A Rotative Electrical Impedance Tomography Reconstruction System

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Abstract. Electrical impedance tomography (EIT) is a powerful tool for mapping the conductivity distribution of estimated objects. The EIT system is entirely implemented by electrical technique, so it is a relatively cheap system and data can be collected very rapidly. But it has few commercially medical EIT systems available. This is because impedance image unable to achieve the essential spatial resolution and this technique has an intrinsically poor signal to noise ratio. In this paper, we have developed a high performance rotative EIT system (REIT) for expanding the independent measurements. By rotate the electrodes successive, REIT could change the position of electrodes and acquire more measurement data. This rotative measurement method not only can increase the resolution of impedance images, but also reduce the complexity of measurement system. We hope the improvement of REIT will bring some help in electrical impedance tomography.

1. Introduction

Electrical impedance tomography is a powerful tool for mapping the conductivity distribution of estimated objects. The cross-section of object was accessed from the measurement made on its surface. Because of several potential advantages, the EIT technique has been developed in many industrial applications, such as the fields of process tomography, non-destructive testing, geological studies and medical image [1-4]. For biomedical applications, the EIT technique has several advantages over the current medical image methods. The measurement of impedance does not produce any harmful radiation, so it has no known hazards attached to the subjects. Therefore, EIT systems are possible to monitor the physiological function in the long term. Furthermore, the EIT system is entirely implemented by electrical technique, so it is a relatively cheap system and data can be collected very rapidly. The impedance image has been applied in many clinical applications, but it has few commercially medical EIT systems available. This is because impedance image unable to achieve the essential spatial resolution and this technique has an intrinsically poor signal to noise ratio [5]. Thus the image quality of the EIT could not compete with the established medical image, such as the computerized tomography (CT) and magnetic resonance imaging (MRI).

The quality of impedance image is limited by the ill-posed problem of EIT [6]. For a conventional N electrodes EIT system, we could obtain at most N(N-1)/2 individual measurement data to reconstruct the impedance distribution. This means that the resolution of the EIT image can be...
improved by increasing the number of electrodes. Nevertheless, increasing the electrodes is a difficult task. The total number of electrode is restricted by the volume of object and the size of electrodes. The area of measurement site is also invariable. Besides, reducing the size of electrodes could bring severe contact impedance. Therefore, the number of electrode is limited.

The ill-posed problem means that the small error in measurement will result in large error of reconstructed image. In order to eliminate the ill-posed noise, we have developed a high performance rotary EIT (REIT) system for expanding the independent measurements. In order to increase the independent measurement, the idea of movable electrodes is described in the following section.

2. System Description

2.1. System Overview

In this work, the rotary EIT is expanded from conventional EIT system. The REIT system can be divided into three parts, moving scheme, switches network and measurement system. All this three parts are properly controlled by the host computer. A moving scheme (dynamic measurement) is proposed to increase independent measurements. The moving scheme includes a phantom equipped with movable electrodes and a stepping motor to drive the electrodes. Switches network is constructed by a lot of solid state relays to create current or voltage transmission channels. A constant current source injects fixed current into estimated object at specific frequency. The electrodes pick up the potential, responded to injecting current, on estimated object. The Lock-in amplifier and other electrical circuit filter out unwanted component from measured signal. Figure 1 shows the block diagram of REIT system.

2.2. Electrode configuration and Moving scheme

The proposed REIT system has 16 electrode pairs which are distributed on the periphery of cylindrical tank. Each electrode pair includes both voltage electrode and current electrode. In order to get optimum measurements, we need to put more effort on the design of electrodes especially for the size and shape of electrodes [1]. To ensure that a uniform current density is generated within the tank, a large surface area is required for the current-injecting electrodes. For voltage electrodes, a small surface area is optimal to avoid ‘averaging effect’ from several equipotentials. The compound electrode applied in this study is illustrated in the figure 2.

The moving electrode scheme is the most important part in this system. The moving electrode scheme is composed of 16 compound electrodes which are fixed on a movable ring frame. The electrodes are distributed averagely on the circumference of ring frame. Figure 3 is a vertical view of movable ring frame with electrode array. The ring frame is driving by stepping-motor with minimal rotating angle 0.018°. The motor would drive the electrode pairs to change the electrode site. By applying data acquiring procedure of neighborhood method, we could obtain 16x(16-3)/2=104 independent measurements from each rotation. The rotating step angle we chosen is 4.5° and the angle between the adjacent electrodes is 22.5°. To complete scan the circumference of phantom tank, the
stepping motor rotates a step angle (4.5°) 5 times and drives the electrodes simultaneously. Finally, the total of measurement data would raise 5 times (104x5=520).

![Figure 2](image1.png)

**Figure 2.** The configuration of compound electrode.

![Figure 3](image2.png)

**Figure 3.** The vertical view of movable ring electrode array.

2.3. Switch networks and Measurement system

In this work, we adopt the terapolar method (four terminals) to measure the impedance. For each measurement, we require two electrode pairs, the driving pair and the receive pair. The driving electrode pair injects the current into the object and receive electrode pair measures the boundary voltage. The switch network, shown in figure 1, is divided into current switch and voltage switch. The current switch transmits the excitation current from current source to different driving pair. The voltage switch would pass the measurement voltage from every receive pair to lock-in amplifier. This tetrapolar method is useful to deal with the unknown contact impedance problem.
The driving pair is driven by the voltage control current source. A good current source has high output impedance and strong capability of noise rejection. The relationship between control voltage and output current should be linear. The modified-floating current source, shown in the figure 4, was applied in this work. Comparing with conventional floating current source, the modified circuit contains huge resistance between $V_-$ and $V_+$. It can avoid the disturbance coming from ground. We can conclude the output current $I_{\text{exc}}$ as:

$$I_{\text{exc}} = I_{\text{ref}} = \frac{1}{R_1} \frac{R_2}{R_2 + R_3} V_{\text{ref}}$$

(1)

In REIT we use the excitation current with 20 KHz to map the impedance distribution. Because we are not interested in the carrier signal, we need to demodulate the carrier signal to get the amplitude and phase information. Although the measured signals corrupted by external disturbances exceeds in thousands of times the interesting signal, the lock-in amplifier can estimate the amplitude and phase of the interesting signal. A lock-in amplifier acts as a narrow band-pass filter (almost equal to 1 mHz) around the reference signal frequency [7-9]. According to these advantages, we chose the National Instruments new Lock-in Amplifier Start-Up Kit to obtain the precise measurement of AC signals. The block diagram of lock-in amplifier is shown in figure 5.

In figure 5, the measured signal $V_m(t)$ and the reference signal $V_{\text{ref}}(t)$ are expressed as

$$V_m(t) = A \cos(\omega_m t + \theta_m)$$

(2)

$$V_{\text{ref}}(t) = 2 \cos \omega_R t$$

(3)
The measured signal $V_m(t)$ is multiplied by reference signal $V_{ref}(t)$ and reference's quadrature, then the mixed signal is filtered by the low-pass filter. If the reference frequency $w_{ref}$ is equal to the measured frequency $w_m$, the output signal $V_x$ can be calculated as:

$$V_x = A_m \cos \theta_m$$  \hspace{1cm} (4)

In the same way, the quadrature $V_y$ can be obtained as:

$$V_y = A_m \sin \theta_m$$  \hspace{1cm} (5)

According to these quantities, the amplitude and the phase of the signal $V_m$ will be calculated:

$$A_m = (V_x^2 + V_y^2)^{\frac{1}{2}}$$  \hspace{1cm} (6)

$$\theta_m = \tan^{-1} \frac{V_y}{V_x}$$  \hspace{1cm} (7)

The demodulated data of the lock-in amplifier would pass to computer by data acquire card, NI-DAQ 6251. The resolution of the A/D converter has 16 bit accuracy and limitation of the input voltage can be expressed up to $\pm 10$ V. Since the output of lock-in amplifier is DC signal, we just set the sampling frequency of the data acquire card to 1 KHz.

3. Experiment Result

For reconstructing the impedance images from measurement data, a developed Matlab package for the EIDORS project is applied in this work [10]. The objective of EIDORS project (Electrical Impedance and Diffuse Optical Reconstruction Software) is to develop freely available software that can be deal with non-linear and ill-posed problem from boundary measurements. The FEM model of phantom is illustrated in figure 6. In Figure 6(a), the model, including 16 elements in circumference, is constructed for EIT configuration. In Figure 6(b), the model, including 80 elements in circumference, is constructed for rotary EIT configuration. The finite element solver included in this toolkit applies the complete electrode model to compute approximate solutions. For general geometries and inhomogeneous materials, the finite element method (FEM) is well suited to the task.

![Figure 6. FEM model of phantom: (a) for static EIT (b) for rotary EIT.](image)

In order to access the performance of REIT system, we measure the impedance image of sample which is put in a cylindrical tank filled with saline solution. The tank is 110mm in height and 170mm in diameter. The conductivity of the saline solution was 11mS-cm$^{-1}$. There are 16 compound...
electrodes located around circumference of tank averagely. Figure 7 depicts a typical experimental setup and overhead view of the REIT system.

![Figure 7. The experimental setup of the REIT system.](image)

To demonstrate the improvement of resolution in rotary EIT system, we compare the conductivity of phantom reconstructed from conventional EIT and REIT, separately. The Phantom tank with a metal object is illustrated in Figure 8. By applying the conventional EIT measurement configuration, we could reconstruct the conductivity image shown in Figure 9(a). The image reconstructed form REIT is shown in Figure 9(b). Because REIT collects more measurement data, REIT system could reconstruct the image with higher resolution FEM model. It is easier to identify the shape of sample and indicate the position of metal object in phantom tank in Figure 9(b).

![Figure 8. The Phantom tank with a metal object.](image)
Figure 9. Conductivity image in phantom tank: (a) from EIT (b) from REIT.

4. Conclusion
This rotative measurement method not only can increase the resolution of impedance images, but also reduce the complexity of measurement system. The authors have proposed simple rotative architecture in previous work (8 electrodes, small phantom). In this work, we improve the performance of measurement system to provide a feasibility of high performance impedance in REIT. However, it still exist some drawbacks in REIT. Rotating electrodes would increase the data acquiring period and bring the position error of electrodes. The great number of measurement data obtained from REIT will cause serious problem in image reconstruction. We hope the improvement of REIT will bring some help in electrical impedance tomography.

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