# A novel Electrical Impedance Tomography system using rectangular electrodes array

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**Abstract —Electrical Impedance Tomography (EIT) is a new medical imaging modality that produces images by computing electrical properties within the human body. The electrical interface is through electrodes that are placed on the body's surface. This article proposes a novel EIT system with rectangular electrodes array and back electrode. We have studied the forward, inverse problem, display modes of this kind of EIT system, and established its simulate model. Furthermore, we have realized EIT system, and introduce the system construction. Then, we completed the physical experiments. Simulate and experiment results show that this EIT system can obtain a better spatial resolution and positioning accuracy, and is more suitable for future clinical applications.**

## I. INTRODUCTION

There are three types of EIT systems using rectangular electrodes array: TS2000 system of Israel [1], MEIK® system of Russia [2], ACT-4 of Rensselaer Polytechnic Institute [3]. In practical situations, these systems have some limitation: (1) the electrode system contains rectangular electrodes array and hand electrode, so the electric field is not uniform. The measuring depth is shallow, for example the depth of MEIK is 2cm; (2) there is not a proper 3D reconstruction algorithm and visualization method. The reconstruction algorithm of EIT is classified as the linear method and the non-linear method. Due to the particularity of 3D field: larger field, more elements, increasing the calculation complexity and amount, a new reconstruction algorithm is necessary. We have proposed a novel EIT system: the rectangular electrodes array and back electrode are used, so the electric field is more uniform and the investigation depth is deeper [4]; the reconstruction algorithm is Tikhonov's regularization method.

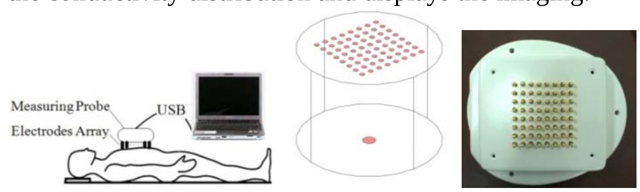
## II. SYSTEM CONSTRUCTION

### A. Principle of EIT

The conductivity difference of tumor tissue compared with normal tissue could be used to detect cancer. EIT can operate by applying a sinusoidal current to the electrodes attached to the skin and measuring the resulting voltages. The normal and tumor tissue could be differentiated by the resulting voltages. Reconstruction algorithms use the current and voltages to compute and form images of the electrical conductivity distribution in the body [5].

### B. System construction

As shown in Fig.1a, EIT system construction consists of the measuring probe and a computer with inverse software, which are connected by USB. The electrode array directly contacted with skin is on the front of measuring probe. It can inject current into body, measure the voltage of body skin and send it to the computer. The computer calculates the conductivity distribution and displays the imaging.




(a) (b) (c)

Fig. 1. EIT system using rectangular electrodes array

An EIT field model is shown in Fig. 1b. An 8×8 electrodes array is placed on the upper surface of cylinder; a back electrode used to be ground is placed on the center of lower surface. The measuring and reconstruction field is the area between the electrodes array and the back electrode. Fig. 1c is the photograph of measuring probe with 64 electrodes. The diameter of each electrode with 8mm gap is 4mm. And the back electrode's diameter is 10mm.

## III. RECONSTRUCTION ALGORITHM AND EXPERIMENT RESULT

### A. Inverse Problem

Since the study of EIT forward problem is very mature, the conclusion of [6] could be used. The inverse problem of EIT is to calculate the internal conductivity distribution based on the boundary voltage. EIT image reconstruction is a nonlinear ill-posed problem, and there is no feasible way to predict what the correct image will be.

The inverse problem is consider as an approximate linear problem Ax = b. The Least squares method (LS) could be used to solve this equation

$$\min_x \|Ax-b\|_2 \tag{1}$$

For the linear least squares problem, a general version of Tikhonov's regularization method takes the form

$$\min\left\{\|Ax-b\|_2^2+\lambda\|Lx\|_2^2\right\} \tag{2}$$

Where $\lambda$ is regularization parameter, and $L$ is a matrix that defines a (semi)norm on the solution through which the "size" is measured. Often, $L$ represents the first or second derivative operator. If $L$ is the identity matrix, then the Tikhonov problem is said to be in standard form. The solution $x_\lambda$ to (2) solves the problem

$$\left(A^TA+\lambda L^TL\right)x=A^Tb \tag{3}$$

In principle, small enough perturbations in conductivity can be reconstructed accurately enough by considering just the linear problem. In EIT, starting from a known and usually homogeneous distribution $x_p$, a set of measurement $V_p$ are gathered. In sequence, a perturbation $\delta x$ occurs causing a new $x \neq x_p$ and consequently a $V \neq V_p$. Calculating the Jacobian matrix($J$) which computing method is introduced in [7] based on $x_p$, the discrete form of the linear forward problem used in difference imaging becomes

$$J\delta x = \delta V \Leftrightarrow J\left(x_p - x\right) = V_p - V \qquad (4)$$

In the (4) only $V$ is physically collected from the boundary of the volume as $V_p$ is obtained by forward calculations.

$$J\left(x_p - x\right) = F\left(x_p\right) - V \qquad (5)$$

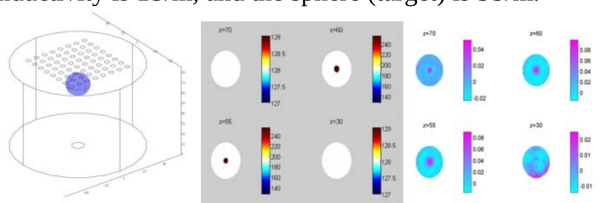
where $F(x_p)$ denotes the vector of simulated measurements derived from forward computations based on a model $x_p$.

Equation (5) is similar with Ax = b, so we can get the solution from the (2)~(4)：

$$x = x_p + \left(J * J + \lambda L * L\right)^{-1} J * \left[F\left(x_p\right) - V\right] \qquad (6)$$

### B. Simulation Result

In Fig. 2a, a cylindrical model is built to validating the algorithm. The height is 80mm, and the radius is 55mm. Target is a sphere which radius is 10mm, and the distance to upper surface is 20mm. In this simulation, the cylindrical conductivity is 1S/m, and the sphere (target) is 5S/m.

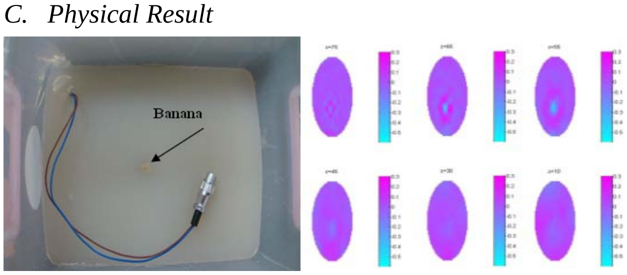


(a) (b) (c)

Fig. 2. The simulation model and reconstruction result

The horizontal slice graph of Fig. 2a which height is 30,55,60 and 70mm is shown in Fig. 2b. We can found the target (brown area) in the 55 and 60mm slice graph. Fig. 2c is the slice graph of reconstruction result with the same height. Clearly, the reconstruction image is of better spatial resolution as it provides a good qualitative and quantitative information about the interior distribution. The simulated measurements used for reconstruction was contaminated with 1% Gaussian noise. The shortage of the image is that there is an artifact in 70mm slice.

### C. Physical Result




(a) (b)

Fig. 3. Physical experiment and result

The inverse algorithm was tested in experiment using a phantom shown in Fig. 3a. It is made of plastic and has the inner dimension 27cm(W)×20cm(D)×18cm(H). Measuring probe is located on the surface of agar and the top side in the figure, and the ground electrode is placed on the phantom undersurface. The phantom is filled with agar of $9.2\times10^{-2}$S/m(@50kHz), and the height (H) of agar is 6cm. A 15mm×9mm×9mm cuboids banana with $2.5\times10^{-2}$S/m is embedded into agar. The depth between banana and top surface is 1.5cm, and the signal frequency is 50 kHz.

Fig. 3b illustrates the horizontal slice graph which the height are 75,65,55,45,30 and 10mm of the reconstruction result. The reconstruction model of this experiment is the same as simulation model shown in Fig.2a. In the result images, the blue area means the area with lower conductivity (banana). From the image which the height is 65 and 55mm, we can found the location, size and depth of banana. Considering the different height of reconstructed model and agar model, the depth of reconstructed image should transform to real depth. After calculation, the depth of the banana in the agar is 1.3~2.6cm with a little error.

## IV. Conclusion

For some applications of EIT like breast tumor imaging, the EIT system with rectangular electrodes array and back electrode can get a better performance. From the results of simulation and physical experiment, this system is of a better spatial resolution such as target's location and size. But there are some limitations: (1) the number of subdivision elements is not enough, so the image quality is not good; (2) with the increasing of the elements, calculated quantity is bigger and the calculation time is longer; (3) there is artifact in the image, target is not clear enough.

In future work, we plan to modify the inverse algorithm to improve the image quality, optimize the inverse software code to keep or reduce the calculation time when the subdivision density is increasing. And take more physical experiment to check the whole system performance.

## V. Acknowledgements

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