Numerical Simulations and Experimental Study of Magneto-Acousto-Electrical Tomography with Plane Transducer

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This paper presents a new coupled and multi-physics method called Magneto-Acousto-Electrical Tomography (MAET), which has the advantage of high contrast and spatial resolution. At the presence of static magnetic field, a beam of ultrasound applied to the tissue, the ultrasonic vibration leads to the separation of the charges due to the Lorenz force and produces current distributed in the tissue. In this paper, the equations of mathematical physical model were deduced. Based on the physical model, simulations were conducted, and the images of gradient of conductivity were reconstructed, which shows the interface of conductivity changes. In this paper we also established experimental platform, and detected the low noise voltage signal of μV level by the electrodes placed around the tissue. Experiments were conducted on sample of low conductivity gelatin phantom (0.2S/m) and pork, successively placed in a 260mT magnetic field and sonicated with a ultrasonic transducer of frequency range from 1.4 to 3.6 MHz. Based on experimental results high-resolution images were obtained, which shows the interface of conductivity changes.

***Index Terms*—Electromagnetic analysis, Ultrasonic transducer, Biomedical imaging, MAET, Acoustic wave**

I. Introduction

The electrical conductivity of biological tissue arouses great interest for medical imaging researchers, that is because this parameter shows good contrast in the human body. For instance, fat is ten times less conductive than muscle [1]. Moreover the change of the conductivity is a typical characteristic of most tumor in the early stage, thus the change of conductivity become an important assessment tool for the early diagnosis of cancer [2]. Thus, the parameter of electrical conductivity can be used to find cancer in its early stage, which could significantly reduce the morality rate. The advanced technique today to measure the electrical conductivity of tissue is the Electrical Impedance Tomography (EIT) and Magnetic Induction Tomography (MIT), though the resolutions of EIT and MIT are much lower than that of the ultrasonography. Moreover, only when the density of tissues is changed to a certain extent, will the ultrasonic methods be effective [3].

Magneto-Acousto-Electrical Tomography (MAET) combines the advantages of electrical methods in acquiring conductivities and ultrasonography in high spatial resolution, which is a new coupled method also called Hall Effect Imaging and Lorentz Force Impedance Tomography. Thus, MAET may be an assessment tool for the detection and /or characterization of cancer in the future. In this paper we deduced mathematical physical model of the MAET and also established experimental platform. Experiments were conducted on gelatin phantom (0.2S/m) and on pork sample and the signal to noise ratio of test results are greatly improved. Based on the experimental results high-resolution images were obtained. The electrical conductivity of normal human biological tissue is approximately 0.2S/m, while that of tumor tissue is more than tenfold different from the normal [4]-[5], thus our research in the MAET promote the progress of its application in clinic.

II. Principle of MAET

The scenario of MAET is illustrated in Fig.1. An ultrasound produced by transducer transmitted along the direction $\boldsymbol{e}_x$ into a sample placed in the static magnetic field being in the direction of $\boldsymbol{e}_z$. The positive and negative ions inside the sample deviate from their tracks due to the Lorentz forces acting on them in the direction of $\boldsymbol{e}_y$, which results in local electrical current density $\boldsymbol{J}_e$ in the sample, as shown in (1), which is the coupled equation of ultrasound and magnetic field.

$$\boldsymbol{J}_e = \sigma \boldsymbol{V} \times \boldsymbol{B}_0 \tag{1}$$

Where σ is the local electrical conductivity, $\boldsymbol{V}$ is the vibration velocity of ions along $\boldsymbol{e}_x$, $\boldsymbol{B}_0$ is the static magnetic field along $\boldsymbol{e}_z$.

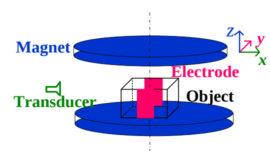


Fig.1 The scenario of voltage detection mode MAET

The net current derives from integrating $\boldsymbol{J}_e$ over the ultrasound beam width W and the ultrasound path

$$\boldsymbol{I}(t) = \boldsymbol{e}_y \cdot W B_0 \int_{soundpath} \sigma(x) V(x,t)\, dx \tag{2}$$

The ultrasound pressure is definite as p(x,t) satisfices the liner inviscid force equation

$$\rho(x)\frac{\partial v(x,t)}{\partial t} + \frac{\partial p(x,t)}{\partial x} = 0 \tag{3}$$

The induced current is found to be proportional to the convolution product of the gradient of electrical conductivity with the ultrasound pressure shape P

$$\boldsymbol{I}(t) = \boldsymbol{e}_y \cdot \int (\frac{B_0}{\rho}\frac{d\sigma}{dx}) * (\int_0^t p(t)dt) dS = c(H * P)(t) \tag{4}$$

The electrical signal is detected by electrode, thus the voltage measured is found to be proportional to the gradient of electrical conductivity.

III. Simulation and Experimental Results

In the process of simulation, the distribution of conductivity is uniform in the direction of of $\boldsymbol{e}_z$, thus a cross section is selected along z axis as shown in Fig. 2. As shown in Fig.1, the two permanent magnet produce a static magnetic field of 260mT in the region of 5cm×5cm×5cm with the direction of $\boldsymbol{e}_z$. Plane electrodes were used to collect the electrical current signal which direction is $\boldsymbol{e}_y$ as shown in Fig.1. The simulations were conducted by the FEM simulation software with MATLAB. The simulation results of voltage measured by the electrode in Fig. 3(a) and Fig.3(b) show the MAET signal has two or four opposite polarity, which corresponds to the change of conductivity. The image of conductivity changes is obtained by simulation as shown in Fig.3(c), which shows the two or four interfaces in Fig.2.

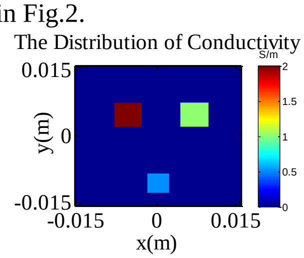
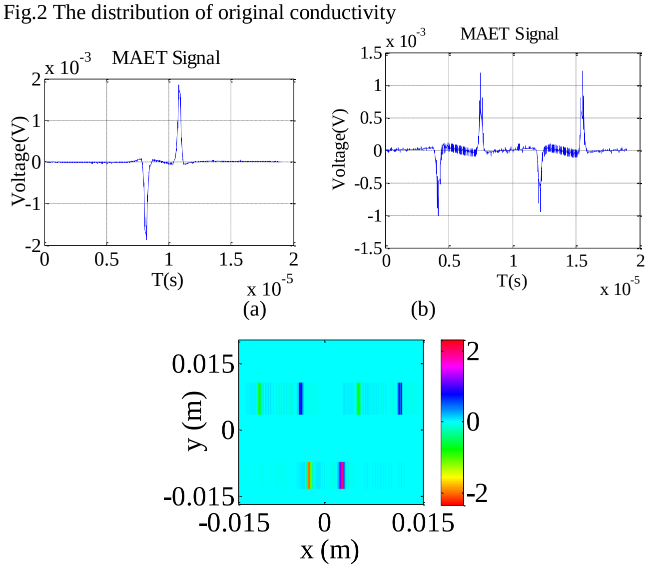


Fig.2 The distribution of original conductivity



(a) (b) (c)

Fig.3 Simulation results (a) Individual MAET signal at y=-10mm (b) Individual MAET signal at y=10mm (c) image of the gradient of conductivity

In the process of test, an ultrasound transducer is emitting ultrasound in a sample placed in an oil tank in the middle of a magnetic field. The ultrasound transducer was stimulated with a 400V pulse of 400ns pulse width, and the pulse repeat frequency is 100Hz. Plane electrodes made from copper foil were used to collect the electrical current signal. The distance between the transducer and the center of the Gel phantom is 8.5cm. The size of gel phantoms is 30mm ×70mm×50mm(X×Y×Z), the middle rectangular hole was 10mm×10mm×50mm, as shown in Fig.4. The electrical conductivity of the gel phantom sample is 0.2S/m.

From the reconstructed image shown in Fig.5, four $\sigma(x)$ discontinuities, including two at the outer (x=70mm) front and back interfaces (x=100mm) of the sample and two at the rectangular hole (x=79mm, x=89mm) were clearly recognized. The length of the recognized inner discontinuity was approximately 10mm, equal to the width of the hole.

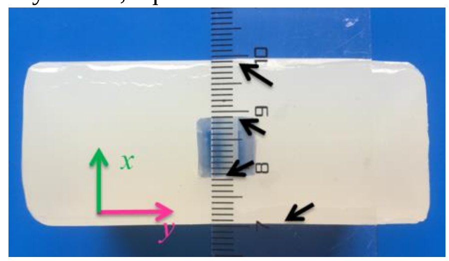
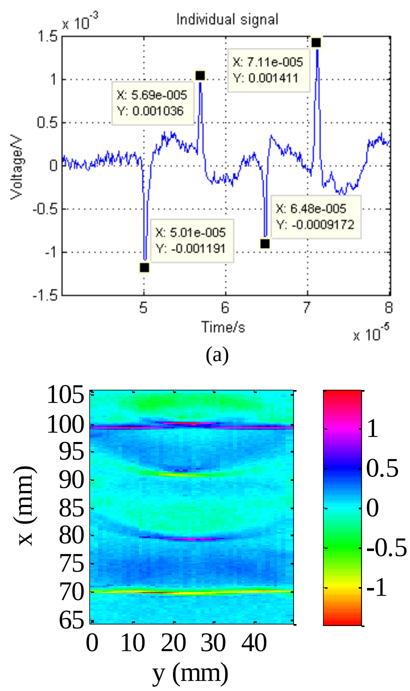


Fig.4 Top view of Gel phantom sample



(a)

(b)

Fig.5 test results (a) Individual MAET signal at y=25mm (b) Image of the gradient of conductivity

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