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Two-Step Inverse Problem Algorithm for Ground Penetrating Radar Technique

***Abstract**. The aim of the article is to present the new method of GPR data interpretation. The presented methodology allows to determine the depths and diameters of hidden objects. To generate the data and to solve the forward problem the Finite-Difference Time-Domain method was used. In order to solve the inverse problem of rebar diameter estimation the author's two-step algorithm was constructed. The algorithm was based on edges detection methods mixed with neural networks.*

***Streszczenie:** W artykule przedstawiono metodę interpretacji danych uzyskanych z geo-radaru. Zaprezentowana metodologia pozwala na wyznaczanie głębokości oraz średnicy ukrytych obiektów. Do generacji danych użyto metody różnic skończonych w dziedzinie czasu, zaś w celu rozwiązania zagadnienia odwrotnego posłużono się autorskim algorytmem opartym na metodach detekcji krawędzi oraz sieciach neuronowych. . (**Dwustopniowy algorytm do rozwiązywania zagadnienia odwrotnego w georadarach**).*

Keywords: GPR, inverse problem, FDTD, neural networks.
Słowa kluczowe: georadar, zagadninie odwrotne, FDTD, sieci neuronowe.

Introduction

Ground penetrating radar (GPR) is a non-destructive technique for investigating hidden objects. It detects changes in the electromagnetic properties of materials, principally their permittivity, and is capable of producing cross-sectional representations of what is beneath surfaces [1]. That idea can be seen in Fig. 1 where GPR antenna transmits a signal to the ground, and then scattered signals are collected in a storage unit via control one.

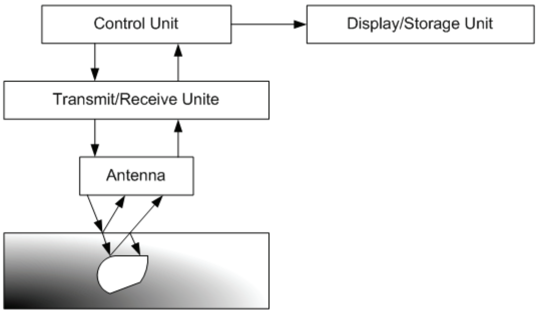

Fig.1. The idea of GPG technique.

In this study the authors have used the Finite-Difference Time-Domain (FDTD) [2] method to numerically describe the basic ideas of GPR technique [3] i.e. to generate synthetic data, and then they have used the data to solve the inverse problem.

The process of acquiring information from GPR radarogram is based on inverse problem solution. There are two main methods of solving such ill-posed inverse problems [4]:

a) Statistical approach – which consists in using prepared database with a forward model calculation to learn the statistical model, which maps the artificial measurement data to solution space

b) Physical approach – which consists in iterative optimization process of calculating the forward model and minimizing the difference between the calculated and measured data.

The method of signal processing used to solve the inverse problem in GPR imaging can be divided into three categories [5-7]:

a) Pattern matching method, which is mainly based on neural networks;

b) Image-then-detect method, which is some form of tomography ,

c) Statistical signal processing method.

In this study the authors have proposed a new method consisting of two steps. First, the method of signal enhancing is used, and then the statistical method based on artificial intelligence is applied to estimate the required parameters. In our research we have used simulated data from freely available GprMax2D/3D software.

Numerical model and its parameters

In order to consider the problem numerically some assumptions for the modeling of GPR in two dimensions have been made:

a) all media are considered to be linear and isotropic;

b) the transmitting antenna is modelled as a line source, as a consequence of the assumption of the invariance of the problem in one direction.

In our case the model of concrete slab with dimensions of 0.6x0.3 meter has been considered. Moreover, the perfectly conducting rebar of radius r = 0.025 m located in the slab has been investigated. The model under consideration can be seen in Fig. 2.

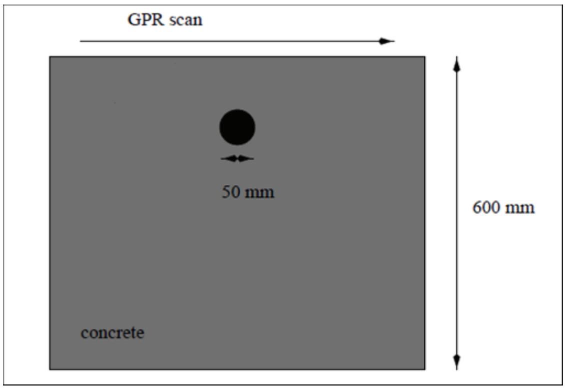

Fig.2. Schematic drawing of the perfect conductor in concrete (the model under consideration).

To the concrete slab a constitutive parameters of concrete have been assigned e.g. $\varepsilon_r = 6$ and $\sigma = 0.01$ S/m. As for the rebar there is no need to define constitutive parameters for perfect conductors in GPRMax software. To simulate GPR antenna at centre frequency of f = 900 MHz a ricker source has been used (see Fig. 3).

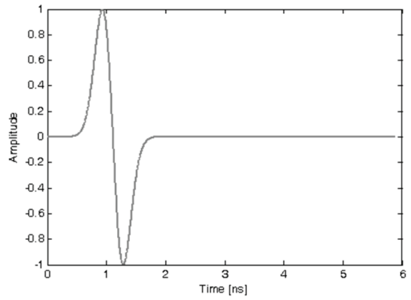

Fig.3. Time waveform of the ricker excitation function. The centre frequency is 900 MHz..

To fulfil the stability criterion of FDTD method it has been assumed that the highest frequency in the pulse spectrum was fm = 3f = 3x900 MHz = 2700 MHz. It means that the wavelength should be calculated as follows:

$$\lambda = \frac{c}{f_m\sqrt{\varepsilon_r}} \approx 4.5cm \tag{1}$$

Hence, the spatial steps λ/10=Δx=Δy=4.5 mm should be set. Moreover, when taking into account the rebar radius r≈6Δx it is proper to set spatial resolution as Δx=2.5 mm in order to improve the model. Finally, since Δx=Δy= 2.5 mm has been set the time step Δt should be calculated as

$$\Delta t = \frac{\Delta x}{c\sqrt{2}} \tag{2}$$

which gives Δt=5.896 ps.

Two-step inverse algorithm

Taking into account the above the authors have generated the input data used in the algorithm as follows. Firstly, to determine the shape of the hyperbola for different diameters of the rebar the following formula has been applied:

$$t_x^2 = 4\frac{(x-x_0)^2}{v^2} + t_0^2 \tag{3}$$

where: t_x is the propagation time from antenna position to the object, x is the distance between the object and antenna, t_0 is the propagation time when the antenna is located exactly above the object and ν is the speed of wave in the medium surrounding the object (in our case – the concrete). In Fig. 4 GPR scan can be seen with the rebar shape (the hyperbola one). That image is often called B-scan.

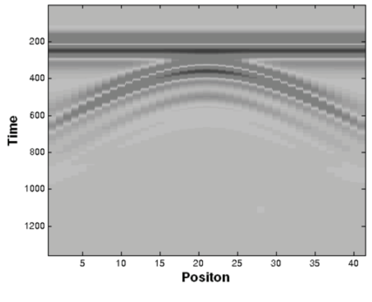

Fig.4. Simulated GPR scan with the rebar – B-scan.

In our case the B-scan has been received from 41 antenna positions (see Fig. 1 where GPR scan direction is indicated by the arrow). In the first step the edges of each hyperbola were detected with regards to the diameters and positions of the rebars in concrete. In our case the diameters of rebars have changed from 5 to 30 mm and the position (depth) from 40 to 175 mm. In Fig. 5 the bunch of hyperbolas for 10 different diameters and for one of rebar positions can be seen.

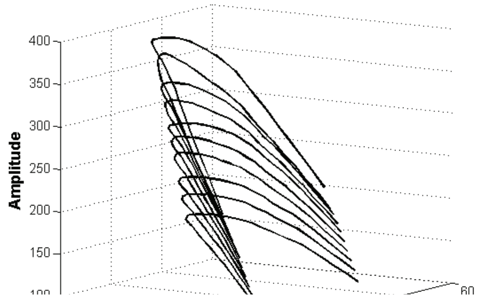

Fig.5. The detected edges of the hyperbolas for one of the rebar positions.

The above can be understood as the first step in the proposed algorithm. Secondly, in order to realize the second step of the algorithm the information about the shape of hyperbolas and their maximum amplitudes as the function of time are needed.

Taking into account Fig. 5 one can receive the maximum amplitudes of scattered signals for: the different diameters (see Fig. 6) and different positions (see Fig. 7) of the rebars.

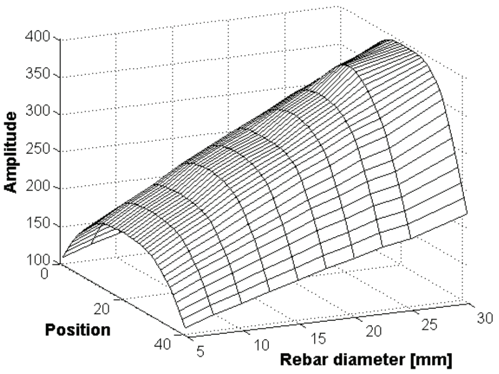

Fig.6. The maximum amplitudes of scattered signas as the function of rebar diameter.

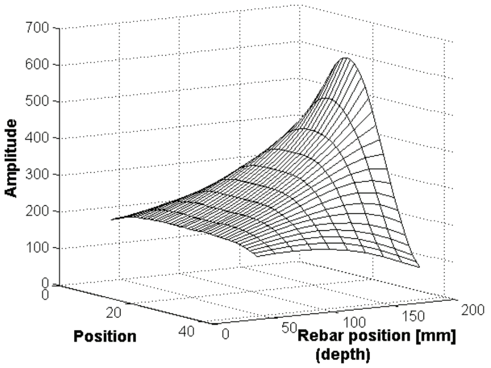

Fig.7. The maximum amplitudes of scattered signals as the function of rebar position in the concrete.

Next, the authors applied Principal Component Analysis (PCA) in order to reduce the dimension of data. In our case the input dimension was 82 because of 41 different antenna positions and 41 different hyperbola shapes (see Fig. 5 where the times and the amplitudes of the considered model are gathered). Finally the data have been reduced to 10 from 82, and then they have been used as the input data to the two-layer feed-forward neural network

The above described two-step algorithm can be schematically presented as follows:

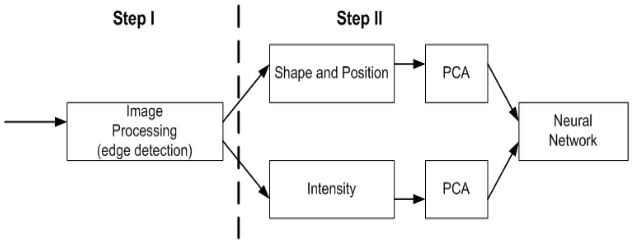

Fig.8. Two-step GPR data interpretation algorithm.

To verify the presented algorithm 100 samples have been used i.e. 10 different dimensions and 10 different depths of the rebar in the concrete. In Fig. 9 the output from the neural network and the inversion neural model error can be seen.

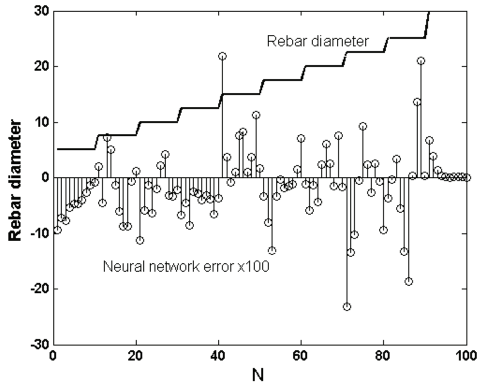

Fig.9. The output from the neural network and the error .

Moreover, in Fig. 9 the predicted radius of the rebars and the error related with estimation of the radius are shown. The data in Fig. 9 are ordered from the highest to the lowest depth for each of the 10 diameters of rebars.

Conclusions

The presented two-step algorithm can be used for GPR data interpretation and with its help the depth and the radius of rebars can be predicted. In our algorithm the collection of signal processing methods has been applied. The algorithm has been divided into two main steps. The first one has been designed to detect and provide the data (the hyperbolas shapes and the intensity of the reflected signals) to the second step. In this step the data have been interpreted quantitatively to determine the diameters of the objects under test.

In order to solve the inverse problem of rebar diameter estimation neural network model has been successfully applied. To conduct more detailed analysis, with regard to wider range of depths, one can divide the model of concrete with rebar into a few layers and connect each of them with a separate neural network model.

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