Evaluation of Combined Ground Penetrating and Through-the-Wall Surveillance UWB Technology

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***Abstract* — This paper investigates the possible identification of underground targets using UWB pulsed GPR operating in the frequency range of around 300 MHz. For this test, the site was chosen where various pre-known objects were buried previously. Depth, location, shape, and material of testing targets were known before the experiment. In addition, the same device with different software for signal processing has been tested as a TWS for detecting human movement behind a thick wall.**

Keywords — UWB; GPR; 3D image.

I. Introduction

UWB signal processing technology has developed considerably during recent years [1]. One of the most important applications of UWB radar is Ground Penetrating Radar (GPR) [2]. This is well evident on extending the functionality of GPR and Through-the-Wall Surveillance (TWS) systems [3], [8]. However, any GPR has difficulty with the unambiguous identification of targets located in the ground. Similar problem concerns TWS. Information given to GPR operator is very specific and ambiguous in nature [4], and often it can be verified only by doing direct excavations of significant volume of the ground.

This paper investigates the possible identification of underground targets using UWB pulsed GPR operating in the frequency range of around 300 MHz. For this test, the site was chosen where various pre-known objects were buried previously. Depth, location, shape, and material of testing targets were known before the experiment.

In addition, the same device with different software for signal processing has been tested as a TWS for detecting human movement behind a thick wall.

This article will show the photographs, target parameters, and radargrams obtained during the study. Signal processing algorithms will be discussed that are used to improve the image of GPR profile and increase its information content. The restoration of 3D images of the object, which is located under the ground, will also be affected.

II. Principles and Performance Characteristics of the Device

A. *Technical brief:*

- Antenna frequency: 300 MHz
- Analogue-to-Digital Converter range: 18 bit
- Dynamic range: at least 135 dB
- Measuring rate: up to 55 traces per second
- Survey window: 66, 100, 133, 166 ns
- Maximum number of samples per trace: 1000
- Trace stacking number: up to 128
- Depth of sounding: up to 8 m (determined by soil properties)
- Spatial resolution: better than 0.3 m
- Operating modes: point collection, continuous, measuring wheel
- File size of a single profile: up to 2 GB
- Interface: USB2
- Dimensions (L x W x H): 610 У 312 У 170 mm
- Weight: 8.4 kg

B. *Some features of this device are:*

- Monoblock design - all GPR modules are arranged all together into a single case, which is connected to computer via USB2 communication cable.
- Spectrum randomizing (quasi-random sampling sequence) - interference immunity improvement especially to coherent influences
- Increased dynamic range owing to digitally stacking of received signals
- Real time signal pre-processing

III. Description of the Proving Ground

As an experimental test site to investigate the possibilities of modern GPR, the area reserved for the construction of private houses was chosen. There were various underground objects and communications at that site, such as a cellar, an underground concrete pit for waste water, sewage pipes, plastic gas pipes, electric cables, and various metal objects buried.

Position and shape of all the objects were well known a priory; there were appropriate photographs taken in advance during construction. The aim of the study is to assess the capacity to identify objects with the help of modern technology GPR.

IV. Solving Inverse Problem

It is well known that the problem of object image reconstruction belongs to the class of inverse applications, more exactly it is so called ill-posed inverse problem. The essence of the inverse problem is in the fact that there is a function *f* that was measured with some errors (in our case, the reflected signal), as well as the instrument function *A* (in our

$$Ay = f \quad (1)$$

case, antenna and receiver characteristics), and we can determine the source function *y* (object shape) by solving the equation:

which may be integral equations, differential equations, system of linear equations, linear systems of nonlinear equations, etc. [5].

This can be displayed in two schemes, shown in Fig. 1 and Fig. 2.

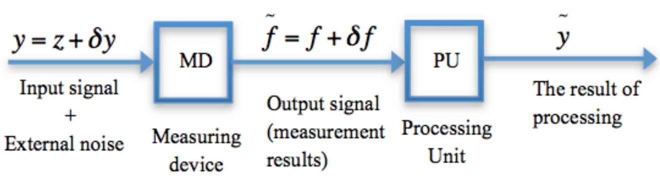

Fig. 1. Technical scheme

According to the technical scheme (Fig. 1) the input of the measuring device (MD) receives an input process, namely, the input signal *z* + noise (interference) δy from the environment. After passing through the measuring device, characterized by an instrumental function (IF), for example, the characteristic of the antenna, the signal + noise is converted into an output signal (measured value), for example, the scanning function:

$$\tilde{f} = f + \delta f \quad (2)$$

where $\delta\phi$ is an instrument error of measurements [5]. The purpose of the processing unit (PU) is to get the result of processing $\tilde{y}$ as close as possible to the process $y = z + \delta y$, or even to the signal *z*.

It is necessary to note that the interference δf is a hindering factor which should be filtered, and δy according to some criteria may be also related to interference, but it can refer to one of the components of the input signal (this is typical for adaptive signal processing techniques).

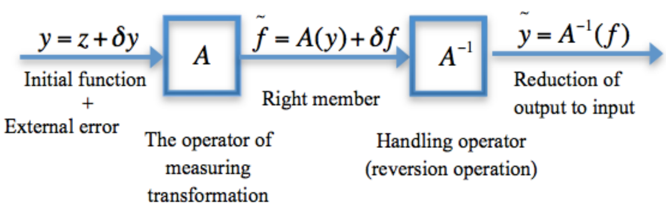

Fig. 2. The mathematical scheme

The mathematical algorithm illustrating a mechanism for solving inverse problem is presented in Fig. 2. It logically corresponds to the technical scheme shown in Fig.1. In the mathematical scheme the operator of measuring

$$\tilde{f} = A(y) + \delta f \quad (3)$$

transformation *A* (similar to instrumental function) will transform an input signal + exterior noise $y = z + \delta y$ to a so-called right member (an output signal):
where $\delta\phi$ is a right member error. Further by means of inverse operator A^{-1} the approached solution $\tilde{y} = A^{-1}(f)$ is calculated. The purpose of mathematical methods and algorithms is to construct such inverse operator A^{-1} that gives good approach to the process $y = z + \delta y$ or even to a signal *z*, and was thus steady in relation to errors $\delta\phi$.

From the engineering point of view *A* is an instrumental function (IF) of the measuring gear, for example, an antenna directional characteristic. From the mathematical point of view *A* is some operator (integral, differential, algebraic, nonlinear, etc). The solution of the equation (1) allows completing a reduction of outcomes of measurements to the ideal measuring instrument, for example, to the antenna with infinitely narrow antenna pattern. And using the mathematical solution of a problem of a reduction, for measurements in practice it is possible to use even an incomplete, inexpensive measuring instrument.

Application of UWB-radars for detection and recognition of underground installations has definite specificity. The wide spectrum of UWB-radars provides its potentially high space resolution and accuracy of ranging. The high spatial resolution provides also a possibility of good target selection on the background noise [6].

UWB-radar can detect the type and shape of a target, as adopted by the echo gives information not only about the subject in general, but also of its elements. The length of a picosecond pulse in space $c\tau$ (where *c* is speed of light, τ is pulse duration) could be much smaller than the target, and in this case the target is no longer a point reflector like for traditional radar but an array of reflecting elements (micro targets).

Probe signal of UWB-radar alternately reflected from the individual elements forming the pulse sequence, the parameters of which depend on the geometry of the object and from it impulse responses. This sequence, called a target frame, is the distribution of the reflected power over time.

As a result, the RCS (radar cross-section) is also time-dependent, and the character of this dependence (the form of a target frame) depends on changing the angle of target observation. The amplitude of the pulses that make a target frame depends on the relevant RCS of reflecting elements, and their polarity depends on the magnetic permeability of the element material [6].

V. Features of Signal Processing

Software filters (tools) that we used perform linear operations; that is why the order of application does not matter. The following tools were used.

1. Gain. As the signal is weakened as a consequence of scattering (the effect of the radiation pattern) and attenuation in the ground (for some types of ground the attenuation is -20 dB/m). We use different gain for different depths to compensate this weakening.
2. Wavelet filter (Waveleter) is used to improve SNR as a kind of matched filter. For UWB case, application of narrow-band filters or any other processing in the frequency domain is not effective. In this case we perform the convolution of the received signal with the wavelet function "Mexican hat" (MHat).
3. Windowed Background Removal is used as a subtraction of the average. This is an effective tool in the case when a sonogram (profile) is periodic, and the iterative noise can be reduced. Calculation of the average is done in the specified window, and then it is subtracted. The window is shifted and the averaging process is repeated for the next input trace. This is similar to the traditional radar MTI.

Besides, signal accumulation in antenna also performs a kind matched filtering that reduces the effects of white noise and any other non-synchronous interference. This accumulation increases the equivalent dynamic range. The dynamic range increases proportionally to the square root of the accumulation time.

VI. Results of GPR Function Implementation

Let us consider an example of investigating the underground object using GPR VIY [7]. The results are illustrated in Fig. 3 – 7 where radar images are shown (Fig.3 and Fig. 4) as well as the objects and the device (Fig. 5 and Fig.6).

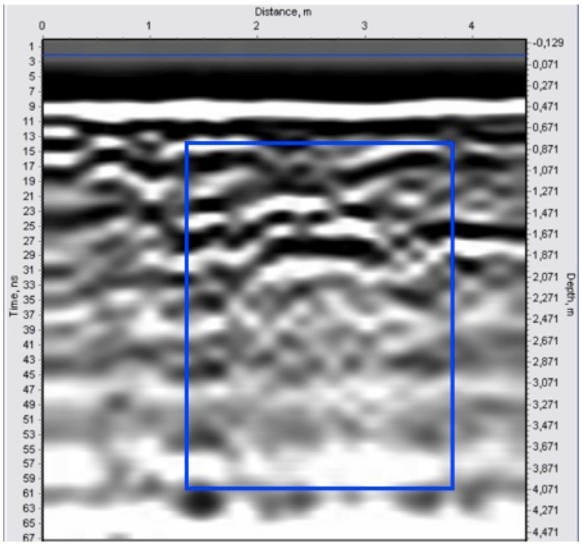

Fig. 3. Vertical scan profile. Rectangle allocated intended location well.

The object under study is a round concrete pit, which is filled with water. The diameter of the pit is 2 m. The pit has a concrete bottom and a lid with steel reinforcement. Height is of about 2.5 m underground, the depth of the top cover is of about 50 cm from the surface. The ground is of sand deposits type.

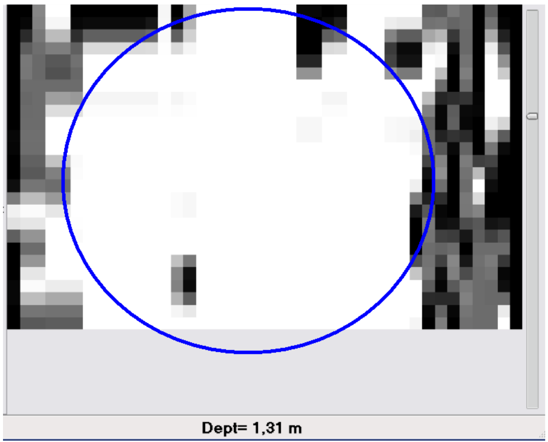

Fig. 4. View from above. Horizontal section of ground, built with 10 parallel profiles. Depth of 1.3 m, corresponding to the depth of standing water surface in the well

Fig. 5. GPR and study areas

Recovering 3D image was done using the Slicer software and Matlab.

Fig. 6. Researched well during construction

In Fig. 7 from the top down one can distinguish a ground, a concrete cover, a space between the cover and the water surface, and then water and concrete floor respectively.

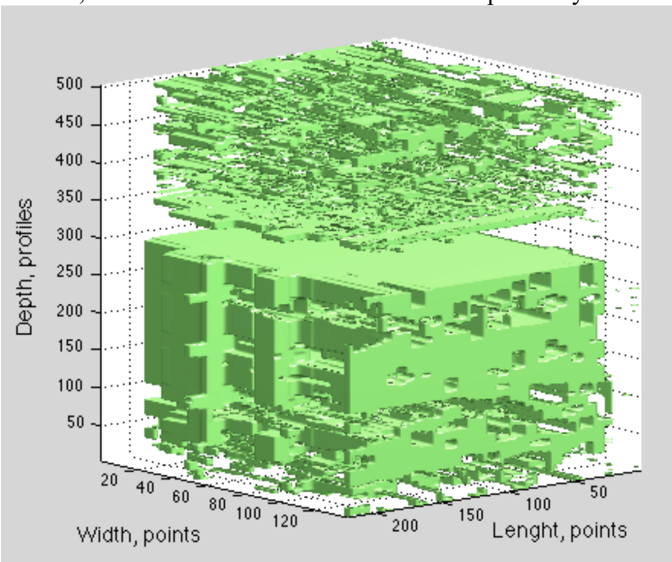

Fig. 7. 3D recovered well image.

A drainage collector (Fig 8) was used as the second object under study. Actually the collector is a pit, filled with cinder blocks and topped with geotextile and metal sheets, where wastewater are discharged. In fact, the internal construction of the reservoir in this case is not important. It should look like at sounding diagrams as large metal object. The dimensions are 2x3m size hole, the depth of the top metal layer is 1.7 m.

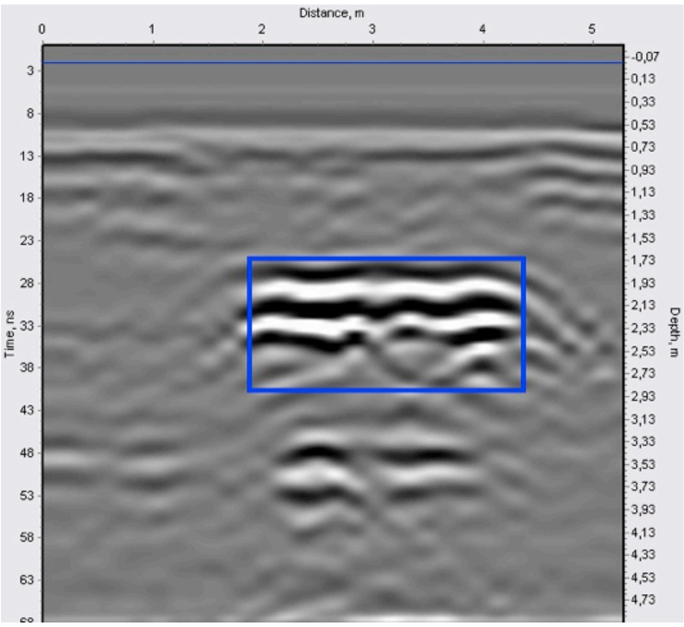

Fig. 8. Vertical scan profile of the collector. Rectangle allocated intended location.

Thus, we can observe some elements of undeground structure and detect targets there.

VII. EXAMPLE OF TWS FUNCTION IMPLEMENTATION

The test of the system as TWS was done in the building using the plastered brick wall of about one meter thickness. A man was sitting on the chair, making different kinds of movements, namely:

- test 1: waving his hand from side to side;
- test 2: bending his body from side to side;
- test 3: just breathing, keeping the body in the stable position.

The results of the experiment are presented in [9]. Signal processing detected changes of reflections due to the motion of the object under observation. Very strong changes were observed for test 1 and test 2. Comparatively weak but still detectable changes were observed in case of test 3.

VIII. CONCLUSIONS

Modern methods of signal processing in conjunction with the development of UWB technology can detect the presence of underground objects and inhomogeneities, but there is ambiguity in their identification. Efforts should be applied to develop methods and algorithms of object identification that is a very difficult task. Sometimes a two-dimensional view of data in the diagram is not enough for decision making. One method of improving the quality of image representation is transition from 2D to 3D view of information in the graphs as has been shown in the paper.

Similar UWB technology can be adopted for both GPR and TWS applications.

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