UDC 535.42

D. V. Lyasota, V. M. Morozov, V. I. Magro

Oles Honchar Dnipropetrovsk National University, Dnipropetrovsk, Ukraine
**e-mail: morozovvmd@yandex.ua*

RECOGNITION OF WIRE STRUCTURE BY CHARACTERIZATION OF ITS BACKSCATTERING WITH NEURAL NETWORKS

The work is devoted to study the recognition algorithm for a body made of perfectly conducting wire, on the basis of the spatial distribution of normalized power and the polarization ellipse parameters for the scattered electromagnetic wave. The diffraction problem is solved by the integral equation method. A Fredholm equation of the first kind for electric field vector with boundary conditions of Dirichlet is solved. The numerical solution of the integral equation is carried out via a system of linear algebraic equations by direct sampling. The feature of kernel integrating is taken into account. Structure detection was performed using a probabilistic neural network. Feature vector is defined as the value of the Shannon entropy of the first few components of the wavelet packet decomposition of scattering characteristics. The decomposition was performed using a Daubechies wavelet of the second order.

Keywords: diffraction of electromagnetic waves, the integral equation method, probabilistic neural network, wavelet packet transform, objects recognition.

Робота присвячена вивченню алгоритму розпізнавання тіла, виготовленого з ідеально провідного дроту, на основі просторового розподілу нормованої потужності та параметрів еліпса поляризації розсіяної електромагнітної хвилі. Задачу дифракції розв'язано методом інтегрального рівняння. З урахуванням граничних умов Діріхле отримано та розв'язано вирішено інтегральне рівняння Фредгольма першого роду для вектора напруженості електричного поля. Чисельне розв'язання інтегрального рівняння виконано способом зведення його до системи лінійних алгебраїчних рівнянь шляхом прямої дискретизації. Враховано особливість ядра інтегрування. Розпізнавання структури проводилося за допомогою імовірнісної нейронної мережі. Вектор ознак визначений як значення ентропії Шеннона кількох перших компонент вейвлет пакетного розкладання характеристик розсіювання. Розкладання виконано за допомогою вейвлета Добеши другого порядку.

Ключові слова: дифракція електромагнітної хвилі, метод інтегрального рівняння, імовірнісна нейронна мережа, вейвлет пакетне перетворення, розпізнавання об'єкта.

Работа посвящена исследованию алгоритма распознавания тела, изготовленного из идеально проводящей проволоки, на основании пространственного распределения нормированной мощности и параметров эллипса поляризации рассеянной им электромагнитной волны. Задача дифракции решена методом интегрального уравнения. С учётом граничных условий Дирихле получено и решено интегральное уравнение Фредгольма первого рода для вектора напряженности электрического поля. Численное решение интегрального уравнения выполнено способом сведения его к системе линейных алгебраических уравнений путём прямой дискретизации. Учтена особенность ядра интегрирования. Распознавание структуры производилось с помощью вероятностной нейронной сети. Вектор признаков определён как значения энтропии Шеннона нескольких первых компонент вейвлет пакетного разложения характеристик рассеивания. Разложение выполнено с помощью вейвлета Добеши второго порядка.

Ключевые слова: дифракция электромагнитной волны, метод интегрального уравнения, вероятностная нейронная сеть, вейвлет пакетное преобразование, распознавание объекта

1. Introduction

Neural networks are well established in the classification problems, approximation and recognition. At the moment they are being increasingly used in various fields of science and technology. The ability of neural networks to learn led to their use in image recognition systems, speech processing, construction of prognostic models in economics, etc. [1, 2].

There are a large number of works devoted to the problem of recognition of metal objects on the characteristics of scattering of electromagnetic waves in various ranges. Underwater object recognition method based on the information on the distortion of the constant magnetic field and body image in the optical range is given in [3]. In [4] subsurface object identification is made on the basis of the impulse response of the reflected electromagnetic waves.

In the present paper the solution for object recognition is given. The object is made of conductive wire. Backscattering characteristics in the resonance wavelengths and probabilistic neural network are used. Similar problems arise in the determination of parameters of radar targets in the detection and recognition of metallic objects hidden under a layer of earth or beyond the dielectric wall, etc.

Another problem in the application of neural networks is to construct a feature vector based on the received signal. In this paper we used an approach of energy allocation vector signs based on wavelet packet decomposition, which is applied for the recognition of geometric textures [5].

2. Formulation of the problem

The solution of the problem of body recognition based on the power parameters and of the polarization ellipse of scattered it on plane harmonic electromagnetic waves is considered. The incident wave is circularly polarized and propagates along the z-axis. At a distance h from the origin the body is located, it rotating in the plane $x0z$ at an angle θ.

Basing on the complex amplitudes values in the vertical and horizontal planes, we calculate the power values, the ratio of the semi-axes and the angle of the semi-major axis of the polarization ellipse of the reflected wave. We carry out our investigation at 256 points equally spaced on the interval of the length L = 200 mm. The segment lies on the axis of abscissas symmetrically to the origin. Upon decomposition signal approximating and detailing component using as Daubechies wavelet filter of the second order, the number of samples in a discrete representation of the signal is reduced by half. Procedure for wavelet packet decomposition is N-fold repetition of expansion of each of the previous step constituents. Since $256 = 2^8$, it is easy to estimate the dimension obtained by multiple expansion vectors.

We consider four kinds of bodies as scatterers. They are made of perfectly conducting thin wire: metal rod, metal ring, square frame and two perpendicular rod welded in the center. We assume that their characteristic geometric parameters (the rod length, the ring diameter, the length of the square, the length of crossing bars) are equal to 30 mm.

3. Solution of the diffraction problem

The electric field vector of the incident electromagnetic wave has two components (at the initial phase shift $\frac{\pi}{2}$ of one of them, for circular polarization):

$$\overline{E}^{inc} = \exp\left(-i\left(\overline{k}\overline{r}\right)\right)\cdot \overline{x}_0 , \tag{1}$$

$$\overline{E}^{inc} = \exp\left(-i\left(\overline{k}\overline{r}\right)\right)\cdot \overline{y}_0 , \tag{2}$$

Here are $\overline{k} = k\overline{z}_0$, $k = \frac{2\pi}{\lambda}$, $\lambda = 30\ \text{mm}$. Orths of coordinate axes are denoted as $\overline{x}_0$, $\overline{y}_0$, $\overline{z}_0$. Parentheses denote the operation of scalar multiplication.

The solution of the diffraction problem was obtained by the method of integral equations for the electric field (EFIE) [6, 7, 8, 9]. An incident electromagnetic wave excites the body surface current density. By virtue of the assumptions about the subtleties conductor, we neglect azimuthal and radial current components of and present the current in the form [10]:

$$\overline{J} = 2\pi bJ \cdot \overline{\tau} \tag{3}$$

where $\overline{\tau}$ is a unit vector of the body defined by its structure, it is tangent to the surface; b is the conductor radius.

Induced surface current excites the diffracted electromagnetic wave, which is given by:

$$\overline{E}^{scat}\left(\overline{r}\right) = \int_L \hat{P}\left(\overline{r},\overline{r}'\right)\overline{J}\left(\overline{r}'\right)dl' . \tag{4}$$

The operator kernel is a tensor:

$$\hat{P}\left(\overline{r},\overline{r}'\right) = \frac{Z}{ik}\left(\Delta\overline{r}\Delta\overline{r}^T f + k^2\hat{I}\right)g . \tag{5}$$

Here: $g = \frac{\exp(ikR)}{4\pi R}$ – the Green function of free space, $\Delta\overline{r} = \overline{r} - \overline{r}'$, $R = \left|\Delta\overline{r}\right|$, $f = \frac{3 + 3ikR - (kR)^2}{R^4}$, $\hat{I}$ – the unit tensor, $Z = 120\pi$ – impedance of free space.

The Dirichlet boundary conditions on the surface of an ideal conductor are represented in the convenient form

$$\left(\overline{\tau};\overline{E}\right) = 0 . \tag{6}$$

Here $\overline{E} = \overline{E}^{inc} + \overline{E}^{scat}$ is the total electric field vector.

Substituting expressions (3) and (4) into the boundary condition (6) gives the Fredholm equation of the first kind relatively the surface current

$$\left(\overline{\tau};\overline{E}^{inc}\right) + \left(\overline{\tau};2\pi b\int_a \hat{P}\left(\overline{r},\overline{r}'\right)\overline{\tau}'J\left(\overline{r}'\right)dl'\right) = 0 . \tag{7}$$

We rewrite (7) in a more convenient form for numerical calculations.

We calculate the components of the scattered electric field $\overline{E}_x$ and $\overline{E}_y$, reflected power P, the ratio of the polarization axes of the ellipse ξ, the angle of the semi-major axis of the x-axis ψ. The calculations are performed in the above 256 points.

Fig. 1 - 3 show the characteristics of the scattered electric field of the bodies. Removing size from the center of the body coordinate system starts from $h = 100$ mm, the rotation angle of the body $\theta = 0^0$.

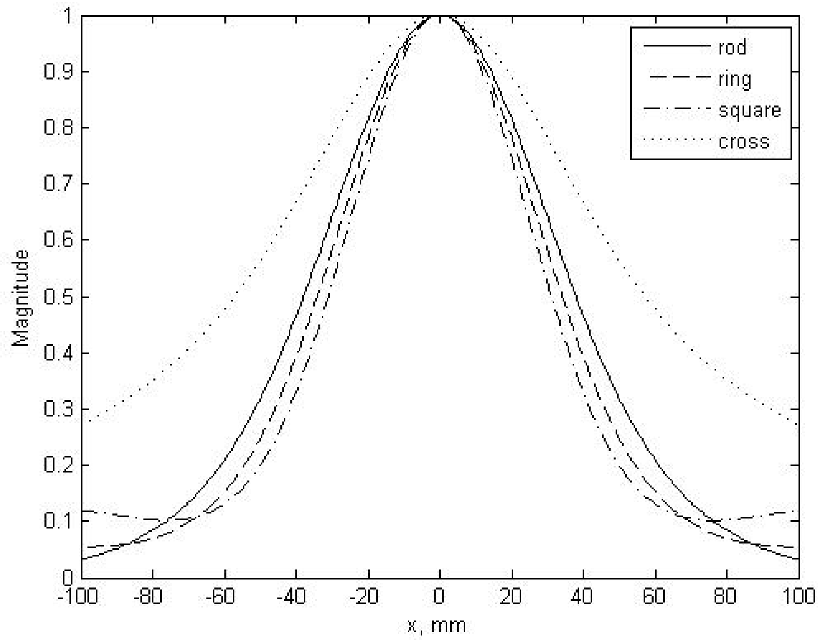

Fig. 1. Normalized amplitude of the scattered wave.

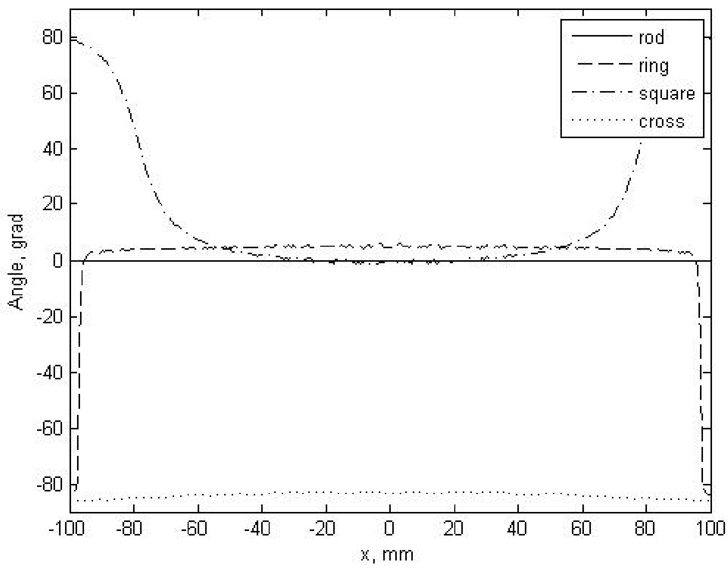

Fig. 2. The angle of inclination of the semimajor axis of the ellipse of polarization of the reflected wave.

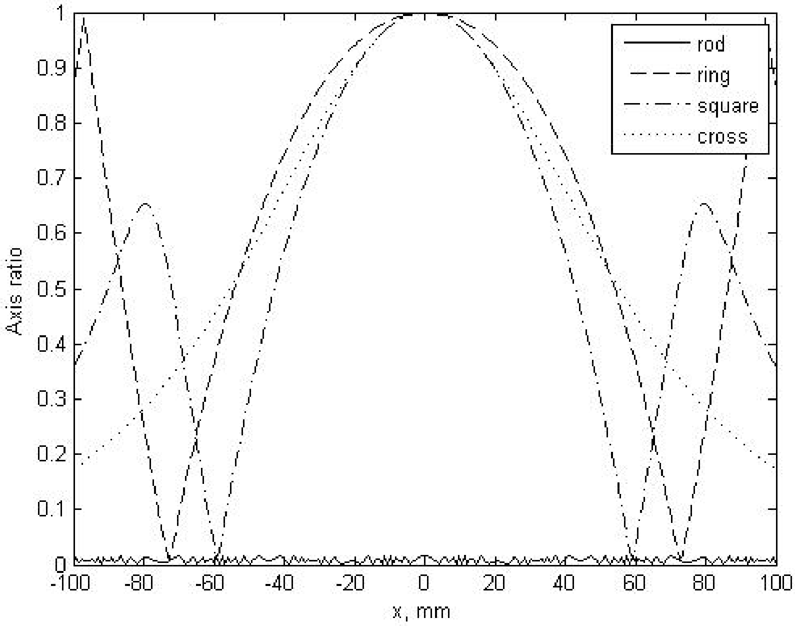

Fig. 3. The ratio of axes of the ellipse of polarization of the reflected wave.

3. Construction of the feature vector. The structure of the neural network

Detection was accomplished by the body parameters described above of the reflected wave. Thus, the power distributions produced by the normalization at its maximum value are performed. This procedure is used to detect body shape characteristics. This approach allows to reduce (but not eliminate) the impact of the volatility of the generator and power absorption in the medium.

Detection is performed by a body applied to the input of the neural network feature vector, which is obtained based on the calculated parameters. According to the theory of neural networks for the effective recognition of the dimension of the input vector must not exceed the value $10-15$ [2]. Note that these assumptions are only estimates and depend on the structure of the neural network and the available computing resources. Use of a feature vector composed of the 256×3 calculated values is not possible.

The preparation of the feature vector, which contains a sufficient amount of information for recognition, was performed with using a wavelet packet transform. Characteristics of the power distribution are expanded on the approximating and detailing components using Daubechies wavelet of the 2nd order. The consistent application of the procedure of multiple n expansions allowed reducing the original feature 2^n vectors. Dimensionality of the data vectors is $\frac{256}{2^n}=2^{8-n}$ [11, 12].

Calculated energy values (Shannon entropy) derived vectors, and selected the first five of its values. Note that the choice of the wavelet decomposition level and of the number of selected energy values is not straightforward. Determination of the optimal type and its values is an issue that needs special consideration.

Repeating the described characteristics of the distribution operations for axial ratio and inclination of the major axis of the polarization ellipse of the reflected wave also leads to the five energy values for each of the characteristics. The consistent association defines the values obtained-dimensional feature vector signal input to the neural network. In addition, reducing the dimension of the input vector of the present approach allows partially cutting little information of the signal components and increases its immunity.

To solve the problem of recognition, probabilistic neural network was used. The network consists of two layers (Fig. 4). The first hidden layer consists of 400 radial basis elements. The second layer comprises four neurons with linear transfer characteristic.

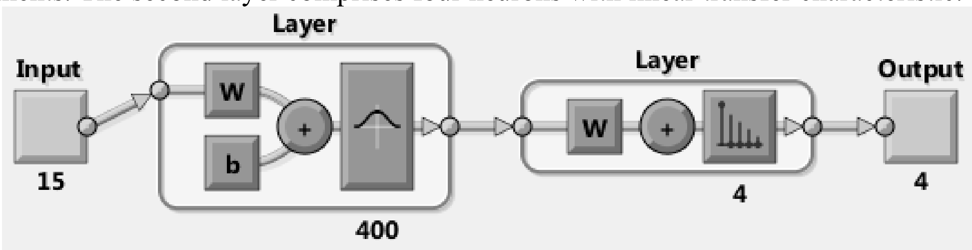

Fig. 4. The structure of the neural network.

Output vector is four-dimensional. Each of the outputs of the neural network of this type corresponds to one of the recognized classes of bodies. Thus, the decision on a particular class of lens accessories is based on an element of the output vector having the greatest value [2].

4. Training and testing the neural network recognition algorithm

To construct a training set, samples were chosen as follows: 10 of the parameter h in the range of 50 to 150 mm and 10 of the angle of rotation θ of the body in a range $0^0 \div 90^0$. For each case the calculated feature vector was defined according to the procedure described above. Trust is a four-vector, in which the only nonzero element is the one that corresponds to the considered body:

$$Y = \begin{pmatrix} 1 \\ 0 \\ 0 \\ 0 \end{pmatrix} \text{- for the rod; } Y = \begin{pmatrix} 0 \\ 1 \\ 0 \\ 0 \end{pmatrix} \text{- for the ring;}$$

$$Y = \begin{pmatrix} 0 \\ 0 \\ 1 \\ 0 \end{pmatrix} \text{- for a square frame; } Y = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 1 \end{pmatrix} \text{- for the skew rods.}$$

Thus, the training set consists of $10 \times 10 \times 4 = 400$ pairs of vectors.

When testing, the algorithm determines the probability of correct recognition of the body on the ratio of signal power to the noise power is carries out. Testing technique is as follows: for certain values of signal-to-noise randomly selected scattering body and parameters in the specified ranges. Values of vertical and horizontal components of the scattered electric field, to which is added a certain random signal power calculated. After calculating the dispersion characteristics determined a feature vector, which is input to the neural network. The network with maximum value of the signal provided the possibility to a particular class. This procedure is repeated once for each value of the ratio of signal power to noise power. The probability of correct recognition was estimated as a ratio of the number of correct results of the tests to the total number.

Fig. 5 shows the probability of the correct recognition of the body from the power ratio of the signal power to noise power.

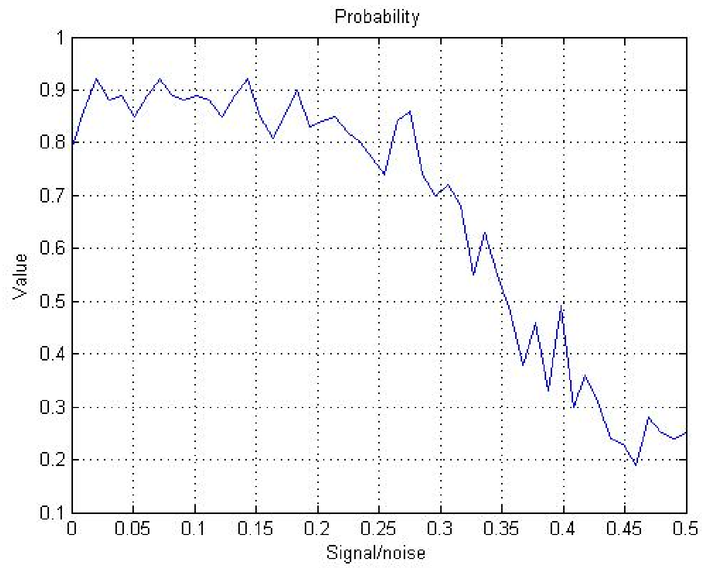

Fig. 5. Dependence of the probability of correct recognition of the level of the signal-to-noise.

Feature of statistical research method determines the characteristics of affectation curve in Fig. 5 [8]. The graph shows that the correct recognition of a body with a probability of about 80-90% is retained in the growth signal to noise ratio to around 20%.

5. Conclusions

The numerical solution of the problem of diffraction of a circularly polarized electromagnetic wave on the bodies of various configurations made of perfectly conducting wire is carried out. The diffraction problem is solved by the integral equation method. An algorithm for determining the feature vector with using wavelet packet transform is described. Probabilistic neural network is created and trained.

The methods described here show the possibility of correct recognition of a body from its backscatter characteristics. Thus, a high probability value is maintained when the additive noise power is present. This method can be developed for the case of electromagnetic wave scattering by bodies of other configurations that may be in a dielectric medium or behind the wall.

References

1. **Soldatova**, **O.P.** Application of the convolution neural network for recognition of handwritten digits [Text] / O.P. Soldatova, A.A Garshin // Computer Optics. – 2010. – Vol. 34, No. 2. – P. 252 – 259

2. **Haykin**, **S.** Neural networks: a complete course [Text] / S. Haykin. – Moscow: ID Williams, 2006. – 1104 p.

3. **Marigodov**, **V.K.** Recognition method of underwater objects / [Text] / V.K. Marigodov, G.A. Tikhonov // Herald SevNTU. – 2011. – Vol. 114. – P. 123 – 126.

4. **Zalewski**, **G.S.** Method of radar detection and identification of metal and dielectric objects resonant sizes located in a dielectric medium / [Text] / G.S. Zalewski, A.V. Musychenko, O.I. Sukharevskiy // Radioelectronics. – 2012. – Vol. 58, No. 8. – P. 28 – 43.

5. **Pang, Chee Meng.** Log-polar wavelet signatures for texture classification invariant to rotation and scale / [Text] / Chee Meng Pang, Moon Chuen Lee // IEEE Transactions on Patern Analysis and Machine Intellegence. – 2003. – Vol. 25, No. 5. – P. 132 – 141.

6. **Gibson, Walton C.** The Method of Moments in Electromagnetics [Text] / Walton C**.** Gibson.– New York: CRC, 2008. – 272 p.

7. **Volakis, John L.** Integral Equation Methods for Electromagnetics [Text] / John L. Volakis, Kubilay Sertel. – Ohio: Scitech, 2012. – 408 p.

8. **Sadiku, Mathew N. O.** Numerical Techniques in Electromagnetics [Text] / Mathew N. O. Sadiku.– New York: CRC, 2001. – 750 p.

9. **Colton**, **D.** Integral equation methods in scattering theory [Text] / D. Colton, R. Kress. – Moscow: Mir, 1987. – 311 p.

10. **Mitra**, **R.** Computational methods in electrodynamics [Text] / P. Mitra.– Moscow: Mir, 1977. – 487 p.

11. **Daubechies**, **I.** Ten lectures on wavelets [Text] / I. Daubechies.– Izhevsk: NITs "Regular and Chaotic Dynamics", 2001. – 464 p.

12. **Chui**, **Ch**. Introduction to Wavelets [Text] / Ch. Chui.– Moscow: Mir, 2001.– 412 p.

Received 06.04.2014.