

Probing multilayer road structures using the GPR “Terrazond”

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Abstract

The paper describes a method for obtaining information about the thickness of road pavement layers using the “Terrazond” multichannel ground penetrating radar. The method includes the use of signal pre-processing to eliminate common-mode interference on radar data of the road surface. The results of applying the methodology to data obtained during sounding of a road test site are presented. Using the example of a radar data of a test section, it is shown that three iterations of the proposed filtering contrastively highlight three layers of the road structure. The results of automated construction of the boundaries of road layers in the GeoReader program using machine learning technology are shown.

1. Introduction

The diverse characteristics of materials, variations in the thickness of pavement layers, and the existence of imperfections and damage on the road surface and in layers present difficulties in precisely identifying the boundaries between layers. The existing signal processing methods used to determine the boundaries of layers have disadvantages that limit their application in practical conditions.

Previously, authors developed a signal processing method for filtering common-mode interference [1], which largely eliminates the problem of accurately determining layer boundaries. The use of data processing allows for improving the image quality obtained using GPR and making it more accurate and reliable for studying road structures to determine layer boundaries and thickness [2]. It also allows for detecting other underground objects, making GPR very useful in engineering geology, construction, and other industries. At the same time, the definition of the boundaries between layers of the road structure can be done using machine learning on large data sets in an automated manner, which would



significantly reduce time and resource costs, decrease reliance on operator expertise, and increase the overall efficiency of the data interpretation process. It is known that, by using computer vision algorithms and neural networks, it is possible to implement the functionality of recognizing various defects on the road surface, such as cracks, potholes and voids. This allows quickly and accurately determining their location and size, which helps prevent accidents and improves road safety [3].

The article [4] notes that the accuracy of measuring of the characteristics of the underground environment using neural networks depends on the quality of data obtained using GPRS. For example, the accuracy of methods may decrease if there is strong noises in the data. Therefore, using processed data such as based on common mode interference filtering will allow more widespread use of neural networks for processing big data. This data is then used to create digital models of roads, recording their actual condition and increasing the efficiency of planning repairs.

This paper demonstrates the main characteristics of the multi-channel ground penetrating radar “Terrazond” and the data obtained from it when probing various sections of highways. The results of processing this data using common-mode interference filtering and further processing with machine learning methods are also presented.

2. Hardware of Terrazond GPR

As the main instrument for collecting GPR data, we used the wide-range multi-channel GPR Terrazond (figure 1). This instrument has several advantages over common mono-pulse ground-penetrating radar systems. Let's list some important feature of this radar. Firstly, this device is a distributed antenna array with high-speed electronic switching, allowing for simultaneous sensing over 32 channels and a capture of up to 2.5 m in pavement width (figure 2). The radiation pattern of one element retains its characteristics within the operating frequency range (figure 3). This allows us to evaluate the characteristics of road surfaces and inhomogeneities across the entire scanning plane of a road (figure 4), rather than just along a single route. Secondly, the radar is equipped with a high-speed signal generator operating on the principle of LFM location, which provides sensing at speeds up to 130 km/h. The GPR consists of a UWB antenna unit of receiving and transmitting antennas operating in the frequency range from 0.71 to 2.6 GHz, a sensitive high-speed LFM generator provides the operation of the GPR at speeds up to 130 km/h (with a recording density of GPR tracks - every 10 cm), a high-speed electronic relay, a programmable logic integrated circuit (FPGA) for receiving, processing and storing geodata (figure 5). The ground-penetrating radar antenna array is fixed in front or behind the car at a height of 30-40 cm from the road surface (figure 6). Currently, the ground-penetrating radar Terrazond is serial-produced. It use for the road laboratories by organizations such as RosdorNII and Rosavtodor.

The advantages of using multi-channel georadar systems over single-channel ones are:

1. Measurement of the radar response from the roadway in both transverse and longitudinal directions during the movement of a vehicle equipped with a radar.
2. Data processing, and obtaining a three-dimensional array, as well as amplitude maps linked to geolocation.
3. The possibility of using the common depth point method, which allows the procedure for calculating electrophysical properties of roadway layers. This opens up opportunities to conduct a more detailed analysis of these layers [2, 5, 6].
4. The software implements the functions of primary signal processing in real time with all channels. Such as converting the received LFM signal in frequency representation into a time sequence of data, filtering common-mode interference, linking each received radar trace to interpolated GPS coordinates [7].



Figure 1. Multi-array ground radio imaging system «TerraZond».

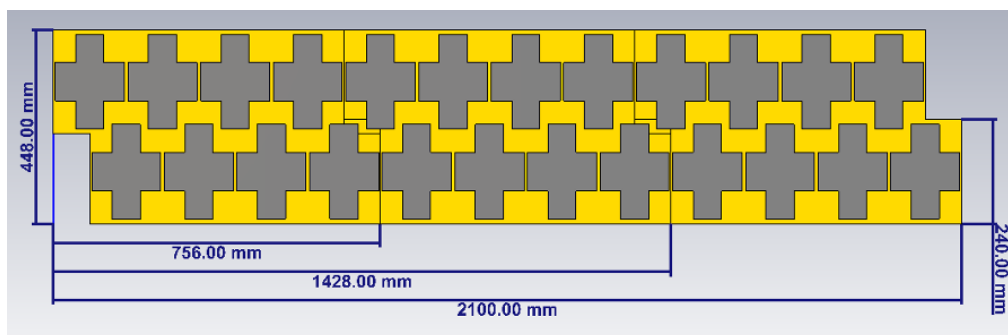


Figure 2. 8-32 elements antenna array.

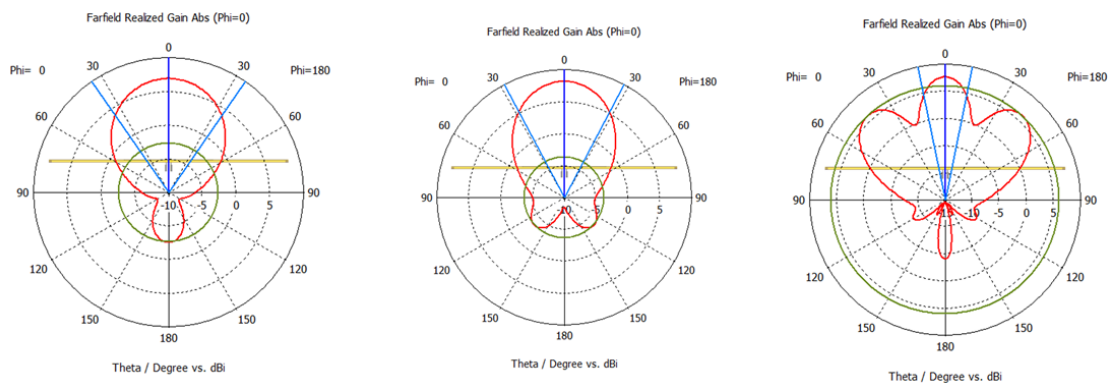


Figure 3. Radiation patterns of antennas element.

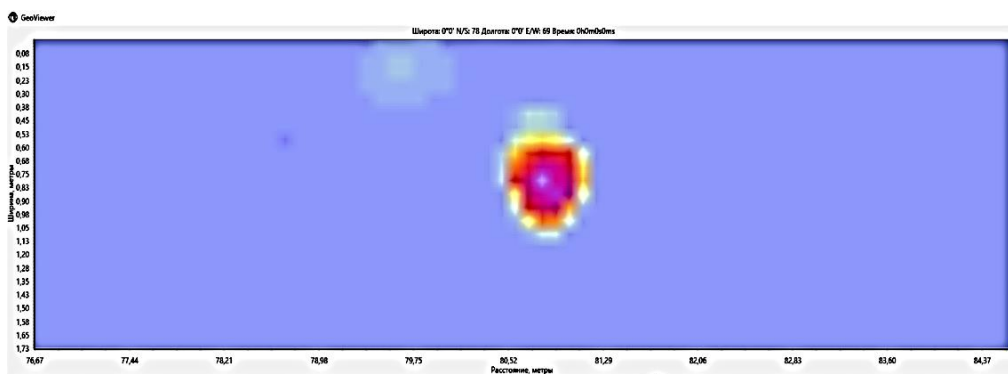


Figure 4. An amplitude map with heterogeneity obtained in multichannel mode.

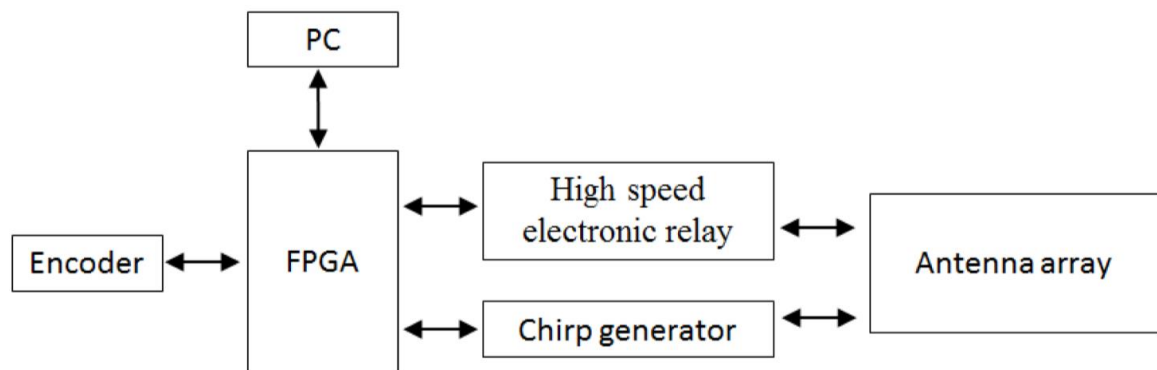


Figure 5. Structural diagram of the device.



Figure 6. GPR mounting on a road car of a laboratory.

3. Software of Terrazond GPR

Common-mode interference in the radar image is caused by multiple interference between the antenna and the air-environment boundary. These disturbances appear as multiple bands, which prevent the determination of the boundaries between layers of pavement. Its occurrence is mainly due to the repetitive reflection of the probing signal from the road surface and other reflectors associated with the design of the antenna array housing and its mounting on the car. Its occurrence is mainly due to the repetitive reflection of the probing signal from the road surface and other reflectors associated with the design of the antenna array housing and its mounting on the car. The authors proposed [1] an algorithm for eliminating common-mode interference using an iterative procedure to sequentially eliminate common-mode from the upper layer down to the lower layer. Figure 7 shows the initial radar image of the 160-meter test section of the M-12 road polygon, Moscow, obtained in 2022. Figure 8 shows the results obtained after three iterations of radar signal filtering.

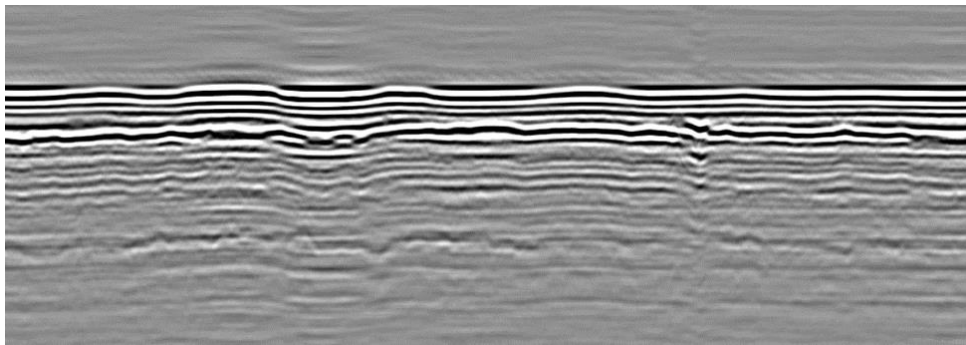


Figure 7. A set of initial radar images of a 160-meter-long road section.

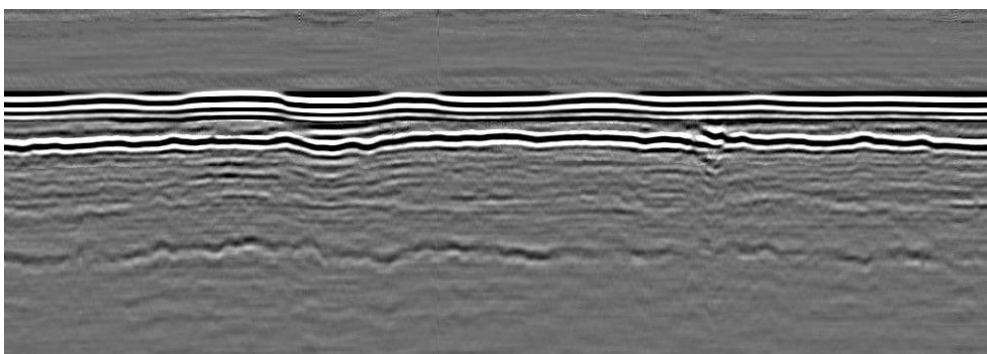


Figure 8. Radar image of a road section after three iterations of interference filtering.

The figure shows that the localization of the amplitude maxima of the reflected signal corresponding to 3 layers significantly increases after filtering. This allows us not only to talk about increasing the accuracy of determining the location of the boundary, but in some cases also about the possibility of separating layers in general. This feature gives hope for the application of this technology as pre-filtration in the task of constructing layer boundaries using neural networks.

The methodology for calculating the thickness of pavement layers based on georadar sounding data using Terrazond equipment provides for data processing using machine learning methods in GeoReader software [5]. The results of such processing are shown in Figure 9.

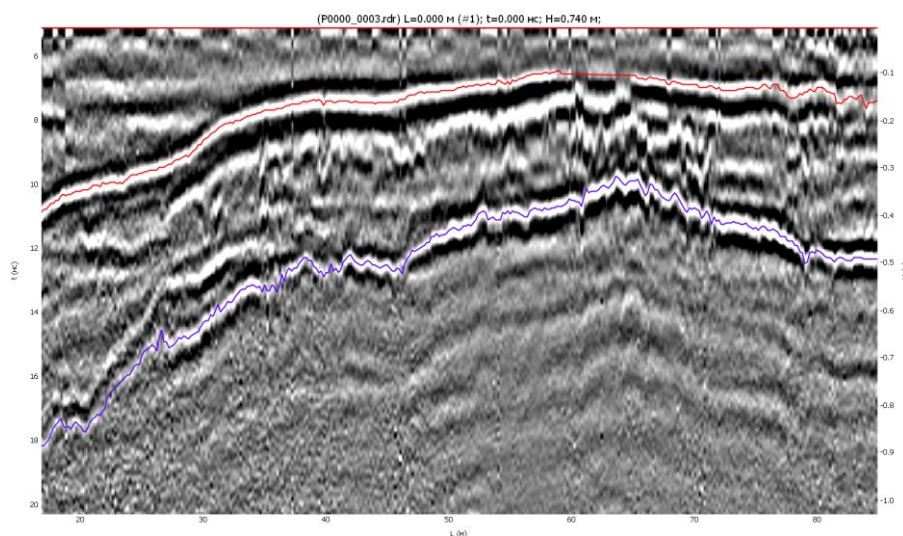


Figure 9. The result of processing the received data using machine learning.

As a result of the survey of highways using the method described above, it is possible to create an amplitude map to monitor compliance of pavement thickness with design requirements and present results in CAD and BIM solutions along with laser scanning data (figure 10).

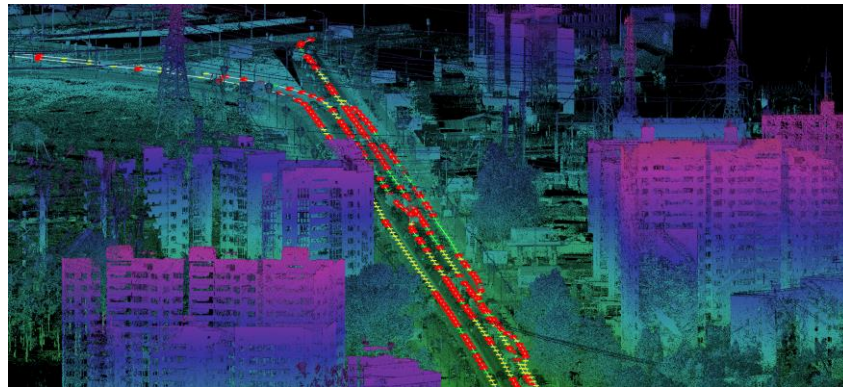


Figure 10. Display asphalt concrete thickness information from GPR with point cloud from 3d laser scanning inside “Credo 3D Scan” environment.

4. Conclusion

A method for obtaining information on the thickness of pavement layers has been developed for the Terrazond multichannel ground-penetrating radar. This method involves the use of signal preprocessing to eliminate common-mode interference on roadway radars. The method has been tested on the results of probing the test site of the M-12 road. The example of the radar image of the test area shows that three iterations of the proposed filtering contrast three layers of road structure. For further processing of the results, we used the technique of automated boundary construction for road layers in the GeoReader program, which includes machine learning methods. The results can be presented as an amplitude map showing changes in the thickness of the road layers, superimposed onto a three-dimensional city map in the form of a cloud of laser scanning points.

Acknowledgments

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References

- [1] Gorst A, Tseplyaev I, Ereemeev A, Shipilov S, Romanov D and Eremin R 2023 *Remote Sensing* **15** 2751
- [2] Karim, Hussein & Al-Qaissi, Ammar 2014 *Eng. & Technology Jour.* **32** 1240-1250
- [3] Yang X; Guan J; Ding L; You Z; Lee V C; Hasan M R M ; Cheng X 2021 *J Traffic Transp. Eng.* **8** 1000–1021
- [4] Liu Z, Gu X, Chen J, Wang D, Chen Y and Wang L 2023 *Autom. Constr.* **146** 104698
- [5] Sukhobok Y A and Kurbatov M S 2019 *CAD GIS Roads* **2** 26–31
- [6] Romanov D, Zykov A, Fedyanin I, Sukhobok Y 2020 *Russian Physics J.* **63** 214-220
- [7] Li J., Liu C, Zeng, Z., & Chen, L (2015). GPR Signal Denoising and Target Extraction with the CEEMD Method. *IEEE Geoscience and Remote Sensing Letter*, 12 (8), 1615-1619.