Simulative Anomaly Detection using 2D Tomography

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***Abstract* — We present a novel technique for predicting the imaging quality of anomalies (such as cancer cells etc...) located inside organic tissues. This technique is useful for evaluating and designing RF tomography sensors.**

1 INTRODUCTION

Research in the field of microwave ablation has increased in recent years due to improved capabilities of antenna arrays. This treatment has the potential to offer benefits both in detection and annihilation of tumors in living tissues [1][2]. The use of microwave radiation for detection offer the ability to detect malignant tissues without harm to the patient by injecting radioactive materials. Microwave ablation treatment has the potential to annihilate tumors without the need to perform risky surgeries. The fact the both exploit the observation that malignant tissues have different dielectric properties than healthy tissues gives rise to the idea of performing both procedures simultaneously.

In this paper we focus on malignant tissues imaging. We present a simplified 2D technique for predicting the imaging quality of anomalies (such as cancer cells) located inside organic tissues. This technique is useful for evaluating and designing RF tomography systems. In contrast to 3D tomography, 2D tomography simulative approaches are significantly less time consuming, hence it is more convenient for validation and robustness tests. The term 2D addresses anomalies which obey translational invariance in one direction (e.g. an infinite cylinder) which we refer to as "2D anomalies", see Fig.1. This simplification is justified due to high conductivity of the organic tissue. The fact that the attenuation is proportional to the conductivity set a limit to the maximum length from which signal can be received.

2 ANALYSIS DESCRIPTION

The geometry of our model is shown in Fig.1. We consider a planar wave propagating though space, impinging on the organic tissue which contains a malignant tissue which defines the zone of anomaly.

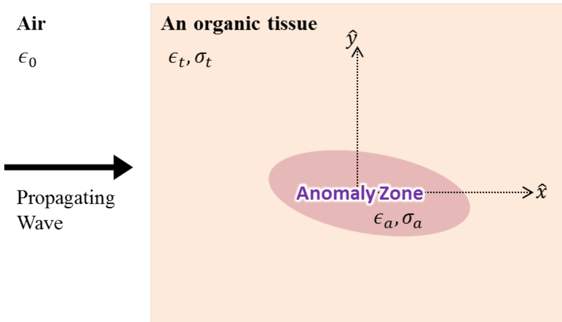

Figure 1: A description of the 2D geometry of an anomaly located inside the organic tissue. Each zone (air/tissue/anomaly) is separately characterized by relative permittivity and conductivity.

Each zone is defined electromagnetically by frequency dependent relative permittivity and conductivity.

The purpose of the presented analysis is to give an efficient way to estimate the reduction in system performance in terms of image quality due to typical inaccuracies inevitably existing in the reconstruction process. We believe that the proposed analysis can provide an estimation for the robustness of the image reconstruction procedure, which projects on the ability to empirically detect anomalies in different types of tissues.

2.1 Model

Our model is based on 2D Scattering equations for anomalies [3], which are formulated in matrix form and can be solved by using a variety of matrix inversion methods [4]. The inverse matrix is used to form an image of the area of interest by using RF tomography. Each pixel in the image gives an indication which is proportional to the relative dielectric permittivity of the tissue at a given frequency.

One key ingredient of the procedure described above is the electric field in the area of interest without any scatterers which we define as the incident field, E_{inc} [4]. This ingredient strongly affects the quality of the reconstruction process of the image. The incidence field is prone to suffer from severe inaccuracies, thus it is important to examine its influence over the reconstruction process.

The selection of operating frequency must take in to account the attenuation of propagating waves

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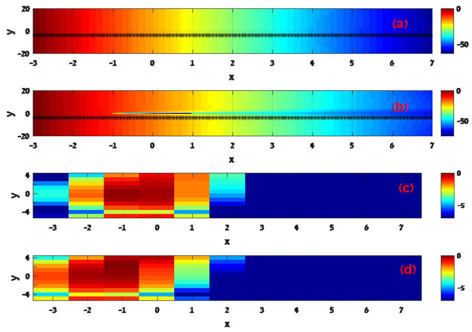

Figure 2: An analysis with an error of 5% in the relative permittivity. The center of the anomaly is located at the origin. (a) NFD of the organic tissue without an anomaly in dB (b) NFD of the organic tissue with an anomaly in dB (c) RF tomography with accurate E_{inc}. (d) RF tomography with inaccurate E_{inc}.

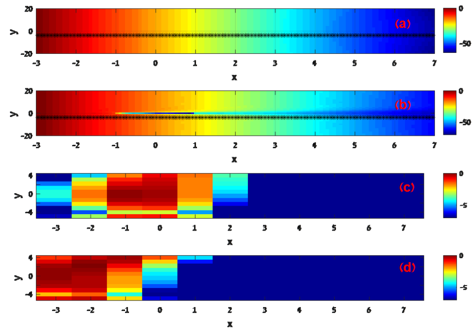

Figure 3: An analysis with an error of 15% in the relative permittivity. The center of the anomaly is located at the origin. (a) NFD of the organic tissue without an anomaly in dB (b) NFD of the organic tissue with an anomaly in dB (c) RF tomography with accurate E_{inc}. (d) RF tomography with inaccurate E_{inc}.

through the tissue. Therefore it is convenient to select a frequency with a wavelength of the same length scale as the depth used for imaging. Note that the effective resolution which sets the size of anomaly that can be detected is also frequency dependent and should be taken into account.

2.2 Simulation

We used the WIPL-D 2D Solver which is part of the WIPL-D software package[5]. The simulation time was of the order of several minutes, which allows performance of a large number of robustness tests. The simulation consisted of a planner wave propagating along the $\hat{x}$ axis, and a set of sensors located on a line parallel to the $\hat{x}$ axis but shifted in some distance d. The sampling of the Near-field Distribution (NFD) of the electric field was done at the locations marked by black asterisks. We chose the location of the anomaly to be at the origin, hence the depth of the anomaly is set by a shift of the location where the tissue begins (this can be seen in Fig.2b). The electric field measured by the sensors was provided by a simulation of the NFD of the electric field inside the tissue.

3 RESULTS

In Fig.2a and Fig.2b we present the NFD of the electric field with and without an anomaly respectively. Note that the incidence field is easily given in the simulation; in the case of real measurement, the measurement of the incidence field is not trivial. An RF tomography image was generated from the NFD results see Fig.2c. As can be seen the tomography image detects the anomaly at the correct depth.

As mentioned above, a measurement of the incidence field is easy with simulation, but rather problematic in a real experiment. Hence we decided to test the variability of our image reconstruction process to errors in the incidence field. In Fig.2d we present an RF tomography image, where we introduced a 5% error in the relative permittivity of the incidence field. As can be seen, the anomaly can is still detected. Nevertheless, the image is slightly blurred, and the depth of the anomaly is inaccurately estimated. We further increased the error in the relative permittivity to 15% and performed the same analysis. In Fig.3d we present the result. As can be seen, the depth of the anomaly is shifted to a non-realistic value. This sets a maximum level of excepted error.

4 CONCLUSIONS

We presented an example for an analysis which provides an estimation for the robustness of our imaging process for a given model, and electromagnetic properties. Note that this analysis can be done for different parameters and a wide variety of geometries.

Additional advantage of our approach is the fact that the signal processing of the presented technique is based on scattering equations which restricts the spectrum to a single frequency component. Thus it provides low sensitivity to white noise [4]. This fact is in line with the simplified simulative approach which neglects this kind of noise.

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