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Classification of geological structure using ground penetrating radar and Laplace transform artificial neural networks

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ABSTRACT

This paper focuses on a new kind of artificial neural networks – the Laplace transform artificial neural networks (LTANN). It is proposed to use the Laplace transform instead of ordinary weights and a linear activation function of an artificial neuron. This extension allows to use artificial neural networks in new areas. The ordinary description of artificial neural networks is a special case of the description proposed in this paper.

Three models of different geological structures based on the LTANN are discussed in this paper. Using these models, it is possible to classify an unknown geological structure as the structure without anomaly, the structure with a sinkhole or the structure with a loose zone.

1. Introduction

1.1. Problem with interpretation and recognizing of ground penetrating radar signal

GPR (Ground Penetrating Radar) has been widely used for almost twenty years in archeology, geology, and civil engineering [1,2].

GPR sends EM waves in the ground and then collects backscattered echoes (Fig. 1). GPR acquires signal traces moving along survey line. These raw data are then collected to form 2D GPR profile (radargram) [3]. The example of radargram is shown in Fig. 2, the example of transmitted signal is shown in Fig. 3 and the example of one trace is shown in Fig. 4.

GPR signal is difficult to interpret because it is disturbed and distorted. Attenuation of electromagnetic waves in a real geological medium is often large, and the power of GPR signal must be small for safety reasons. GPR method is sensitive to noises from other devices, such as mobile phones, GSM, WiFi, Bluetooth, all kinds of cables and wires for power and data transmission. GPR is also susceptible to numerous disturbances caused, for example by the presence of nearby buildings, rails, pipes, various metal objects, strong electromagnetic calls, etc. The terrain (uneven ground, troughs, depressions, vegetation, trees, landscaping elements) impede and distort the measurement results. They are very much dependent on the degree of saturation of the soil with water so they depend on the amount of rainfall in the period immediately preceding the measurements.

Geological structure is practically always composed of different materials, the interporous spaces (if any) are filled with water (with different mineral composition) or gas (usually air). The quality of recorded results is dependent on the choice of measurement parameters of GPR, which are often difficult to be optimally defined. Interpretation of radargrams is performed by a specialist, based on their experience and intuition. It is often affected by error. There is no unambiguous automatic recognition method of GPR records.

The use of neural networks to solve the described problem appears promising. Typical neural networks to solve this task are not very suitable because of the difficulty of taking into account the dynamics of the problem. Therefore, the paper attempts to apply a new type of neural network taking into consideration the dynamics of the waveforms to solve a given problem – LTANN network.

1.2. Classification problem

Classification is a problem of identifying to which set of categories a new observation belongs, on the basis of a training set of data

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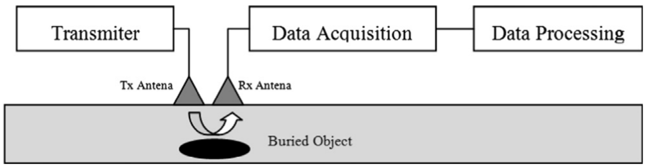

Fig. 1. GPR system.

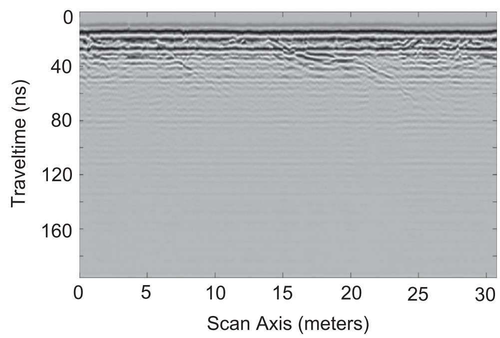

Fig. 2. The radargram.

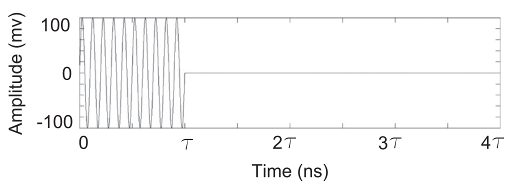

Fig. 3. The transmitted signal.

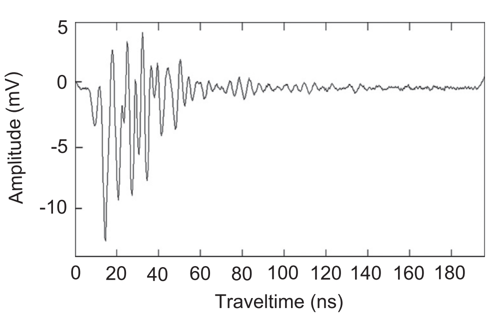

Fig. 4. The example trace from radargram.

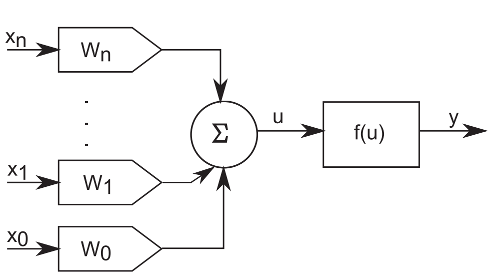

Fig. 5. The simple artificial neuron.

containing observations whose category membership is known. An algorithm that implements classification is known as a classifier. The examples of classification algorithms are listed below [4,5]:

- Linear classifiers
  - Fisher's linear discriminant
  - Logistic regression
  - Naive Bayes classifier
  - Perceptron
- Support vector machines
- Quadratic classifiers
- Kernel estimation (k-nearest neighbor)
- Boosting (meta-algorithm)
- Decision trees (Random forests)
- Neural networks
- Gene Expression Programming
- Bayesian networks
- Hidden Markov models
- Learning vector quantization

Each classifier has its own strengths and weaknesses. The most widely used classifiers are the neural networks. Neural networks have been selected for further consideration because they are simple, easy to build, efficient and reliable classifier. They are also give good results. There are many tools for building, using and analyzing neural networks, for example Matlab, Statistica, etc.

1.3. *The simple artificial neuron*

In Fig. 5 the simple artificial neuron with $n+1$ inputs $x_0, x_1, \ldots, x_n$ is shown. Each input has the corresponding weight $w_0, w_1, \ldots, w_n$. The neuron has a bias $b = w_0 x_0$.

It can be written as the following equation:

$$u = \sum_{i=0}^{n} w_i x_i \quad (1)$$

and the formula for the neuron output:

$$y = f(u) \quad (2)$$

where:

i - the number of given input,
n - the number of inputs.

If we put Eqs. (1) into (2), we obtain:

$$y = f\left(\sum_{i=0}^{n} w_i x_i\right) \quad (3)$$

The transfer function in Fig. 5 and in Eqs. (2) and (3) may be a linear or a nonlinear function of variable u. A particular transfer function is chosen to satisfy some specification of the problem that the neuron attempts to solve [6,7].

There are a lot of different transfer functions, but three of the most commonly used functions are shown below:

- Hard limit transfer function:

$$y = \begin{cases} 0 & \text{for } u < 0 \\ 1 & \text{for } u \geq 0 \end{cases} \quad (4)$$

- Linear transfer function:

$$y = u \quad (5)$$

- Log-Sigmoid transfer function:

$$y = \frac{1}{1 + e^{-u}} \quad (6)$$