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Comparative study of signal processing of two UWB GPR antenna units

The results of laboratory experiments on the use of two antenna units of pulsed GPR for nondestructive testing are presented. The antenna units have similar antenna configuration, but different values of the central frequencies of the probing UWB pulses. The purpose of the experiments is to find the best sensing parameters and optimize the technique for processing signals reflected from plane-layered media. The analysis of the obtained results showed the possibility of improving the quality of nondestructive testing and remote sensing of road pavements and other building structures by means of UWB pulsed GPR by solving the thickness measurement problem of plane-layered media.

Introduction

The goal of the paper is to increase the reliability and accuracy of estimates of physical and geometric characteristics of heterogeneous plane-layered media. To achieve this purpose, a series of laboratory experiments were carried out with two GPR whose antenna units have different values of the central frequency. Significance of this problems is governed by the necessity of the correct formulation and solution of layer's thickness measurement problems. This is necessary, for example, to assess the current condition of the road pavement structure and to diagnose various defects (such as subsurface cracks) in it [1, 2].

Within solving the actual problem of monitoring the current condition of road pavement while the vehicle is moving with the transport stream speed, a slight change in the orientation of the radiation direction can occur both due to the vehicle body oscillations on the ridges of the pavement and because of the presence of road pavement defects such as potholes or rutting. With that the errors caused by the violation of the orthogonality of the sensing direction orientation with respect to the layer boundaries of the structure will accumulate with increasing depth of sensing.

The possible solutions for the correction of the procedure for obtaining primary data should be taken taking into account the features of specific antenna systems. One of the possible solutions of the problem in this case is the procedure of preliminary calibration of the GPR. For the correct implementation of such procedure, in practice, it is necessary to carry out primary laboratory experiments in order to study in detail the effect of the direction of probing pulse radiation on the results of data processing.

Such experiments and detailed analysis of their results are the subject of research and discussion presented in the paper. The experiments were carried out in the Kharkiv National Automobile and Highway University at the Department of Highway Design, Geodesy and Land Management and V. N. Karazin Kharkiv National University at the Department of Theoretical Radiophysics. The results were processed with the aid of the developed software GeoVizy according to algorithms previously proposed by the authors [3, 4].

The advantages of this approach arise from the possibility of step-by-step determination of permittivity values and layer thicknesses, starting from the outer boundary of the plane-layer medium under study in the direction of deeper boundaries. Finally, we note that in practical applications related to the assessment of the current condition of road pavements [5, 6], there is also the problem of detecting and evaluating the parameters of such critical defects as subsurface cracks in the road pavements. This problem can be solved both on the basis of the analysis of indirect information [7], and using GPR technologies [8, 9]. However, this approach still requires the solution of the supportive in this case problem of determining the thickness of layers, which can be solved both on the basis of processing the pulse signals delay [10] and by processing the spectrum of reflected signals [11].

Problem statement and solution

In the course of experimental studies, measurements of the reflection of UWB pulse signals from various structures were carried out. The measurement sequence was standard: the feedthrough signal was measured firstly Fig.1. Then the signal reflected from the metal sheet was measured (the position of the antenna unit was standard, i.e. the direction of the sensing was orthogonal to the plane of the metal). After the registration of these signals, sensing of the plane-layered media was carried out (Fig. 2).

The first angle Alp (Fig. 2.b) is the angle of inclination of the antenna unit along the longitudinal axis. It is counted in such way that at positive values of this angle close to $3°$ and the distance to the surface of the sensed medium is 30 cm. the probing beam reflected from the surface of the medium hit the center of the receiving antenna system. The second angle Bet is the angle of inclination of the antenna system in the transverse direction. Due to the antennas symmetry, the direction of reference of this angle does not matter. For comparison, Fig. 3 shows three signals reflected from the surface of asphalt concrete (pavement section), at different values of the angle Alp (the measurements were carried out using GPR "TRF-1"). We also note that some shift of the maximum of the signal *S0* is caused by a small variation of the signal path. In this case, the so-called electric path length increases due to the structural features of the antenna unit of the GPR TRF-1 and the measurement procedure. Fig. 4 shows the dependence of GPR signals "TRF-1" on the angle Alp when the sign of the angle Alp changes. For convenience of perception and the next processing, now the signal graphs are shifted along the time axis so that the main maxima of all signals coincide.

Experiments with GPR "TRF-1" for sensing at different values of the Bet angle ($0 \div 5°$) showed a weak dependence of the amplitude and shape of the signals on the Bet angle (visually, all signals had almost the same shape and amplitude).
The next step is the study of the influence of orientation angles of the GPR antenna units on the final result, on the values of the thickness and permittivity of the plane-layered medium layers. The solution of this problem has the greatest practical significance. To obtain solution, we used the previously proposed computational

algorithm [10] and the developed software "GeoVizy" [3]. The essence of the processing method previously was described in detail.

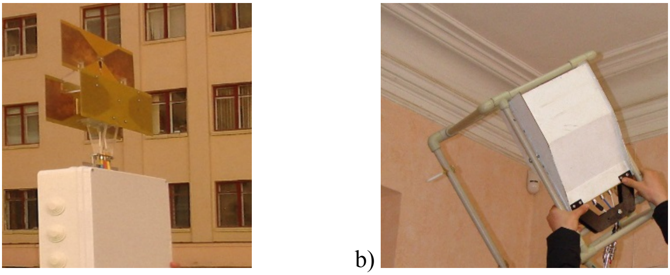
a)  b)

Fig. 1. The feedthrough signal registration. a) unit TRF-1; b) unit AB GPR Odyag-1

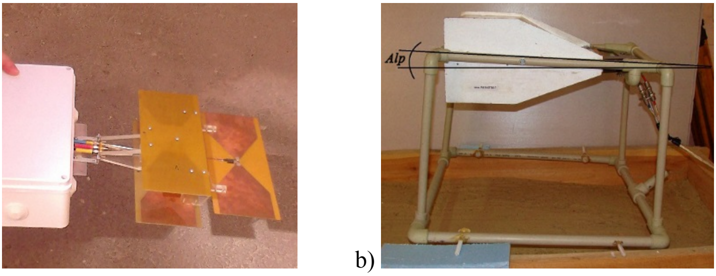
a)  b)

Fig. 2. Sensing process. a) unit TRF-1; b) unit AB GPR Odyag-1

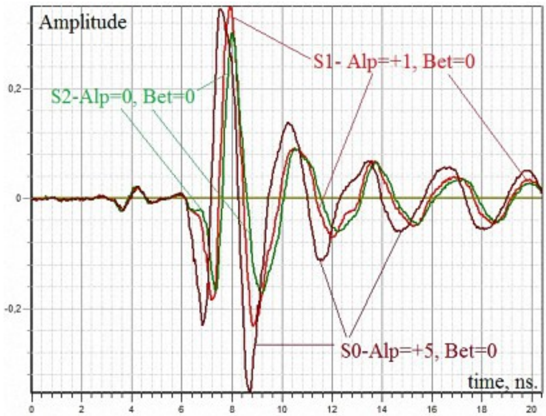


Fig. 3. Change of GPR signals "TRF-1" depending on the angle *Alp*

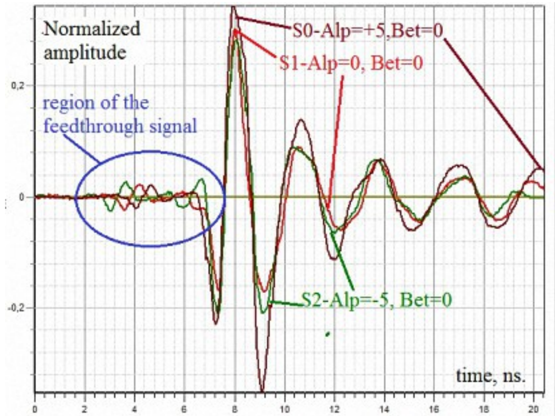


Fig. 4. Change of shifted signals GPR "TRF-1" depending on the angle *Alp*

As a result of the experimental data processing, the values of the thickness of the top layer (in cm) and values of the permittivity of two top layers (ε_1 and ε_2), presented in the table 1 for three values of angle *Alp* , were obtained. Angle *Bet* equals zero. The true value of the top layer thickness, obtained as a result of direct measurements was 10 cm.

Table 1.

Results of Experimental Data Processing.

Alp	h_1	ε_1	ε_2	Δh %
5	9,8	4.3	2.5	2%
0	10.7	4.2	3.3	7%
- 5	10.8	4.0	3.0	8%

Conclusions

The performed laboratory experiments have confirmed the effect of even relatively small changes in the orientation angle of the sensing axis in the longitudinal plane on the amplitude and shape of the pulsed signals reflected from the plane-layered media. It is established that when using antenna units with two shifted receiving antennas the small (not more then $5°$) changes of the antenna unit inclination in a transverse plane don't affect substantially the final result of the signal processing i.e. measuring the permittivity and the thickness of layers of plane-layered medium. On the contrary, a small change in the angle of the longitudinal inclination of the antenna unit (not more than $5°$), can have a significant effect on the final error in the estimates of the thickness and permittivity of the layers. Thus, to increase the accuracy of assessment of the physical-geometric parameters of road pavement, it is proposed to take into account the current angle of longitudinal inclination of the sensing axis. From a technical point of view, this can be done on the basis of additional measurements using several laser rangefinders.

References

1. Ground penetrating radar, theory and applications. [Jol Harry M. (Editor)], Amsterdam : Elsevier B.V., 2009, 508 p.
2. Evans R.D. Optimizing Ground Penetrating Radar (GPR) to assess Pavements. A dissertation thesis submitted in partial fulfillment of the requirements for the award of the degree Doctor of Engineering (EngD), at Loughborough University, August 2009, 219 pages.
3. Batrakov D. O., Antyufeyeva M. S., Antyufeyev A. V., Batrakova A. G. “UWB Signal Processing During Thin Layers Thickness Assessment”, 2016 IEEE Radar Methods and Systems Workshop, Kyiv, Ukraine, pp. 36-39.
4. Batrakov D.O., Antyufeyeva M.S., Antyufeyev A. V., Batrakova A.G. Inverse problems and UWB signals in biomedical engineering and remote sensing. 2016 8th International Conference on Ultrawideband and Ultrashort Impulse Signals, Odessa, Ukraine, pp. 148-151.
5. Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys : ASTM D 6433–11. 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, United States, 2011, 49 p.
6. S. Cafiso, A. Di-Graziano, H.R. Kerali, J.B. Odoki “Multicriteria Analysis Method for Pavement Maintenance Management”, Transportation Research Record, 2002, № 1816. pp. 73–84.
7. Muhammad Mubaraki, Highway subsurface assessment using pavement surface distress and roughness data. International Journal of Pavement Research and Technology, Vol. 9, N 5, September 2016, pp 393-402. Open access https://doi.org/10.1016/j.ijprt.2016.10.001
8. Batrakov D. O., Batrakova A. G., Golovin D. V. Numerical simulation of UWB impulse response of plane layered media with 2D inclusion. 2012 6th International Conference on Ultrawideband and Ultrashort Impulse Signals, 2012, pp. 153 – 155 http://ieeexplore.ieee.org/document/6379763/
9. Batrakov D. O., Antyufeyeva M. S., Antyufeyev A. V.; Batrakova A. G. GPR data processing for evaluation of the subsurface cracks in road pavements. Proc. IWAGPR-2017, Edinbourgh, pp. 1–6, http://ieeexplore.ieee.org/document/7996072/
10. Batrakov, D.O., Golovin, D.V., Simachev, A.A., Batrakova, A.G. Hilbert transform application to the impulse signal processing. 2010 5th International Conference on Ultrawideband and Ultrashort Impulse Signals, pp. 113-115, DOI: 10.1109/UWBUSIS.2010.5609110
11. Batrakov, D.O., Tarasov, M.M. Algorithm of solving inverse scattering problems using the Pontryagin maximum principle. Radiotekhnika i Elektronika, 1999, Vol. 44, № 2, pp. 137-142. (In Russian)