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NEURAL NETWORK APPROACH TO SHAPE RECONSTRUCTION OF A CONDUCTING CYLINDER

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ABSTRACT

In this study, the shape reconstruction of a conducting cylinder by making use of electromagnetic scattered fields is presented. The problem is treated with the Method of Moment (MoM) and Feed Forward Neural Networks (FF-NN) is applied. The shape of the cylinder is represented by a Fourier series while applying MoM, a matrix equation is obtained whose elements are expressed numerically by using discrete points. The scattered field data and Fourier coefficients of the cylinder are used for training the NN as inputs and outputs respectively. The NN results are compared with exact shapes of some conducting cylinders; and good agreements with the original shapes are observed. The effect of the noise on the scattering field is also investigated.

Keywords: : *Inverse Electromagnetic Scattering, Shape Reconstruction, Neural Network*

1. INTRODUCTION

Direct and Inverse Scattering of electromagnetic waves is one of the main objects of electromagnetic theory and has considerable applications such as radar remote sensing or harmless imaging. Direct scattering problems investigate the scattered fields for some given object and an incident field. However, the aim of inverse scattering problems is to deduce object information, such as shape, electromagnetic parameters, and position from the scattered fields. Because of the fact that scattered fields can only be measured in a limited region of the space, solution of the inverse scattering problems is inherently ill-posed and non-unique, consequently, it requires regularizations and time consuming iterative algorithms [1]. Therefore, these techniques are not suitable for real time application. On the other hand, if a direct scattering problem is solved using any analytical or numerical methods for plenty of different situations, the data obtained can be used for training the neural network. Therefore, neural networks can be used for solving inverse scattering problems.

Recently, neural network based approaches have been applied to electromagnetic inverse problems for finding geometric and electromagnetic parameters of the scatterer under investigation [2-9]. Determination of the position and the radius of a conducting cylinder is investigated by using radial-basis functions NN that are constructed by using an orthogonal least square algorithm in [10]. The same problem is also solved by using Wavelet based radial basis functions NN in [11]. Because of the fact that an analytical relation is available between the scattered field and the investigated parameters which are the radius and the position of the

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center of the cylinder; the same problem can also be solved analytically.

On the other hand, to the best of our knowledge, none of the various methods suggested for the solution of the inverse problem using NNs is sufficiently general to obtain the shape of some cylinder of a general type; this scenario is depicted in Fig.1. In the following we will show that a general approach can be obtained. In this study, FF-NN is applied to determine of the shape of the conducting cylinder. The problem considered is depicted in Fig.1. The shape of the cylinder is expressed by a Fourier series. Then, scattered fields are expressed by using numerical MoM technique [12] for a plenty of different shapes. The data of the scattered fields and the Fourier coefficients are used for training the feed forward NN as inputs and outputs respectively. Once a set of feed forward NN is educated by training, it can be used to obtain the coefficients of a Fourier series of an object by making use of the measured values of the scattered field.

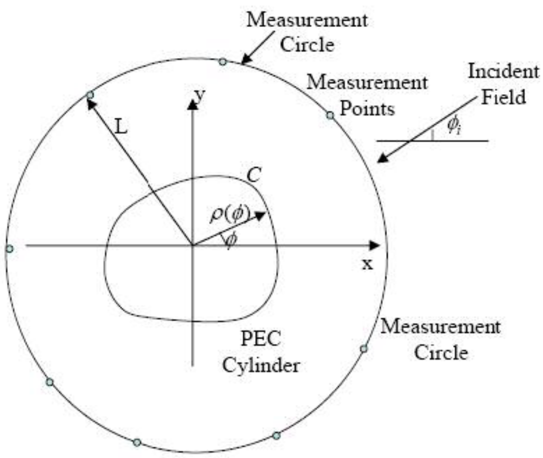

***Figure 1**. Geometry of the considered inverse scattering problem*

2. SOLUTION OF DIRECT SCATTERING PROBLEM

The problem considered is depicted in Fig.1. An arbitrarily shaped, infinitely long, conducting cylinder in free space is illuminated by a plane wave whose polarization is parallel to the cylinder axis (z axis). The shape of the cylinder can be expressed by means of a Fourier series as,

$$\rho(\phi) = \sum_{p=-P}^{P} a_p e^{ip\phi} \tag{1}$$

where a_p's are the Fourier coefficients satisfying $a_{-p} = a_p^*$ and are obtained by

$$a_p = \frac{1}{2\pi}\int_0^{2\pi} \rho(\phi) e^{-ip\phi} d\phi \tag{2}$$

The z polarized incident wave can be expressed as,

$$E_z^i(\vec{r}) = e^{i\vec{k}.\vec{r}} \tag{3}$$

where $\vec{r} = x\vec{u}_x + y\vec{u}_y$ is the position vector and $\vec{k} = -k(\sin\phi_i \vec{u}_x + \cos\phi_i \vec{u}_y)$ is the propagation vector of the incident wave with incidence angle ϕ_i and $k = \omega\sqrt{\varepsilon_0 \mu_0}$ is the wave number of the background medium. Due to the homogeneity of the cylinder with respect to the z axis, the total and the scattered electric fields also will be polarized parallel to the z axis. Therefore, the problem reduces to a TM case scalar problem in the *x-y* plane. The scattered and the incident field satisfy the conducting surface boundary condition as

$$E_z^i + E_z^s = 0\ . \tag{4}$$

The scattered field can be expressed by means of induced electric currents on the circumference C , by

$$E_z^s(\vec{r}) = \frac{-k\eta_0}{4}\int_C J_z(\vec{r}\,')H_0^{(1)}(k|\vec{r}-\vec{r}\,'|)ds(\vec{r}\,') \tag{5}$$

where $\eta_0 = \sqrt{\mu_0/\varepsilon_0} = 120\pi$ is the characteristic impedance of the free space. Substituting (5) into (4) and regarding that $\vec{r} = (\rho(\phi),\phi)$ on C, one gets an integral equation

$$E_z^i(\rho(\phi),\phi) = \frac{k\eta_0}{4}\int_C J_z(\phi')H_0^{(1)}(k\zeta)\xi d\phi \tag{6a}$$

where

$$\zeta = \sqrt{\rho^2(\phi) + \rho^2(\phi') - 2\rho(\phi)\rho(\phi')\cos(\phi-\phi')} \tag{6b}$$

$$\xi = \sqrt{\rho^2(\phi) + \rho'^2(\phi)} \tag{6c}$$

In order to solve (5), point matching MoM technique can be applied. The counter C is divided to N subparts and the integral equation is converted to a matrix equation as,

$$AJ = B \tag{7}$$

where the elements of J represent the discrete electric currents, which are assumed to exist on the sections of the counter C. The elements of the matrix A are defined as

$$a_{mn} = \begin{cases} \dfrac{k\eta_0}{4}\tau_n H_0^{(1)}(k(\chi_{mn}))\Delta\phi, & m \neq n \\ \dfrac{-k\eta_0}{4}\tau_n (1+\dfrac{2i}{\pi}\ln(\dfrac{\gamma k \Delta\phi \tau_n}{e}))\Delta\phi, & m = n \end{cases} \tag{8a}$$

$$\chi_{mn} = \rho^2(\phi_m) + \rho^2(\phi_n) - 2\rho^2(\phi_m)\rho^2(\phi_n)\cos(\phi_m - \phi_n) \tag{8b}$$

$$\tau_n = \sqrt{\rho^2(\phi_n) + \rho'^2(\phi_n)} \tag{8c}$$

where e=2,718.. and γ=0,5772 is Euler's constant and $\Delta\phi$ is the angular discretization size. The elements of the incident field matrix B are

$$b_m = E_z^i(\sum_{p=-P}^{P} a_p e^{ip\phi_m}, \phi_m) = e^{-ik(\sum_{p=-P}^{P} a_p e^{ip\phi_m})\cos(\phi_m - \phi_i)} \tag{9}$$

From (7) one gets the unknown electric current matrix J as,

$$J = A^{-1}B\,. \tag{10}$$

Once the boundary integral equation (6) is solved the fields of the scattered wave at any position can be calculated through (5) by using the discrete electric currents as,

$$E_z^s(r,\phi) = \frac{-k\eta}{4}\Delta\phi\sum_{n=1}^{N} J_n H_0^{(1)}(k\theta_n)\tau_n \tag{11a}$$

where

$$\theta_n = \left|\sqrt{r^2 + \rho^2(\phi_n) - 2r\rho(\phi_n)\cos(\phi - \phi_n)}\right| \tag{11b}$$

It is obvious that scattered field depends on the Fourier coefficients of counter which describes the shape of the counter. The direct scattering problem is solved for different counter each of which has a different Fourier coefficients sets. Then the scattered field data set which is obtained for finite number points calculated finite points are obtained.

3. SOLUTION OF INVERSE SCATTERING PROBLEM BY USING NNs

The shape of the object can be reconstructed by using NN with a sufficient number of scattered field measurements obtained on the measurement circle which contains the cylinder (see Fig.1). Scattered field measurements on the circle can be given as,

$$E_z^s(L,\phi_m) = \frac{-k\eta}{4}\Delta\phi\sum_{n=1}^{N} J_n H_0^{(1)}(k\theta_L)\tau_n, \quad m = 1,2,...,M \tag{12a}$$

where

$$\theta_L = \left|\sqrt{L^2 + \rho^2(\phi_n) - 2L\rho(\phi_n)\cos(\phi_m - \phi_n)}\right| \tag{12b}$$

where L is radius of the measurement circle, and M is the number of the measurement points. FF-NN is trained by using the M calculated scattered fields as inputs and Fourier coefficients of the counter (5) as outputs. The training process is depicted in Fig.2. To test the sensitivity of the method, scattered fields, which are not in the training set, are applied to NN, and the shape described by NN outputs are compared to the exact shapes of the counters which produce the scattered fields. Effect of the noise on the performance of the NN can also be investigated by adding Gaussian noise to the scattered field measurements. In this case, signal to noise ratio (SNR) is given by

$$SNR = 10\log\frac{\sum_{m=1}^{M}\left|E_z^s(L,\phi_m)\right|^2}{2M\sigma^2} \tag{13}$$

where σ^2 is variance of Gaussian noise.

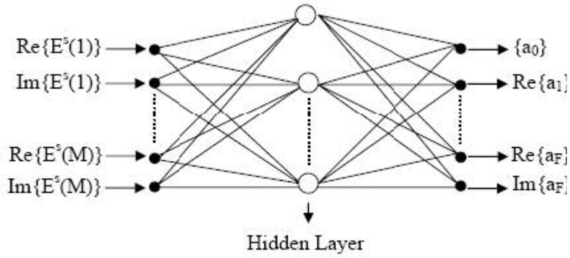

Figure 2. *Architecture of the FF-NN using the scattered electric-field values as input*

4. NUMERICAL RESULTS

The proposed method has been applied to three illustrative cases. In all cases, frequency is chosen as f=33 MHz and the angle of incidence $\phi_i = 0^0$. Levenberg-Marquardt back propagation algorithm [13] is used to training the FF-NN. The scattered electric field is measured at 10 position (M=10) on the measurement circle with L=100 λ radius and the intervals are chosen as having equal angular intervals. The shape of the cylinder is expressed with Fourier coefficients (F=5). Thus, the architecture of NN has 20 components as input (10 real and 10 imaginary), while its output has 9 components (5 real and 4 imaginary). The region of interest is chosen as, $2 \le \rho(\phi) \le 6$. 30 nodes are used in the hidden layer of the NN architecture (Fig. 2). A vector set of 200 elements is used to train the NN. Scattering electric fields are applied to the input of the NN as measured values. Then the output Fourier coefficients of the shape, is obtained. In order to demonstrate the performance of this approach, noisy measurements with SNR=30 and SNR=20 are applied to the NN. Thus the obtained shapes are compared with the exact shapes which produce noiseless measurement data. Reconstructions of the counters are obtained by substituting Fourier coefficients into the Fourier series.

In Fig.3, Fig.4, Fig.5 exact shapes are compared with the ones which are reconstructed by NN for SNR 30 and 20 dB.

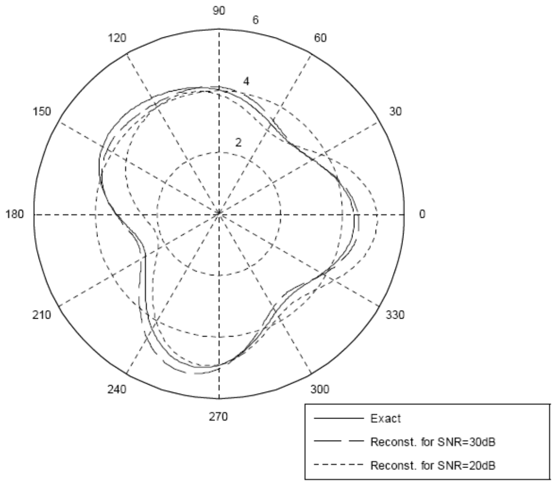

Figure 3. *Comparison of exact shapes of object with MOM, FF-NN results.*

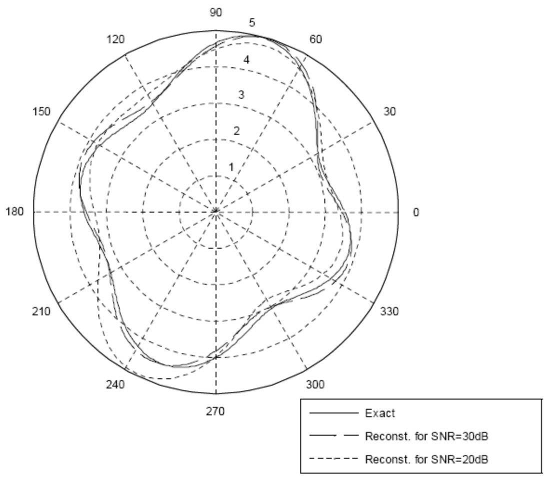

Figure 4. *Comparison of exact shapes of object with MOM, FF-NN results.*

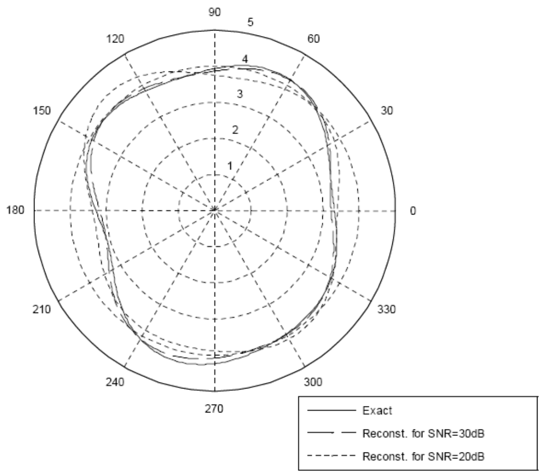

Figure 5. *Comparison of exact shapes of object with MOM, FF-NN results.*

As one observes from Fig.3, Fig.4 and Fig.5, NN results are consistent with the exact shapes.

5. CONCLUSION

In this study, the shape reconstruction of a conducting cylinder from electromagnetic scattered fields is investigated by using FF-NN. The direct scattering problem is solved by point matching MoM for different shapes of conducting cylinders. The results obtained are used for training and testing the NN to solve the inverse problem. The accuracy of our numerical solutions is assessed by comparing our results with noisy data. Effect of the noise on the performance of NN is investigated. As it can be seen from Fig.3- Fig.5, if SNR increases, NN results approach the exact results as expected. More complicated shapes of conducting cylinders can be expressed by considering more Fourier coefficients. In this case, in order to obtain the desired accuracy, more numbers of training sets and more measurement points must be used to train the NN. A similar method can be applied to three dimensional objects for the determination of electromagnetic parameters of the object as well. It can be concluded that the proposed method is quite flexible and can easily be modified to address problems involving more general types of inverse electromagnetic scattering. We believe that this approach may effectively be used for the shape reconstruction of objects.

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