Detection of Discontinuities in the Samples of Changing Sizes with ANN-based Technique

A. V. Brovko
Yuri Gagarin State Technical University of Saratov, Russia

Abstract— The problem of non-destructive evaluation and testing of dielectric samples of changing sizes is considered. The method is based on the application of the artificial neural network, which takes into account not only parameters of discontinuities in the samples, but also sizes of sample. Performance of different measurement systems is explored numerically, and conclusions about possible precision of parameters reconstruction are formulated.

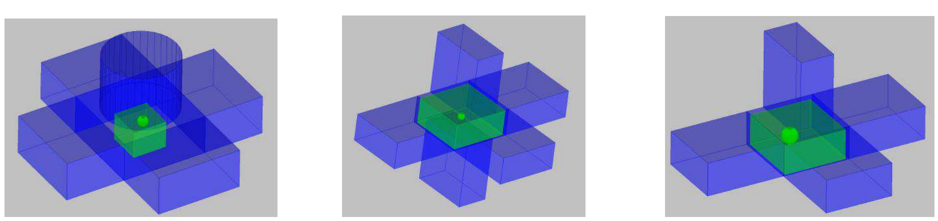
1. INTRODUCTION

Detection of discontinuities in dielectric samples using microwave imaging is an important part of non-destructive evaluation and testing technology. Recently, the technique of detection of a spherical inclusion in homogeneous dielectric sample has been proposed [1]. The technique is based on application of artificial neural network (ANN) as numerical inverter, which is trained with numerical modeling data, and after training the ANN may be applied for reconstruction of the inclusion parameters using physical measurement results. Advantages of the approach described in [1] include simple measurement technique and possibility to work with closed measurement waveguide system. However, the technique is limited to the case of constant sizes of dielectric sample. Variations of sizes may destroy completely the procedure and corrupt the results. Moreover, the technique described in [1] requires changing of the positions of sample inside measurement system in the course of measurement, which is not convenient for practical implementation.

In this paper, the attempt to overcome the limitations of technique, described in [1], is undertaken. The sizes of sample are included into a set of parameters which are reconstructed using ANN. In order to provide more input information for ANN to reconstruct the extended set of parameters, different multiport measurement systems are investigated in this paper, namely, turnstile waveguide junction, and junctions of four and five rectangular waveguides.

2. METHOD

The technique of reconstruction of the parameters of discontinuity in dielectric sample, based on application of a section of rectangular waveguide as measurement system, was proposed in [1]. Here the approach in general follows to one described in [1], but it requires some changes in order to overcome limitations of the technique. Firstly, the linear sizes of the sample may be included into the set of output parameters of the ANN. So, the ANN, after appropriate training, is able to reconstruct not only the parameters of discontinuity in the sample of changing sizes, but also the sizes of sample itself. However, this approach does not work with simple measurement system like a section of rectangular waveguide providing just reflection and transmission coefficients at two ports as measurement data. In this paper, three types of measurement system considered, as shown in Fig. 1.



(a) (b) (c)

Figure 1: Measurement systems for reconstruction of the parameters of discontinuity in the dielectric sample: (a) turnstile junction, (b) five-port junction of rectangular waveguides, and (c) four-port junction of rectangular waveguides.

All the systems depicted in Fig. 1 are multiport waveguide junctions, so they can provide more measurement data (full S-matrix of multiport junction), which can be used for reconstruction.

Reconstruction of the parameters of discontinuity in the dielectric sample is performed with ANN. The architecture of ANN corresponding to turnstile junction (Fig. 1(a)) is shown in Fig. 2. Inputs of the ANN are full S-matrix of the six-port turnstile junction (36 complex values or 72 real values). Outputs of the ANN are the coordinates and radius of spherical discontinuity, and also linear sizes of the sample.

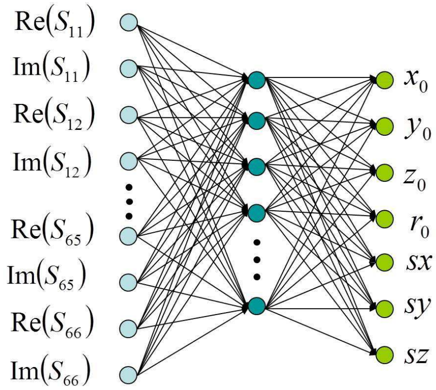


Figure 2: ANN architecture for the case of application of the turnstile junction (Fig. 1(a)) as a measurement system.

In the case of five- and four-port junction of rectangular waveguides (Figs. 1(b) and 1(c)) the number of inputs are 50 real values and 32 real values respectively.

Mathematics behind ANN operation is the same as in [1]. The difference is only in the number of input and output parameters. The ANN is trained using the results of direct numerical modeling of the measurement system with full-wave electromagnetics simulation software QuickWave-3D [2]. After appropriate training the ANN is able to reconstruct the parameters of discontinuity in the sample using measured S-parameters of the electromagnetic system.

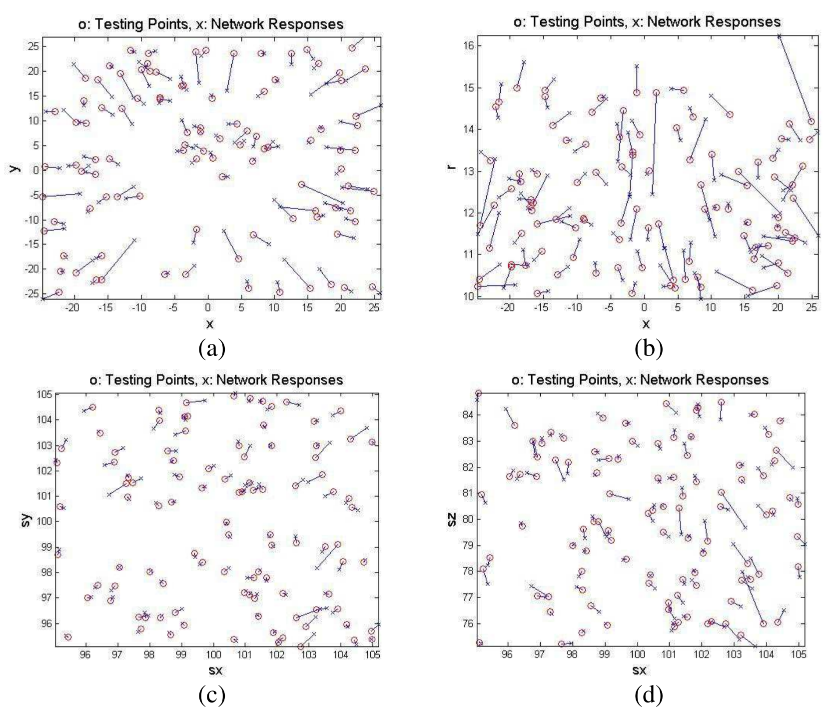


Figure 3: ANN performance in reconstruction of coordinates and radius of spherical inclusion (a), (b), and sizes of dielectric sample (c), (d). Number of ANN training points: 3500; number of testing points: 100.

3. RESULTS

The results obtained with turnstile junction of waveguides are illustrated in Fig. 3. The parameters of the measurement system were the following: cross-section of the rectangular waveguides 248×124 mm, radius of the circular waveguide 107.57 mm. The sample has linear sizes in the range $95 \div 105$ mm along Ox and Oy axes, and $75 \div 85$ mm along Oz axis. Permittivity of the sample was $\varepsilon' = 2.0$, $\varepsilon'' = 0.0$.

In the case of constant permittivity of the spherical discontinuity ($\varepsilon' = 6.0$, $\varepsilon'' = 0.0$) the coordinates of the sphere are reconstructed with absolute error $1.5 \div 2.3$ mm, radius is reconstructed with average error 0.4 mm (for some points the error may be up to 2 mm), and the error in reconstruction of the sample sizes is in the range $0.3 \div 0.7$ mm (for some points up to 2 mm). In the case of constant radius and changing permittivity of the sphere the error in coordinates is in the range $1.3 \div 2.5$ mm, the average error in permittivity reconstruction is 0.86. In the case of changing parameters of both radius and permittivity of the spherical inclusion, the errors become unacceptably large.

The results obtained for five-port junction of rectangular waveguides (Fig. 1(b)) are similar to those for turnstile junction. In the case of constant permittivity and changing radius of the sphere, the error in the reconstruction of coordinates is in the range $2.7 \div 8.6$ mm, average error in reconstruction of the radius is 0.52 mm, average error in reconstruction of sizes of the sample is 0.2 mm. In the case of constant radius and changing permittivity of the sphere, the error in the reconstruction of coordinates is in the range $1.2 \div 3.3$ mm, average error in reconstruction of the permittivity is 0.8, average error in reconstruction of sizes of the sample is 0.64 mm.

The results, obtained for four-port junction (Fig. 1(c)) of rectangular waveguides, lead to conclusion that four-port junction does not provide sufficient amount of measurable data for the reconstruction of discontinuity parameters in the sample with changing sizes. The errors of reconstruction are unacceptably large in the cases of changing radius or permittivity of the sphere.

4. CONCLUSION

In this paper, the modification of ANN based technique for reconstruction of the parameters of the spherical inclusion in the dielectric sample with changing sizes has been presented. The technique permits reconstruction not only for spherical inclusion parameters, but also is able to reconstruct actual sizes of the sample. Performance of the technique with three types of electromagnetic measurement system has been demonstrated. The turnstile junction and five-port junction of rectangular waveguides are able to provide reconstruction of sphere coordinates with relative error 1.5%–10%, reconstruction of radius of the sphere with relative error 3%–7%, reconstruction of sphere permittivity with relative error 7%–16%. Practical implementation of the technique may require development of commutation scheme for the measurement system in order to obtain full S-matrix of the junction.

REFERENCES

1. Brovko, A. V., E. K. Murphy, M. Rother, H. P. Schuchmann, and V. V. Yakovlev, "Waveguide microwave imaging: Spherical inclusion in a dielectric sample," *IEEE Microwave & Wireless Components Lett.*, Vol. 18, No. 9, 1234–1237, 2008.
2. QuickWave-3DTM, QWED Sp. z o.o., ul. Nowowiejska 28, lok. 32, 02-010 Warsaw, Poland, http://www.qwed.com.pl/.