Hemorrhagic Brain Stroke Detection by using Microwaves: Preliminary Two-dimensional Reconstructions

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Abstract—**Preliminary numerical results concerning the application of a Gauss-Newton method for diagnostic purposes of hemorrhagic brain strokes are reported. Interrogating microwaves are used in a multistatic and multiview arrangement. The reported results concern a two-dimensional model under transverse magnetic illumination conditions.**

I. INTRODUCTION

One of the most interesting applications of electromagnetic fields in the biomedical area concerns the development of noninvasive diagnostic systems and techniques [1]-[4]. The retrieval of breast tumors represents a significant example, which has been widely studied in the last decades by using interrogating microwaves [5][6]. More recently, other interesting medical applications have been proposed [7]. Among them, the diagnosis of brain strokes in the human head is currently attracting an increasing interest in the bioelectromagnetism community [8]-[10].

In this paper, preliminary results concerning the reconstruction of two-dimensional models of a hemorrhagic brain stroke are reported. In previous studies, these authors evaluated the interactions between electromagnetic fields at microwave frequencies and the biological tissues of the human head [10]. In particular, the finite-volume time-domain (FVTD) method has been applied.

The inverse problem concerning the retrieval of the dielectric properties of the above mentioned tissues is addressed here by using an efficient solver based on a Gauss - Newton method, which has been developed in [11].

The paper is organized as follows. Section II provides an outline of the reconstruction method. Section III reports some preliminary two-dimensional results, whereas some conclusion are drawn in Section IV.

II. OUTLINE OF THE FORMULATION

In this preliminary assessment, the scalar electromagnetic problem obtained in the two-dimensional (2D) transverse-magnetic (TM) case has been considered. The head of the patient is surrounded by a circular region $\mathbb{D}$ (which coincides with the investigation domain) of radius $r_{\mathbb{D}}$, filled with a coupling medium characterized by complex relative dielectric permittivity ϵ_b. A multistatic and multiview configuration is used [12], in which the observation domain $\mathbb{M}$ is composed by $N_{\mathbb{M}}$ antennas equally distributed on a circumference with radius $r_{\mathbb{M}}$ enclosing the target. We have at our disposal a set of measurements of the actual total electric field $E(\mathbf{r})$ and of the electric field due to a reference model $\tilde{E}(\mathbf{r})$. The z-component of the scattered electric field referred to the reference model $E_s(\mathbf{r}) = E(\mathbf{r}) - \tilde{E}(\mathbf{r})$ is given by a nonlinear functional equation, that is,

$$E_s(\mathbf{r}) = \mathcal{L}(\Delta\chi)(\mathbf{r}), \qquad \mathbf{r} \in \mathbb{M} \tag{1}$$

where $\Delta\chi = \chi - \tilde{\chi}$ (i.e., the unknown of the inverse problem) is the difference between the actual contrast function $\chi = (\epsilon - \epsilon_b)/\epsilon_b$ and the contrast function of the model $\tilde{\chi} = (\tilde{\epsilon} - \epsilon_b)/\epsilon_b$, with $\tilde{\epsilon}$ being the model's complex permittivity.

The inverse problem expressed by equation (1) is solved by means of a Gauss-Newton iterative procedure [11]. This approach consists in two nested loops: in the outer loop the nonlinear equation (1) is linearized around the current dielectric profile by means of the Fréchet derivative of the operator $\mathcal{L}$; in the inner loop the resulting linear equation is solved by means of the conjugate gradient method [12].

III. PRELIMINARY NUMERICAL RESULTS

For evaluating the capabilities of the proposed reconstruction method, some numerical simulations have been performed. The MRI-based Zubal phantom [13] has been used for modelling the patient's head. In particular, the slice #40 (located at $h = 54.6$ mm from the top of the head) has been considered. The dielectric properties of the tissues of interest have been taken from the work by Gabriel et al. [14].

A circular region of radius $r_{\mathbb{D}} = 0.10$ m surrounding the head, filled with a lossless dielectric material with relative dielectric permittivity $\epsilon_r = 30$ has been considered as investigation domain. For the solution of the direct problem by means of the method of moments [15], the investigation region $\mathbb{D}$ has been discretised into $N_{\mathbb{D}}^d = 6496$ square cells of size $l_c^d = 0.0022$ m, whereas $N_{\mathbb{D}}^i = 1626$ cells of dimension $l_c^i = 0.0044$ m have been considered for solving the inverse problem. The measurement domain is located on a circumference of radius $r_{\mathbb{M}} = 0.11$ m and comprises $N_{\mathbb{M}} = 36$ equally spaced antennas. One of these antennas acts in turn as transmitter, while all the other $N_{\mathbb{M}} - 1$ ones are used as receivers. The operating frequency of the imaging system has been chosen equal to $f = 1$ GHz.

A hemorrhagic brain stroke has been simulated as an inclusion with elliptical cross section (major axis $a_{hs} = 0.04$ m, minor axis $b_{hs} = 0.02$ m) centered at the point $\mathbf{r}_{hs} = (0.02, 0.02)$ m and characterized by the dielectric properties of blood, i.e., relative dielectric permittivity $\epsilon_{r,hs} = 61$ and electric conductivity $\sigma_{hs} = 1.583$ S/m. The resulting distribution of the relative dielectric permittivity in the investigation domain (with the inclusion of the simulated brain stroke) is shown in Fig. 1. For simulating realistic measurement conditions, a white Gaussian noise with zero mean value and a signal-to-noise ratio equal to $SNR = 15$ dB has been added to the scattered field term $E_s(\mathbf{r})$.

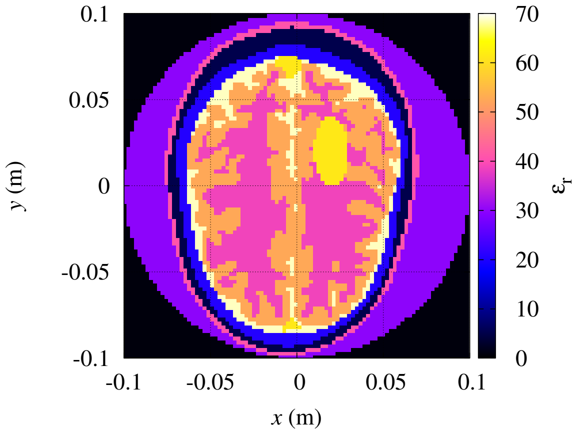

Fig. 1 Distribution of the relative dielectric permittivity ϵ_r within the investigation domain $\mathbb{D}$.

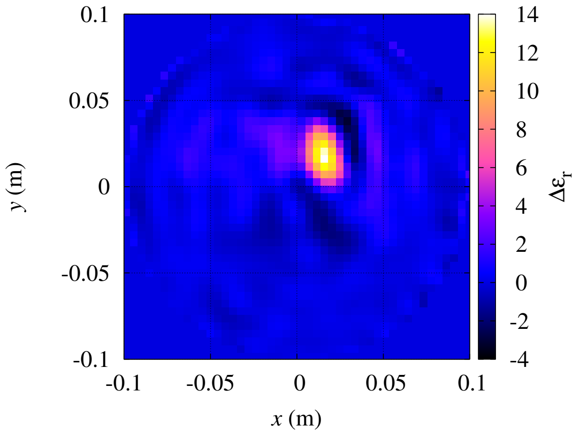

Fig. 2 Reconstructed distribution of the difference between the model relative dielectric permittivity and the actual value, $\Delta\epsilon_r$.

In the inversion procedure, $N_{IN} = 10$ outer steps have been executed, and an upper limit in the number of inner iterations $N_{CG} = 50$ has been fixed. Furthermore, the inner loop can be also terminated when the normalized difference between the residuals in two subsequent iterations is under the threshold $d_{CG} = 0.01$. In this case, the reference model is represented by the healthy head (i.e., without stroke).

The reconstructed distribution of the difference between the relative dielectric permittivity of the model and the actual one, i.e., the quantity $\Delta\epsilon_r = \epsilon_r - \tilde{\epsilon}_r$ is shown in Fig. 2. As can be seen, the included brain stroke has been correctly identified and characterized in the reconstruction. Moreover, the relative reconstruction error on the contrast function χ for three different regions has been computed. In the whole investigation domain $\mathbb{D}$, the relative reconstruction error is equal to $\xi_{tot} = 0.033$; in the region occupied by the stroke only we have $\xi_{obj} = 0.247$, and finally, within the background area, the error value $\xi_{bg} = 0.029$ is obtained.

IV. Conclusions

In this paper, preliminary reconstructions of two-dimensional distributions of human tissues inside the head have been reported. They have been obtained by a microwave imaging approach with the aim of localizing and shaping a hemorrhagic brain stroke. Further developments will be devoted to extend the above method to a three-dimensional configuration in order to simulate more realistic imaging conditions.

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