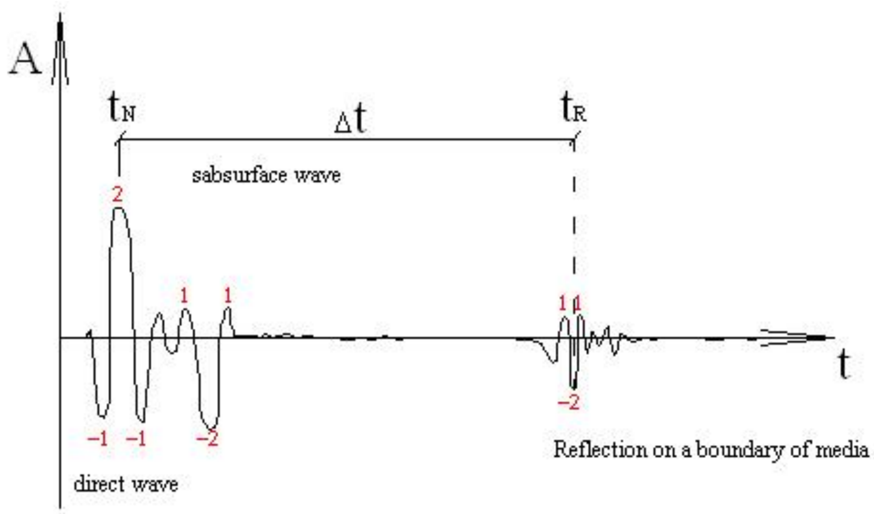

Fig. 4. Distribution of amplitude of the received radar signal.

The sign of wave amplitude is related to the signal polarity phenomenon (Fig. 4). The polarity is governed by change in impedance of the penetrated medium. Metallic objects have very low value of impedance, while air-filled voids - very high. When the detected object has higher impedance than the surrounding medium, the reflection coefficient becomes positive, and it is negative in the opposite case. There is no strict definition, which combination produces what sign of the reflection coefficient, as its choice depends on the particular convention adopted by the manufacturer. The Mala Geoscience company does not inform, what combination is used in the RAMAC/GPR device.
The representation of the steel pipes in the georadar image collected with the 500MHz antenna has the polarity of the type 1, -2, 1, i.e. reciprocal to the polarity of images of PVC conduits. Polarity of images of two pipes of similar diameters, but made of different material, is shown on the Fig. 5a, b. The comparison shown on Fig. 5 presents images of four pipes: R1 and R2 as well as R8 and R9, together with amplitude distribution of traces identified as pertaining to the butt of particular pipe.
An analysis of these results produces additional information on material: steel or PVC like plastic, of which the detected object is made, although the polarity phenomenon is not always well visible or univocal. A reliable detection of material demands additional sensings using antennas of another frequencies, and/or sensings in another places, in order to verify the original detection.

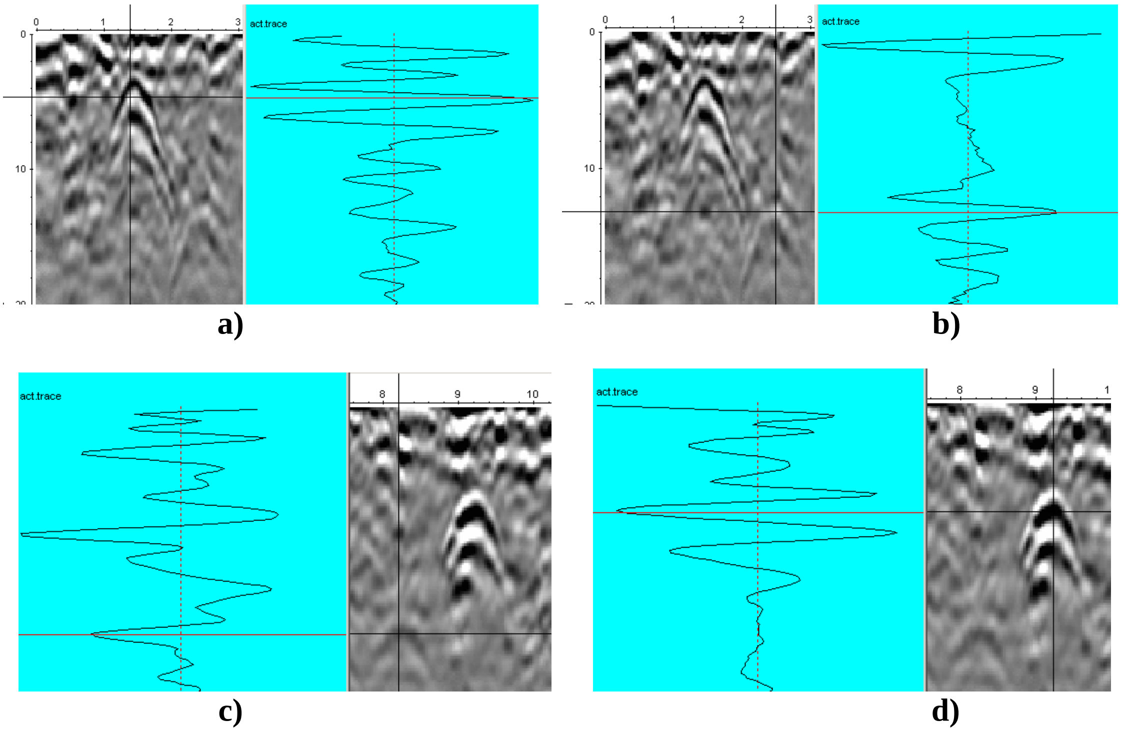

Fig. 5. Differences in polarity of pipe images: a) PVC 500 mm, b) PVC 315 mm, c) steel 320 mm, d) steel 510 mm.

Additional sensings, aimed at the assessment of efficiency of the georadar as a detector of subsurface objects, were performed on three another, arbitrarily chosen locations within the city. The locations contained sewage ducts, power and telecommunications cables together with gas and water mains, all of known positions. The obtained results show, that the real conditions reduce applicability of the georadar as subsurface utility detector and locator. It does not mean, that the georadar method should not be used for this purpose, but one should be conscious of its limitations. Besides of these shortcomings due to the ground conditions, it is the only non-intrusive method, which allows detection of nonmetallic conduits. An additional important trump card of the georadar method is the fact, that it brings comprehensive, general information on the subsurface space within the surveyed area, necessary for compilation of thematic maps. Taking into account the fact, that the content of the facultative part of the thematic map, like of the "basic map" or the "map for planning purposes", depends on the needs of the ordering customer, the georadar sensing significantly broadens possibilities of recognition of subsurface situation within the area to be mapped. In the age of digital cartography it is important to represent the georadar information in a way most suitable for automatic systems of map editing and production. Within the project no. 4 T12E 048 27, financed by the State Committee for Scientific Research, the georadar technique was integrated with GPS and classical surveying methods using robotized total stations. Possibilities of the integrated GPR-GPS system are shaped by methodological and technical conditions. Emerging problems were solved by: proper construction of the GPR-GPS set, preparation of specialized software for simultaneous collection and simultaneous processing of georadar and geodetic data, taking into account external and instrumental factors during computations like antenna movement velocity, frequency of geodetic position determination, corrections for terrain topography and alike. Control of the GPR antenna position with GPS or robotized total station, allows accurate determination of coordinates of subsurface objects detected

with the georadar, what enables elaboration and completion of content of thematic maps.

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