MICROWAVE IMAGING: NUMERICAL SIMULATION AND RESULTS

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ABSTRACT

The feasibility of using the linear reconstruction techniques in microwave imaging is examined numerically using the method of moments. Images of phantoms simulating biological objects are obtained using the algebraic reconstruction technique. The obtained resolution and sensitivity are discussed.

Introduction

In recent years, there have been extensive efforts directed towards developing the X-rays, ultrasonic, and nuclear magnetic resonance imaging techniques [1, 2]. Significant progress toward reducing the data collection time and improving the resolution has been achieved. It is generally recognized, however, that microwave (MW) imaging has several advantages over other imaging techniques. Of particular interest is the superior sensitivity of the MW medical diagnostic techniques, especially in applications involving soft tissues such as lungs [3], where ultrasound is highly attenuated and dispersed, and X-ray techniques have low sensitivity. MW imaging also lends itself to possible use in continuous monitoring because it requires only low-level and thus less hazardous radiation [4].

The development of the MW imaging, however, is still in its preliminary stages basically because of the difficulties involved in developing adequate imaging algorithms [5]. These difficulties occur because the paths between the microwave transmitter and the receivers are object-dependent and not always nearly straight lines, as is the case for X-ray beams. Therefore, the coordinates of these paths are not known in advance and can be determined only after identifying the spatial distribution of the complex permittivity. This simply means that nonlinear extensions of the presently available imaging algorithms are generally required for the MW imaging, the matter which severely limited the progress in this area.

In this paper we first demonstrate the feasibility of using linear reconstruction algorithms in MW imaging. Then we present some calculated MW images of phantoms simulating biological objects. These images were obtained using the algebraic reconstruction technique (ART) which was originally used in X-ray and ultrasound computerized tomographic imaging.

Numerical Procedure and Results

First, to illustrate the feasibility of using linear reconstruction algorithms in MW imaging, a two-dimensional cross-section image of the thorax was obtained using the computerized axial tomographic (CAT) X-ray scanner. The electromagnetic field problem which involves determining the received signal on the periphery of the thorax as a function of the transmitter location is then solved by digitizing the cross-section of the thorax and using the method of moments. The maximum size of the mathematical cells in the digitized cross section was kept smaller than $0.2\ \lambda_o/\sqrt{\varepsilon_r}$ where λ_o is the free space wavelength and ε_r is the relative permittivity of the cell [6]. Numerical results clearly showed that by moving the transmitter around the body, the region of maximum attenuation, shadow region of the heart, moves correspondingly. This simply indicates that it is possible to use the linear reconstruction algorithms for MW imaging [7].

Having arrived at this conclusion, we computed MW images of phantoms simulating biological objects. These images were obtained using ART. The phantom geometry used in our calculations consists of a cylindrical object of 6 cm diameter (region A in Fig. 1a)

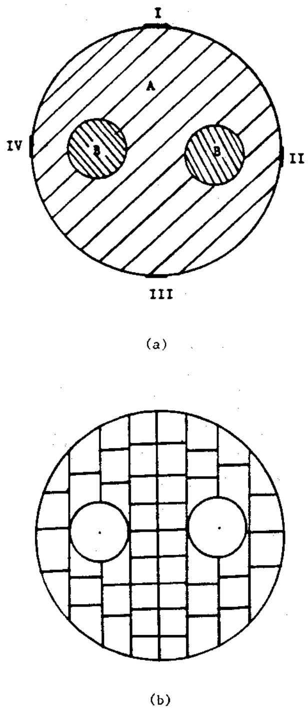

Fig. 1. (a) Schematic diagram illustrating the phantom geometry used in the calculations; (b) the digitized cross section used in the MW calculations using the method of moments.

which surrounds two smaller circular cylindrical tubes each of 1.6 cm diameter (region B in Fig. 1a) and separated by a distance d. Regions A and B consist of materials of different complex permittivities $\varepsilon^*_{A,B} = \varepsilon'_{A,B} + j\varepsilon''_{A,B}$, which are varied to allow separate examination of sensitivity and the resolution of the MW images. The projection data to be used in the reconstruction by ART are computed using the method of moments program described elsewhere [7]. In particular, for a given location of the MW transmitter, we calculated the received electric field at the periphery of the object and use the magnitude of the electric field as a projection for the ART reconstruction. For the reconstruction purposes, the cross section of the phantom in Fig. 1a was divided into a 12 x 12 square pixel grid, each pixel of size (0.5 x 0.5) cm^2.

To investigate the resolution of the MW images, two phantoms were examined. In the first phantom, the distance d between regions B was taken to be 0.05 λ, where $\lambda = \lambda_o/\sqrt{\varepsilon_A}$, λ_o is the free space wavelength at 400 MHz, while d was 0.1 λ in the other phantom. In both cases, however, ε_A^* was 34 + j42, which is the average complex permittivity of the human body at 400 MHz, while ε_B^* was taken to be equal to that of free space, i.e., $\varepsilon_B^* = 1 + j0$. The difference in the permittivity values ε_A^* and ε_B^* was chosen to be large enough to avoid the blurring of the image that would be expected from closer values of ε_A^* and ε_B^*. Such blurring would obviously interfere with the determination of the resolution. The images obtained for both phantoms are shown in Fig. 2. Both images clearly

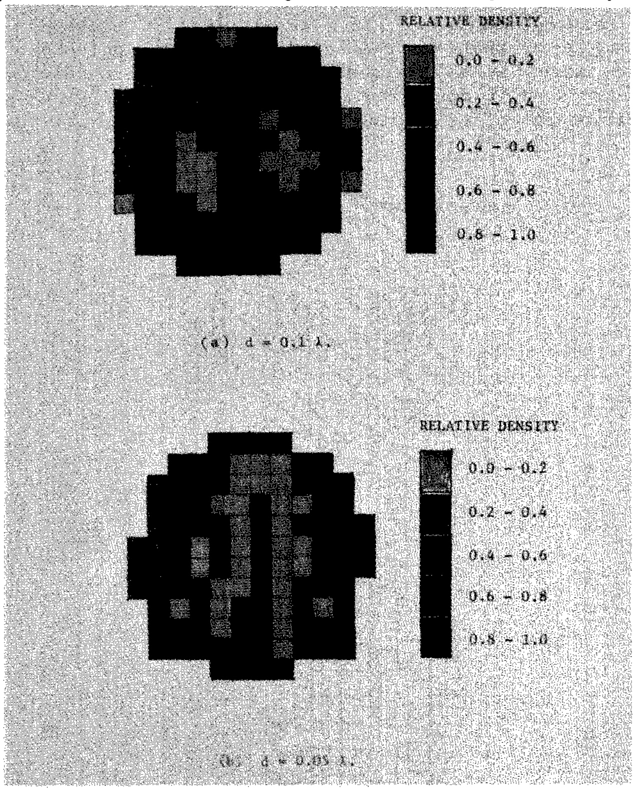

Fig. 2. Images illustrating the resolution of the MW imaging procedure. In both cases we used four projections, four iterations, and with $\varepsilon_A^* = 34 + j42$, $\varepsilon_B^* = 1 + j0$.

depict the presence of a highly attenuating object surrounding a medium of low attenuation (indication of air), but the two separate air-filled cylinders can be distinguished only for the larger separation, d = 0.1 λ, and not for the smaller separation, d = 0.05 λ. This simply suggests that the MW imaging using linear reconstruction algorithms is capable of resolving distances as small as 0.1 λ.

The sensitivity of the microwave images obtained using ART and, in particular, the potential use of such reconstruction procedure in medical radiology were also investigated. In this case, we obtained images for the phantom geometry shown in Fig. 1a, with the permittivities ε_A^* and ε_B^* taken to be equal to those of muscle and lung tissues, respectively. While keeping the distance d = 0.1 λ and $\varepsilon_A^* = 63 + j31$, we specifically examined two cases of different values of ε_B^* which represent the lung. In the first case we took $\varepsilon_B^* = 21 + j13$, which is equal to that of normal lung at 400 MHz [8], while in the other case, $\varepsilon_B^* = 34 + j31$, which is the value usually considered for lung tissue with edema [8]. The images obtained in both cases are shown in Fig. 3, from which it is clear that the two separate circular objects (region B) are distinguishable only when ε_B^* is equal to that of a normal lung. This emphasizes that the previously stated resolution of 0.1 λ is only possible if the images involve regions with relatively large differences in permittivity.

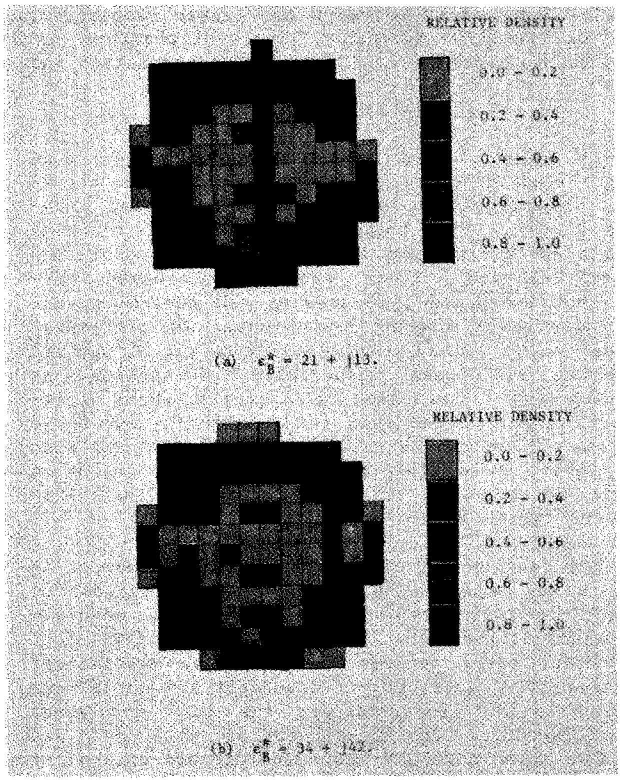

Fig. 3. Images illustrating the sensitivity of the MW imaging procedure. In both cases we used four projections, four iterations, with d = 0.1 λ and $\varepsilon_A^* = 63 + j31$.

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