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ABSTRACT

A cylindrical system for biomedical microwave tomography is presented. The circular algorithms and some numerical reconstructions are discussed. Finally the experimental set-up is described and some preliminary measurements are presented.

INTRODUCTION

Recent studies [1], [2] have shown the potential value of active microwave imaging systems for biomedical applications. They have specific characteristics of penetration and sensitivity with respect to other types of illuminations of interest. In particular they can be useful for the reconstruction of temperature profiles [3] in hypertermia and in the domain of functional imaging [4]. Operating frequencies of the order of a few gigahertz result from a compromise between resolution and attenuation [5].

Until now experiments have been conducted at 3 GHz on isolated animal organs and have confirmed that resolutions of the order of 6mm can be reached in high water-content media. The geometries used, basically linear and planar, require a mechanical rotation around the object.

At present, efforts are made directed to improving the geometry, the illumination, the receivers and the focusing algorithms. In this line this paper presents a original compact cylindrical solution with the intrinsic advantages:

- a) The encircling characteristic of the array avoids the need of a mechanical rotation and improves the resolution characteristics.
- b) Due to the symmetry of the geometry, an algorithm with an angular periodicity can be used.
- c) Due to the water attenuation, a circular curve is more adapted to the diffraction process.

IMAGING BY MEANS OF CIRCULAR ARRAYS

We shall restrict our attention to objects whose properties vary only over the x-y plane. We will also assume that the object is illuminated by a cylindrical wave, constant along the Z direction. With the Born approximation we can define the object profile as:

$$O(x,y) = 1 - \frac{\epsilon_1(x,y)}{\epsilon_m} \quad (1)$$

where ϵ_1 and ϵ_m are the complex permittivities of the object and the surrounding medium respectively.

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For a circular array of N elements where each one acts sequentially as emitter when the others $N-1$ act as receivers, with a reciprocity theorem formulation [6], [7] we can write:

$$\text{FT } \{O(x,y)\} = \frac{4j}{k^3 \eta} \int_0^{2\pi} \psi^{(s)}(\sigma; \sigma_0) F_R(\chi - \sigma) F_R(\chi_0 - \sigma_0) d\sigma d\sigma_0 \quad (2)$$

$$F_R(\chi - \sigma) = \frac{1}{2\pi} \sum_{n=-N/2}^{N/2-1} \frac{j^{-n}}{H_n^{(2)}(kR)} e^{jn(z-\sigma)} \quad (3)$$

where $\psi^{(s)}(\sigma; \sigma_0)$ is the scattered field by the object for each position σ_0 of the emitter and each position σ of the receiver, figure 1. These expressions can be implemented basically with FFT algorithms.

The contrast sensitivity of the system is measured by computing the ratio of the maximum to the minimum object level that is discriminated from the average image noise. For our cylindrical system we have obtained a theoretical contrast ratio of 34 dB, figure 2. Figure 3.a shows the numerical reconstruction of an arm phantom in the Born case, and figure 3.b shows the numerical reconstruction for the real case (no Born assumption).

DESCRIPTION OF THE EXPERIMENTAL SET-UP

A general view of the experimental set-up is shown in figure 4. The object under test is immersed in a cylindrical water tank surrounded by the circular array antenna. Water immersion is particularly convenient to reduce reflexion losses at the surface of the organs and to eliminate parasitic reflexions due to the organ environment.

The array consists of a 20 cm diameter circular horn, feed by 64 guides where each one can work in emission and reception controlled by two sets of RF multiplexers. A double LF modulation is used to mark the emitter and receiver element and to improve the sensitivity with a final LF coherent detection.

A CW signal, in the 2-4 GHz band, is provided by an oscillator followed by a 1 watt amplifier. On account of the limitation of the incident power density at a value smaller than 1 mw/cm² (in order to avoid any thermal effect) a L.N.A. (F= 2dB) followed by a RF coherent detector [8] is used in the receiver chain.

Image reconstruction is calculated on a 32 bits minicomputer HP 9050 by means of FFT algorithms and represented on a high resolution colour display.

DISCUSSION AND RESULTS

The reconstructed images appear as the convolution product of the object profile by the point response of the system. This point response is a basic quality parameter of the system. The initial results show, figure 5, that for a circular array it is possible to achieve a more symmetrical resolution and lower sidelobes level, than for the planar case.

The Born approximation used in the formulation presented, is not exact for a real biological organ, but it is more suitable for a differential mode (one image is obtained by difference of two successive reconstructions) used in a functional imaging case as the temperature variation reconstruction. For this application we can obtain a temperature resolution better than 1°C for a 6mm cube with a measurement time of the order of one image per second. Total processing time is the order of 2 seconds for a 128x128 pixels image.

CONCLUSION

The preliminary results show the potentiality of a cylindrical system for its encircling characteristics and contrast sensitivity. Further research must be done for the no-Born reconstruction algorithms applying in the biological case, and for the search of a liquid medium matched to the biological bodies with less losses than water.

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Figure 1 Tomographic configuration. Object domain and spectral domain

Fig. 2 Contrast sensitivity. Six objects with relative levels: 100,50,25,10,5,2
Tridimensional plot and contour levels.

Fig. 3 Numerical reconstructions of an arm phantom

- (a) Lossless medium imaging (transmission and reflexion)(Born)
- (b) Lossy medium imaging (transmission)(Born)
- (c) Lossy medium imaging (transmission)(no Born assumption)
- (d) Born equivalent current distribution.

Fig. 4 Experimental set-up

Fig.5 Impulse response for the presented geometry, circular array of 15λ diameter (20 cm, $f=2.45$ Ghz), with 64 antennas.

Reconstruction of 4 cylinders spaceds 4λ ($\lambda=1.39$ cm)