ELECTRONICS AND ELECTRICAL ENGINEERING
ISSN 1392 – 1215 2009. No. 2(90)
ELEKTRONIKA IR ELEKTROTECHNIKA

T170 ELECTRONICS
ELEKTRONIKA

Technology For Aggregates Classification in Concrete Compounds

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Introduction

Concrete is a constructional material that consists of cement (commonly Portland cement) as well as other cement materials such as fly ash and slag cement, aggregate (generally a coarse aggregate such as gravel limestone or granite, plus a fine aggregate such as sand and water) and chemical admixtures.

Concrete solidifies and hardens after mixing and placement due to a chemical process known as hydration. Water reacts with cement, which bonds other components together, eventually creating a stone-like material.

Concrete is used more than any other man-made material on the planet [1]. According to the data of year 2006, about seven billion cubic meters of concrete are made each year – more than one cubic meter for every person on Earth [2].

Water is the main part of concrete mixtures alongside cement and aggregates. Water plays several roles in mixture. It participates in concrete hardening process, and it gives workability to the mixture.

Estimation of water content is very important in the mixture. Water comes to mixture from two sources, water added directly to the mixer during mixing process, and water that comes with aggregates. In practice, aggregates are stored mainly in outdoor conditions. In such storage materials are influenced by weather conditions: rain, sun and wind. The water content of aggregates can change very fast.

Today moisture of aggregates is often controlled with microwave moisture sensors [4]. Microwave moisture sensor includes HF signal generator and resonator. Resonant frequency and resonator quality depends on dielectric permittivity and loose tangent of surrounding substance. Water content changes these parameters in the mixture. However, dielectric properties of different materials change in different way. Consequently, it is possible to monitor reliably only one type of material with one sensor. It is disadvantage for microwave moisture meters. It is necessary to calibrate sensor for every mixture type in case of changing proportion of gravels ant sands in mixture.

We haven't found any adaptive sensor in today's world market to measure moisture independently from the ratio of mixture content.

Our goal is to create method ant tools for moisture measurement adaptive and invariant to influential factors.

Sensor design

Time domain reflectometry (TDR) method was used for our experiment [4]. TDR is traditionally used for location faults in cables. Currently high performance TDR instruments, coupled with add-on analysis tools are commonly used as the tool of material dielectric characteristics testing. The most general approach to evaluate the time domain response of any electromagnetic system is to solve Maxwell's equation in time domain. TDR allows to overview wide frequency range in very short time.

TDR is used to determine moisture content in soil and porous media, where over the last two decades substantial advances have been made; including in soils, grains and foodstuffs, and in sediments. The key to TDR's success is its ability to determine accurately the permittivity (dielectric constant) of material from wave propagation, and the fact that there is a strong relationship between the permittivity of material and its water content.

To reach the highest sensitivity and the best results we used coplanar transmission line as a sensor. This transmission line consists of two ground electrodes one central electrode and dielectric material between them (Fig. 1).

Fast rising edge test signal, propagating along the transmission line, creates electric field between central and ground electrodes. Propagation conditions and impedance of transmission line depends on conductor width, thickness, distance between conductor and ground plane and properties of dielectric material, dielectric constant ε and loose angle tangent, tan δ.

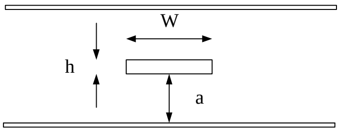

Fig. 1. Transmission line geometry

Denote moisture by Θ, dielectric constant of material ε_m and loose tangent of material $\tan\delta_m$. These parameters depend on frequency for the aggregates [5]. Then we can write as:

$$\varepsilon_m(\mathrm{f}) \neq const. \tag{1}$$

$$\tan\delta_m(\mathrm{f}) \neq const. \tag{2}$$

Dielectric properties of water depend on frequency and temperature. We can write $\varepsilon_w(t,\mathrm{f})$ and $\tan\delta_w(t,\mathrm{f})$. So for common occasion moisture of material Θ is a function of the characteristics mentioned earlier:

$$\Theta = f\left(\varepsilon_m(\mathrm{f}), \tan\delta_m(\mathrm{f}), \varepsilon_w(t,\mathrm{f}),\ \tan\delta_w(t,\mathrm{f})\right). \tag{3}$$

(3) is correct for single material. In the mixtures we will have several different materials, with individual relations of dielectric constant and loose tangent to the frequency and different water content. Though bulk densities of different materials are not the same. Final density of mixture is not the average of all including materials. Density of the mixture varies on granular structure of aggregates. So, effective dielectric constant of a mixture will be a function of dielectric constants of all included materials (4).

$$\varepsilon_{ef}(f) = f\left(\varepsilon_{m1}(\mathrm{f}), \varepsilon_{m2}(\mathrm{f}), .., \varepsilon_{mn}(\mathrm{f}), \varepsilon_w(t,\mathrm{f})\right). \tag{4}$$

We can write the same for loose tangent of the mixture (5).

$$\tan\delta_{ef}(\mathrm{f}) = f(\tan\delta_{m1}(\mathrm{f}), \tan\delta_{m2}(\mathrm{f}), .., \tan\delta_{mn}(\mathrm{f}), \tan\delta_w(t,\mathrm{f})). \tag{5}$$

Summarising written before, mixture moisture content is a function depending on effective dielectric constant and effective loose tangent (6).

$$\Theta = f\left(\varepsilon_{ef}(\mathrm{f}), \mathrm{tg}\delta_{\mathrm{ef}}(\mathrm{f})\right). \tag{6}$$

Out of that, we can find calibration curve and calculate moisture from the measured parameters for every type of material. But these parameters will be different for every type of mixture. Every mixture has unique shape of effective dielectric constant and loose tangent.

Experimental technique and results

We have used picoseconds pulse generator and Agilent Infinium MSO8104A oscilloscope in our experiment. Pulse generator was set to generate square pulses with amplitude of 1V and 1 MHz repetition frequency. Pulse rising front duration is 300 ps. We choose that generator and oscilloscope to cover frequency range 400 MHz - 1.5 GHz.

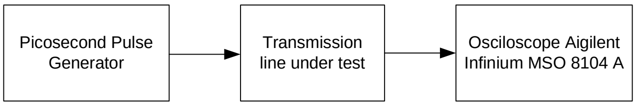

Fig. 2. Experimental equipment

Coplanar strip line has been taken as a sensor in our experiment [7]. It was tuned to dielectric permittivity ε = 6 and electric line length l =¼ λ at operating frequency 1 GHz [8]. Testing material was used as a dielectric in our transmission line. We have filled the gap between ground plane electrodes and signal electrode with it.

It is shown in Fig. 2 the test equipment structure diagram. Generator is connected with transmission line, and after signal propagates through, it is read by oscilloscope. Signal shape will get individual character of distortion depending on characteristics of dielectric material.

We have used two materials, 5–11 of crushed stone and 0–2 of sand. These materials are widely used in concrete production. Crushed stone is the roughest material, hereof it is useful for controlling moisture content, because in rough fractions available maximum moisture is too small, to the influence of overall mix moisture. Maximum available moisture of crushed stone is 1 %. 0–2mm sand fraction is the smallest quantity, used in concrete mixture. It can accumulate up to 15 % of water. So, it is very important to control the moisture of small fraction materials.

Table 1. Materials used in experiments

Sample num.	Sand 0-2, %	Crushed stone 5-11, %
1	100	0
2	75	25
3	50	50
4	25	75
5	0	100

Table 1 represents mixed materials used in our experiments. The first and the last materials where the compounds of pure sand and pure crushed stone respectively. Mixing crushed stone and sand in different proportions makes the middle ones.

Seven moisture values for every type of material was taken 0 %, 1,8 %, 3,7%, 5,4%, 7,1%, 8,6% and 10,2% respectively.

Having 5 material types and 7 moisture values for each type we made 35 measurements in one experiment session.

To get more reliable data we repeated experiment twice. So, totally we had collected 70 curves.

We have shown signal shapes from Fig. 3 to Fig. 7. It was realised to eliminate rectangular time window effect of the measured signal, because informative part of the signal, raising edge, is 300 ps duration. Rise time is limited by oscilloscope input stage bandwidth, but it covers the most interesting frequency range for us [4].

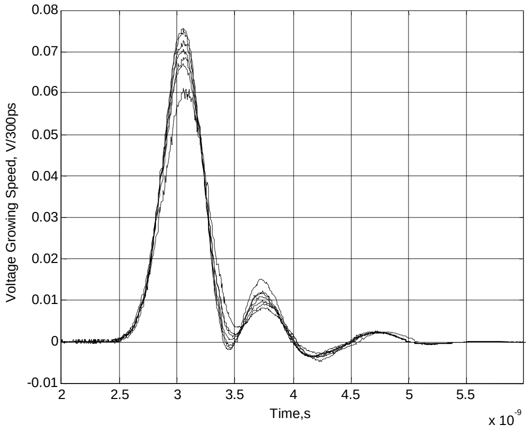

Fig. 3. Signal shapes of pure sand

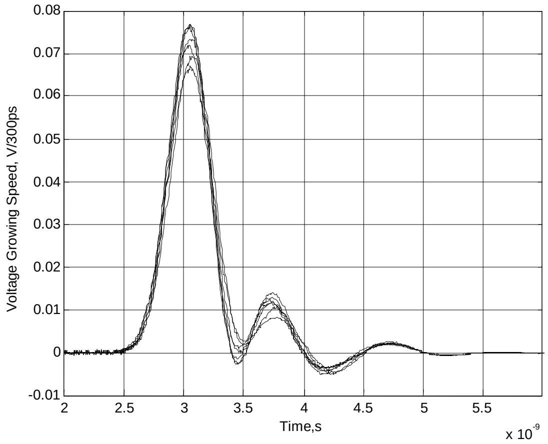

Fig. 4. Signal shapes of 75% sand and 25% crushed stone mix

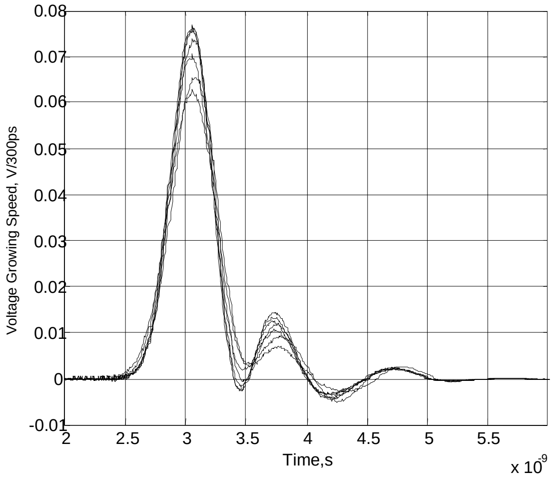

Fig. 5. Signal shapes of 50% sand 50% crushed stone mix

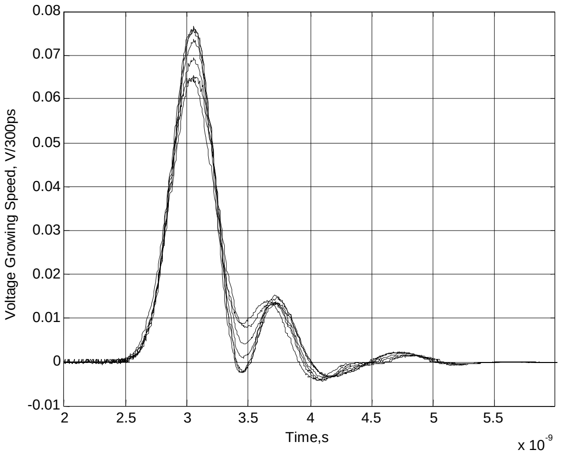

Fig. 6. Signal shapes of 25% sand and 75% crushed stone mix

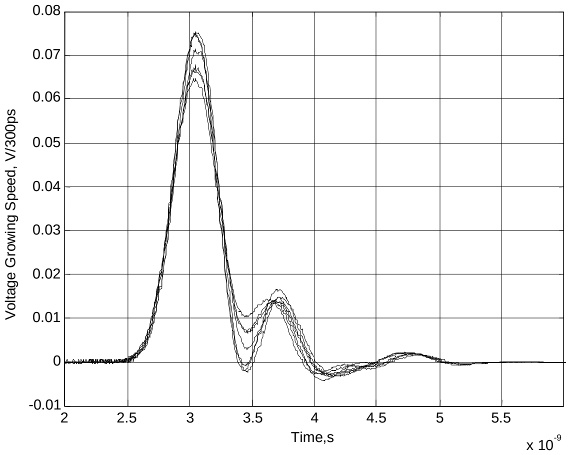

Fig. 7. Signal shapes of pure crushed stone

There are shown signals affected by the different moisture content of the same material respectively Fig. 3. to Fig. 7. Material type and moisture content changes accordingly to the Table 1. The shape of the signal changes depending on the material type and moisture of the material. Different materials have their own shape character. But we see, that moisture content makes higher influence to the shape than the type of the material. We acquired mathematical apparatus to extract information about the type of tested materials.

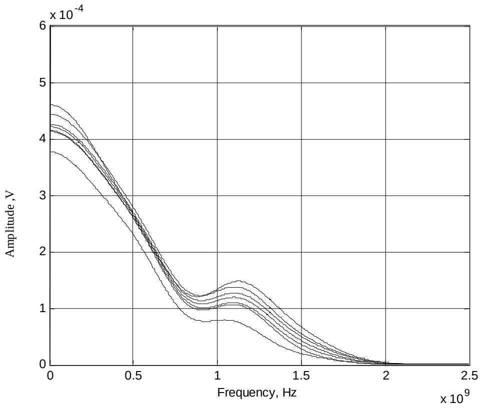

Fig. 8. Signal spectrum of sand

Fig. 8 – Fig. 12 shows spectrum density curves of the tested materials. The highest difference is seen in the frequency range between 800 MHz and 1.5 GHz. These results confirm data collected in early made experiments [8]. In order to find the relationship between materials type and spectrum curve we used artificial neural network technology [9].

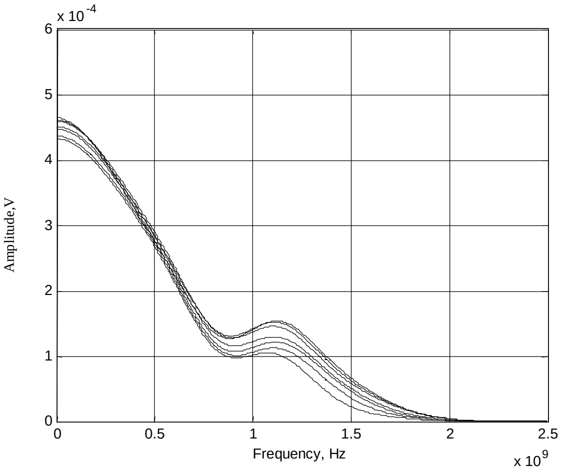

Fig. 9. Signal spectrum of 75% sand and 25% crushed stone mix

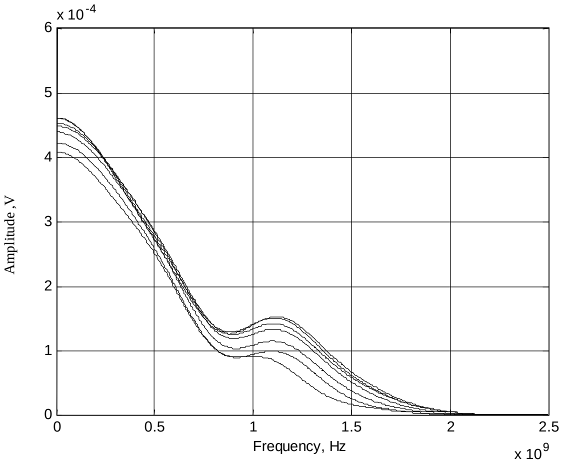

Fig. 10. Signal spectrum of 50% sand and 50% crushed stone mix

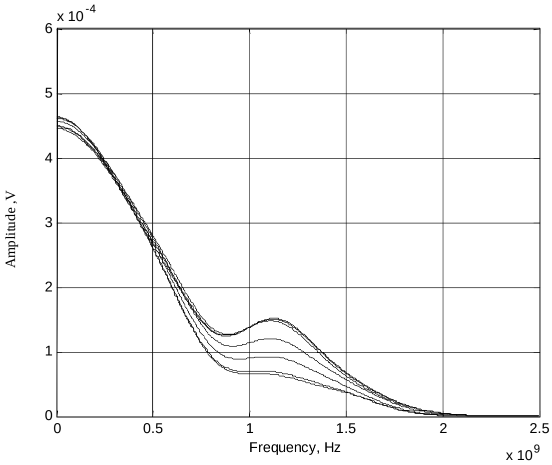

Fig. 11. Signal spectrum of 25% sand and 75% crushed stone mix

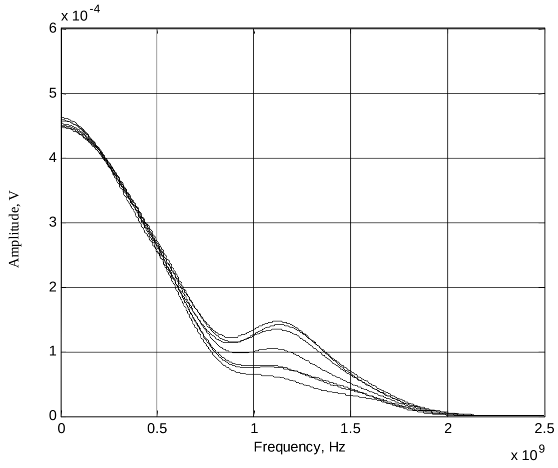

Fig. 12. Signal spectrum of crushed stone

An artificial neural network (ANN) is a collection of interconnected analogue signal processors. The purpose of an ANN is to provide a mathematical structure that can be trained to map a set of inputs to a set of outputs. Fig. 13 illustrates an ANN used in this.

This ANN has three layers: the input, hidden and output layers. Each layer consists of nodes or neurons. Each node has sigmoid activation function, associated with it. Each interconnection between the nodes has a weight associated with it. The nodes in the hidden layers and output layers sum the weighted inputs from sending nodes and apply this net input to the activation function. Applying the inputs and computing the output from the various node activations and interconnection weights determine the output of the network.

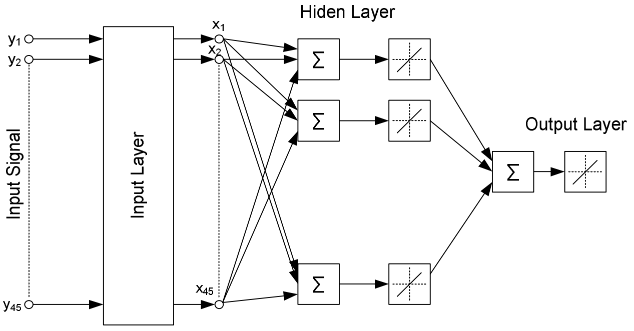

Fig. 13. Artificial Neural Network

Table 2. Output values for ANN

Input data	Learning result
Material No. 1 (7 different moisture values)	-1
Material No. 2 (7 different moisture values)	-0.5
Material No. 3 (7 different moisture values)	0
Material No. 4 (7 different moisture values)	0.5
Material No. 5 (7 different moisture values)	1

We have taken ten spectrum values for different frequencies as an input data. Type of the material was a learning target. Acquired target constants for different materials, in the range from -1 to +1, because it is the range of the output values of ANN.

Neuron number was chosen accordingly to input layer size.

Results

The best results were achieved by analysing spectrum's shapes. The network learning was performed using a collection of data with seven different moisture points for every material. Generated network was tested using the same data used for learning process (Fig. 14), and also data collected during independent experiment with the same materials (Fig. 15).

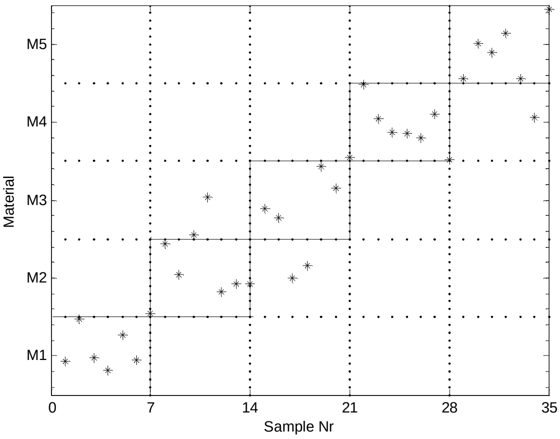

Fig. 14. ANN Tested with data used for learning

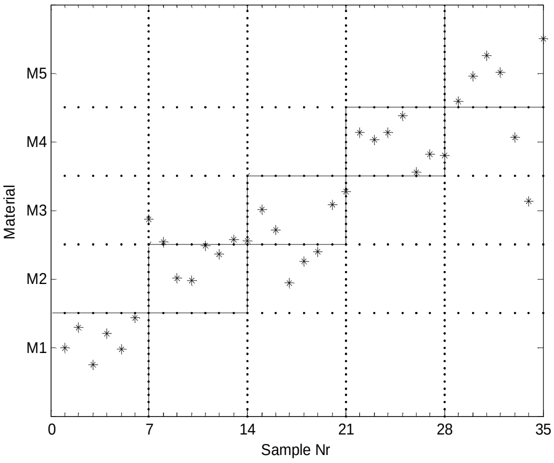

Fig. 15. ANN Tested with independent data

Number of experiment is the set on x-axis. 1-7 – Material No. 1 (Sand), 2-8 Material No. 2, … , 29-35 Material No. 5 (crushed stone). We have set type of material on y-axis.

As it's seen from Fig. 14 and Fig. 15, the possibility to identify the type of material was proved. The 85%confidence was reached during the experiment.

Conclusions

It is still impossible to measure water content in concrete independently from the type of compound.

We illustrated theoretical background and examples of technology for material type classification in this paper. Time domain reflectometry combination with artificial neural network was proposed to identify the material type. Technology do not need extra sensor in moisture measurement system.

Single sensor material independent technology for moisture measurement in concrete compounds enables fast integration of moisture meters without individual calibration for every material used in technological process of concrete manufacturing.

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Received 2008 10 07

G. Lengvinas, V. Deksnys, A. Ragauskas. Technology For Aggregates Classification in Concrete Compounds // Electronics and Electrical Engineering. – Kaunas: Technologija, 2009. – No. 2(90). – P. 61–66.

Increasing concrete market and growing variety of concrete products and requirements for higher quality needs fast and accurate moisture measurement technology. In this paper fast accurate and material independent moisture measurement method is presented. Time domain reflectometry (TDR) sampling method for data acquisition has been used. In order to find the relationship between materials type and spectrum curve artificial neural network classifier (ANN) has been used. 5 mixtures from two materials (sand and crashed stone) in different proportions were correctly recognized using method proposed. Experiment confirmed ability to use TDR combined with ANN in material independent moisture measurement systems. Ill. 15, bibl. 9 (in English; summaries in English, Russian and Lithuanian).

Г. Ленгвинас, В. Декснис, А. Рагаускас. Технология для классификации составляющих в бетонных смесях // Электроника и электротехника. – Каунас: Технология, 2009. – № 2(90). – С. 61–66.

Рост строительного рынка, разнообразие бетонных изделий и повышеные требования к качеству нуждаются в технологии быстрого и точного измерения влажности. Представлен быстрый, точный и инвариантный к составу метод измерения относительной влажности. Для сбора данных был использован метод временной рефлектометрии (МВР). Для того, чтобы найти взаимосвязь между типом материала и кривой плотности мощности, была использована искусственная нейронная сеть (ИНС). Используя предложенный метод для 5 смесей различной влажности из двух составных материалов, смешанных в различных пропорциях, составы были правильно опознаны. Эксперименты подтвердили возможность использования МВР в сочетании с ИНС в автоматических, независимых от измеряемого материала, системах измерения влажности. Ил. 15. библ. 9 (на английском языке; рефераты на английском, русском и литовском яз.).

G. Lengvinas, V. Deksnys, A. Ragauskas. Betono užpildų klasifikavimo technologija // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2009. – Nr. 2(90). – P. 61–66.

Pristatomas mikrobanginis drėgnio matavimo būdas, atsparus tiriamosios medžiagos tipui. Tyrimui buvo taikomas laikinės reflektometrijos metodas. Sąryšio tarp tiriamosios medžiagos tipo ir spektro kreivės paieškai buvo panaudotas dirbtinis neuroninis tinklas. Remiantis pasiūlytu metodu buvo sėkmingai atpažinti 5 skirtingo drėgnio mišiniai, sudaryti iš skirtingomis proporcijomis sumaišyto smėlio ir skaldos. Eksperimentai patvirtino galimybę, naudojant laikinę reflektometriją ir dirbtinius neuroninius tinklus, atlikti drėgnio matavimus, invariantiškus tiriamosios medžiagos tipui. Il. 15, bibl. 9 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).

DOI: 10.5755/j02.eie.10509