Research of Electromagnetic Wave Travel Time in Biological Tissue for Imaging

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Magnetic induction tomography(MIT) involved faint eddy signal and electromagnetic wave travel time signal in biological tissue. In this paper, we proposed a fresh idea that using electromagnetic wave time to represent bio-tissue electrical properties, and reconstructed body biological impedance image. First we derived the phase lag formulation due to electromagnetic wave travel time of the biological tissue in MIT, then we established electromagnetic travel time measuring model for a simple head model and calculated the travel time data according the relationship between the electromagnetic wave propagation and biological impedance. By image reconstruction algorithm, electromagnetic travel time image representing biological impedance distribution were built. The results show that the proposed method will be feasible for imaging bio-impedance tomography.

Index Terms—**magnetic induction tomography, electromagnetic wave, travel time signal, biological tissues, biological impedance**

I. INTRODUCTION

Magnetic induction tomography (MIT) is a noninvasive and contactless imaging modality which aims to reconstruct the electrical conductivity distribution of the human body. Compared to EIT, all the electrodes in MIT are replaced by coils, which do not touch the patient and offer the contactless feature. Since Al-Zeibak et al proposed a reconstruction of salt solution model by MIT in 1993, MIT have more than 20 years. Yet it has not been developed to be applied to a real medical image modality. The biggest challenge for MIT is its low image resolution, which caused by two reasons. First MIT suffers from certain measurement difficulties and limitations. The conductivities of biological tissues are notably low ($\sigma < 3Sm^{-1}$ 1); thus, the induced magnetic field is typically only 1% of the primary magnetic field at a frequency of 10 MHz [1]. When the frequency of the exciting signal is 10 MHz, the whole measurement system requires a phase measurement accuracy of at least 0.01u [2]. On the other side, in MIT, because of the dispersed nature of the electromagnetic field (the transmitting field no longer follows the straight line pattern), the change in conductivity cannot be ''localized'' anymore and can cause signal perturbation on any measurement set, which makes the MIT model more complicated. This non-localization properties cause the MIT inverse problem ill-posed nature.

Our group have developed the MIT system technologies and methods to improve the bottleneck problems since 2005 [3]. We noticed that in MIT process there exists two signals producing the phase lag: the eddy signal and electromagnetic travel signal. In classic MIT, the electromagnetic travel signal is always ignored. This electromagnetic wave propagation effect phase lag is distinguishable from the phase lag due to the conductivity, as illustrated by Fig.1.In [4], they used representing the propagation effects and thought this could be neglected up to 100kHz in biological tissues. we proposed an oscillation circuit for detecting the propagation delay, and the experiment has been tested by two conditions: tank with water and tank without water. Our preliminary works have proved the detection feasibility using wave propagating representing the electrical characters of biological tissues [5].
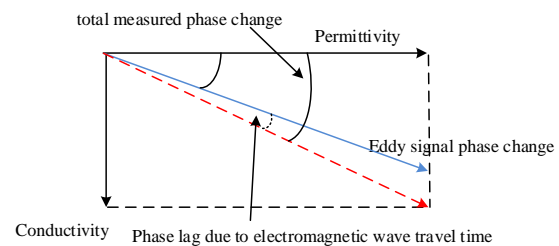

Fig.1 the total phase lag in MIT

In this paper, we present an imaging method using electromagnetic travel time in MIT. In the following, we deducted the theoretical electromagnetic wave travel time data with the biological impedance. Then we simulated the phase lag due to electromagnetic wave travel time and phase lag due to the conductivity in Griff MIT model. A simulated testbed for measuring electromagnetic wave data were built. Some simulated measuring data were calculated by a simple three layers head model was built. By the image reconstruction algorithm, we reconstructed the biological tissue electromagnetic wave travel time image. The reconstructed image by simulated data could represent the biological tissue distribution.

II. METHODOLOGIES

A. Relationship between Electromagnetic Wave Travel time and Electrical Properties of Biological Tissue

The velocity *v* of electromagnetic wave is related with the phase constant β, and the angular frequency then

$$v = \frac{\omega}{\beta} = \frac{1}{\sqrt{\mu\varepsilon}} \left(\frac{2}{\sqrt{1+(\frac{\sigma}{\omega\varepsilon})^2}+1} \right)^{1/2} \qquad (1)$$

For biological tissue conductivity is very low and classic MIT exciting signal is about several kHz to MHz, it can satisfy the condition $\sigma \leq \omega\varepsilon$ .In MIT, the electromagnetic wave propagation velocity can be simplify calculated by

$$v = \frac{1}{\sqrt{\mu\varepsilon}} = \frac{1}{\sqrt{\mu_0\varepsilon_0\mu_r\varepsilon_r}} = \frac{c}{\sqrt{\mu_r\varepsilon_r}} = \frac{c}{\sqrt{\varepsilon_r}} \qquad (2)$$

B. Wave travel Time in Biological Tissue for Imaging

It is assumed that electromagnetic field generating by exciting coil is limited to its primary path and propagates through biological objects along a straight line. Thus, the travel-time t_i of the ith electromagnetic wave propagation path Li in the biological medium of slowness(inverse of velocity) $s(\sigma,\varepsilon)$ is given by the integral:

$$t_i = \int_{L_i} s(\sigma,\varepsilon)dl$$

To approximate the electromagnetic propagating slowness field $s(\sigma,\varepsilon)$ by cells. The imaging system can scan the target object by m times linear scan and n times rotation, the propagation time matrix T can be obtained

$$\begin{bmatrix} t_1 \\ t_2 \\ \vdots \\ t_n \end{bmatrix} = \begin{bmatrix} s_{00} & s_{01} & s_{02} & \cdots & s_{0n} \\ s_{10} & s_{11} & s_{12} & \cdots & s_{1n} \\ s_{20} & s_{21} & s_{22} & \cdots & s_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ s_{m0} & s_{m1} & s_{m2} & \cdots & s_{mn} \end{bmatrix} \begin{bmatrix} l_1 \\ l_2 \\ \vdots \\ l_n \end{bmatrix} \qquad (3)$$

Where s_{ik} is the segment slowness of the l_i path in the kth cell. According to Equ.(3), electromagnetic wave propagation time image representing the biological tissue distribution can be obtained by electromagnetic wave time data collected by the measuring system .

III. SIMULATIONS AND RESULTS

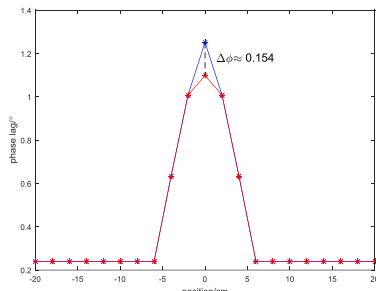*A. Phase Numerical Simulation for Electromagnetic Wave Time in MIT*

Fig. 2 Phase lag simulation value by the Griffiths model

We simulated classic MIT consisted of an excitation coil (4.5 cm radius, 4 turns, area 0.04cm2) and a sensing coil (1.25cm radius, 2 turns, area 0.04 cm2) placed coaxially, 20 cm apart, facing horizontally. A cylinder of saline solution (4.5cm radius, 7.9 cm high, and axis vertical) was set as imaging object. The exciting current is 10MHz, 1A. As an example of an inhomogeneous distribution (1.5cm radius) the conductivity $\sigma_d = 0.79$, the relative permittivity $\varepsilon_{rd} = 236$. The result is

shown in Fig.2, when the model moving alone vertical by 2cm per step. The red line and blue line describe the phase lag due to wave propagation by the model without blood distribution and with blood distribution, respectively. The phase lag difference produced at the saline with the inhomogeneous distribution is about $\Delta\varphi = 0.154°$. For a 10MHz MIT system employing direct phase measurement this would require a phase resolution of 0.003 degrees [2].

B. Electromagnetic Wave Travel Time of Head tissue for Imaging

Fig.2(a) shows a simple head model with an axial changing piecewise conductivity profile simulating tissue layers skull $\varepsilon_r = 53.775$, cerebral spinal fluid (CSF) $\varepsilon_r = 108.6$; brain tissue (spinal cord) $\varepsilon_r = 247.7$ and inner sphere representing brain edema $\varepsilon_r = 280$. The radius of three concentric circles is 85mm,75mm, and 65mm.The radius of blood edma circle is 15mm.

The transmitting coil and receiving coil are model as a rectangle box, positioned 100mm respectively to the origin. We rotate the EXC and REC in 16 positions by the projection angle range $(-pi/2, +3*pi/2)$. At each projection angle θ , paralleled displacement of the EXC and REC would range in $[-100*\sin\theta, 100*\sin\theta]$. Then simulated travel time matrix data can be obtained. The reconstructed travel time image can be gotten by image reconstruction algorithm, as shown in Fig.2(b). The electromagnetic wave time image of the simulated head model displayed the biological tissue distribution according to the original simulated image.
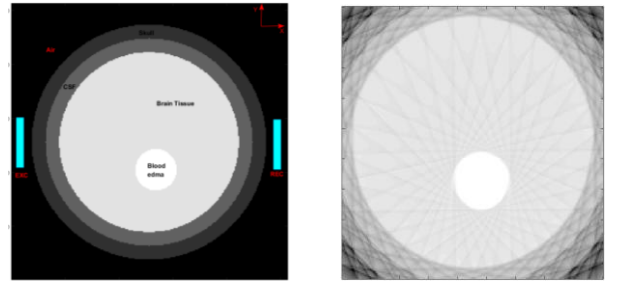
(a) A multi-shell simulated head model l (b) Reconstructed travel time image head model
Fig.3 A multi-shell simulated head model and reconstructed travel time image

REFERENCES

[1] Watson S, Morris A, Williams RJ, Griffiths H, and Gough W, "A primary field compensation scheme for planar array magnetic induction tomography". *Physiol. Meas. London,* vol.25, no.1,pp: 271–279,Feb.2004
[2] Watson S, Williams RJ, Griffiths H, Gough and W, Morris A (2001), "A transceiver for direct phase measurement magnetic induction tomography," *Annu. Rep. Res. React. Inst. Kyoto. Univ., Pontypridd.* ,vol.4, pp.3182–3184, Oct.25-28, 2001.
[3] Jingwen Wang, Xu Wang, Application of particle filtering algorithm in image reconstruction of EMT, *Meas. Sci. Technol.*, vol.26, no.7,075303pp.1-7, July,2015.
[4] Nevzat G. Gencer, M. Nejat Tek, "Imaging tissue conductivity via contactless measurements a feasibility study," *Turk. J. Electr. Eng. Comput. Sci., Elektr.*, Turkey, vol.6,no.3,pp. 183-200,Mar.1998.
[5] Dan Yang, Bin Xu, Chengan Liu, and Xu Wang. A Detection Feasibility for Wave Propagation Delays in Magnetic Induction Tomography, Journal of Medical Imaging and Health Informatics Vol. 6, 1155–1159, 2016