Computation of a 3-D Model for Lung Imaging with Electrical Impedance Tomography

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Abstract — As a relatively new imaging method and modality, Electrical impedance tomography (EIT) has developed and evolved over the past 20 years, Which has the potential to be of great value in clinical diagnosis; however, EIT is a difficult problem to solve in terms of developing hardware for data capture and the algorithms to reconstruct the images technically. In the paper a cylinder geometry 3-D model for human thorax has been established with finite element method (FEM). And the phantom tests have been done in a salt-water tank implemented by the EIT system developed by our group. The in-vivo experiments on subject were made and the lung images were reconstructed during breath. The result shows that with the 3-D model, the reconstruction time is faster than linear back-projection algorithm with node back-projection Algorithm. And it also shows that EIT has the capability to become a useful tool for lung imaging bedside.

I. INTRODUCTION

Electrical impedance tomography is a technique for imaging variations in the conductivity distribution of the section of a body from impedance measurements made with electrodes placed on its surface. It's a relatively new imaging technique with the advantages such as the portability, non-invasiveness, low cost, functional imaging. To monitor pulmonary ventilation or fluid volume changes is one of the promising applications of EIT. The lung resistivity changes with the air or fluid volume change in it. The diseases which cause variation in the lung composition may be monitored using EIT by measuring the lung resistivity change. And there is scientific support for the feasibility of obtaining regional information on lung function using EIT technique.Because the electrical resistivity changes very obviously during breathing, one promising application of EIT is the monitoring of pulmonary ventilation with a ultimate goal becoming a meaningful and reliable tool for clinical used in the Intensive Care Unit(ICU). Driven by the idea of implementing EIT in medical settings, several developments in the area have been achieved in recent years. The former EIT systems of our group worked either in a single frequency or in a lower range of frequency.

In this paper a 3-D FEM model has been established. And the lung's detection and functional images were acquired using the Node Back-Projection Algorithm(NBPA) with a 64-electrode EIT system we developed.

II. METHOD

The mathematical model of EIT is given by Maxwell's equations. Given the resistivity distribution ρ inside the subject, the boundary voltage ϕ satisfies the Laplace equation

$$\nabla \cdot \rho^{-1} \nabla \phi = 0 \qquad \text{in} \quad \Omega \tag{1}$$

with boundary conditions

$$\begin{cases} \phi = \phi_0 & in\Gamma_1 \\ \rho^{-1} \dfrac{\partial \phi}{\partial n} = -\boldsymbol{J}_0 & in\Gamma_2 \end{cases} \tag{2}$$

where ∇ is the gradient operator, Ω represents the static electric field, ϕ_0 is the measured peripheral voltage, $\boldsymbol{J}_0$ denotes the current intensity on the boundary, n is the outward normal, Γ_1 and Γ_2 are the first and the second boundary condition separately.

A 3-D computation model for human thorax is established with FEM seen in Fig 1.

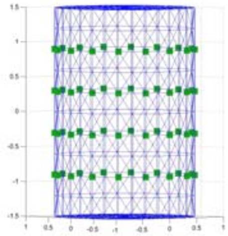

Fig.1 3D model for human thorax

With the Polynomial Curve Fitting method, the approximately the approximately closed formula of potential distribution on the boundary of original time t_0 is computed from the potential of nodes on the boundary

$$\phi(x) = p_1 x^m + p_2 x^{m-1} + \cdots + p_m x + p_{m+1} = \sum_{i=1}^{m} p_i x^{m+1-i} \tag{3}$$

Where m is the order of the polynomial, x is the coordinates of boundary position, $p_i (i = 1,2,3,\cdots,m+1)$ is the coefficient. Similarly, the potential distribution on the boundary of another time also could be acquired. Then the variation of resistivity should be the derivative in two different time, and the approximately resistivity variation of each node can be obtained by:

$$\Delta\rho = \frac{d(\Delta\phi\ (x))}{dx} = \sum_{i=1}^{m} \Delta p_i (m - i + 1) x^{m-i} \tag{4}$$

Changing excited electrodes in turn and computing the derivative difference between the two polynomials, the dynamic resistivity of nodes can be obtained by weighted summing. With the variation of node resistivity inner the model calculated according to original projection relation between boundary voltage and inner node resistivity, the reconstruction time reduced to 0.03s to get an image, which is much faster than the traditional linear back-projection algorithm. The main reason is the nodes' potential instead of elements' potential is used in the computation.

III. EXPERIMENTS AND RESULTS

A. *PhantomTests with EIT System*

Experiments were performed on subjects with the EIT system designed by our group using 16 electrodes at one frequency of 100kHz. EIT data collection was performed at the sampling rates of 10Hz. An alternative current was injected between a pair of adjacent electrodes, and the resulting potential differences were measured via the remaining adjacent electrode pairs. And so on, in turn until all the 16 electrodes were performed as driving electrodes, onset of measurement was completed. The amplitude of the injected current is approximately 0.5mA. A phantom test were made in a salt-water tank seen in Fig. 2.

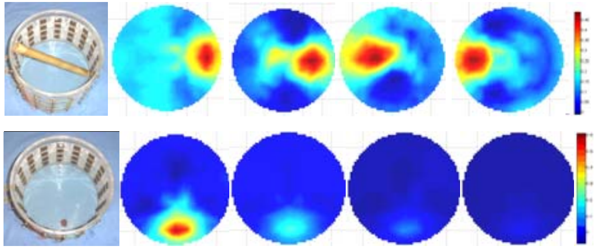

Fig. 2. Experiments of resin different-length rods and the reconstruction images

B. *In-vivo Experiments Results*

An in-vivo experiments were done with a volunteer subject aged 28, male, keeping sitting on a chair, without any pulmonary or cardiac complaints were examined in the study. The conventional self-adhesive ECG electrodes were selected and applied in the measurements. The electrodes ring were placed around the thorax at the level of -1cm and 5 cm around the xiphoid on the studied subjects, seen in Fig. 1. Data was collected in 3D during one respiration process. 16 electrodes was placed in each ring evenly on the surface of the subject. There are 64 combined-typed electrodes in the EIT system.

The individual measurements were performed as follows. After a deep expiration, potential difference data sets used as the referenced sets were collected during the period of the breath holding controlled by the subjects.

The experiments were done with the aim of acquiring lung's functional images reconstructed with NBPA by the detection of electrical information on the surface of volunteer subjects' thorax.

IV. CONCLUSION

The NBPA was firstly used for thorax images reconstruction. Seen in Fig. 3.

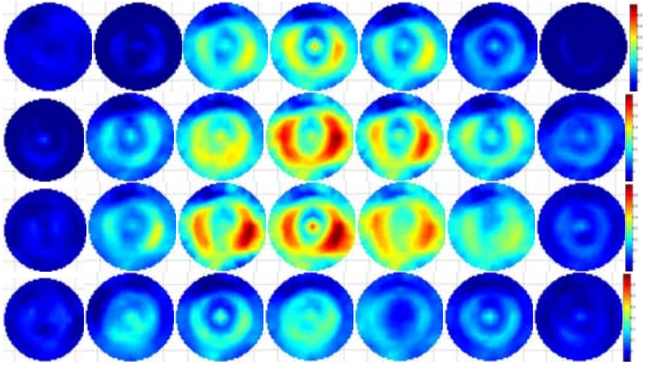

Fig. 3. The reconstruction image series of respirations

The results show that the lung's functional imaging during respiration could be acquired safely, faster and efficiently based on the node back projection algorithm with the EIT system. The approach is reasonable, fast and functional imaging. And it has the potential to become a non-invasive bedside monitoring tool of lung function.

V. ACKNOWLEDGMENT

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