

Microwave Imaging in Closed Cavities — Locating Spatial Inhomogeneities of Dielectric Objects

Alexander V. Brovko¹, Ethan K. Murphy², Matthias Rother³,
Heike P. Schuchmann³, and Vadim V. Yakovlev²

¹Department of Applied Information Technologies, Saratov State Technical University
Saratov 410070, Russia

²Department of Mathematical Sciences, Worcester Polytechnic Institute
Worcester, MA 01609, USA

³Institute of Life Sciences, University of Karlsruhe (TH), Karlsruhe 76131, Germany

Abstract— Detection of inhomogeneities in dielectric materials is required in many practical applications; these include reconstruction of voids inside concrete structures or bricks, detection of defects in wood slabs and in composite panels, detection of porosity in ceramics and molded rubber, monitoring of inhomogeneities in food products, etc. One of possible techniques for its solution is microwave (MW) imaging [1]. The recent advances in the theory and solution techniques for inverse problems in free space (see, e.g., [2]) has inspired substantial progress of MW imaging in open space despite the fact that corresponding experimental implementations of practical techniques of non-destructive evaluation and testing (NDE/NDT) are typically quite complicated. In terms of measurements, MW imaging in closed systems may be simpler and provide high accuracy of measurements [3], however, the techniques of NDE/NDT of materials by the waveguide/resonator fields have not received an in-depth consideration so far — in part, likely due to substantial complexity of theoretical aspects of the related inverse problem.

In this contribution, we present an extension of our original technique [4] for the detection of a position and a size of an object in a dielectric sample placed in a waveguide. The technique relies on an artificial neural network used for the numerical inversion of the problem and reconstruction of geometrical parameters of the tested object. It requires only elementary measurements of complex reflection and transmission coefficients. A direct scattering problem is solved with the use of full-wave 3D FDTD analysis; corresponding numerical data are employed for network training and testing. Here we explore the applicability of this technique introduced in [4] for spherical inclusions to diverse combinations of materials (low and high contracts) and alternative shapes. Required numerical data are obtained with the 3-D conformal FDTD simulator *QuickWave-3D* [5].

We present the numerical results for detection of an inhomogeneity in an object for:

- (1) a glass sphere in a rectangular Teflon block,
- (2) an air sphere in a rectangular Teflon block,
- (3) a sphere of unfrozen raw beef in a rectangular block of frozen raw beef, and
- (4) a sphere of frozen raw beef in a rectangular block of unfrozen raw beef.

Our computational experiments with the WR975 (248 × 124 mm) waveguide show that, at 915 MHz, the sizes and position of the glass and air spheres of more than 15 mm diameter are detected with the average error of 0.9–2.2%. The cases involving raw beef are more complex due to the significantly larger loss factor of the unfrozen beef. However, our technique allows for reconstructing, with an acceptable accuracy and for a reasonable computational cost, the unfrozen spheres of more than 12 mm diameter and the frozen spheres of more than 40 mm diameter. Finally, it is shown that the method can also be straightforwardly adjusted to the scenarios of reconstruction of inclusions of other (e.g., cylindrical, ellipsoidal, etc.) shapes.

REFERENCES

1. Zoughi, R., *Microwave Testing and Evaluation*, Kluwer, Amsterdam, 2000.
2. Colton, D. and R. Kress, *Inverse Acoustic and Electromagnetic Scattering Theory*, Springer, Berlin, 1998.
3. Meyer, T., A. Jostingmeier, and A. S. Omar, “Microwave imaging using a novel regularization scheme,” *Proc. IEEE AP-S Intern. Symp.*, Vol. 3, 175–178, Jun. 2003.
4. 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 and Wireless Comp. Lett.*, Vol. 18, No. 9, 647–649, 2008.
5. *QuickWave-3D*, QWED Sp. z o.o., Warsaw, Poland, 1998–2009 <http://www.qwed.com.pl/>.