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Electrical Impedance Imaging Using Eddy Current

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***Abstract*—**Electric impedance imaging is a method of reconstructing spatial distribution of electrical conductivity inside a subject. In this paper, a new method of electrical impedance imaging using eddy current is proposed. The eddy current distribution in the body depends on the conductivity distribution and the magnetic field pattern. By changing the position of magnetic core, a set of voltage differences is measured with a pair of electrodes. This set of voltage differences is used in image reconstruction of conductivity distribution. The least square error minimization method is used as a reconstruction algorithm. The back projection algorithm is used to get two dimensional images. Based on this principle, a measurement system is developed and some model experiments were performed with a saline filled phantom. The shape of each model in the reconstructed image is similar to the corresponding model, respectively. From the results of these experiments, it is confirmed that the proposed method is applicable in the realization of electrical imaging.

***Keywords*—**Back projection algorithm, electrical impedance tomography, eddy current, magnetic inductance tomography.

I. INTRODUCTION

ELECTRIC impedance imaging is expected to be a very efficient and useful imaging method in biomedical sector. It requires very low level current. So, it dose not hazard in the human body and can be used for long time monitoring for intensive care of patient.

Many researches have been performed on Electric impedance imaging. Most common method is Electrical Impedance Tomography (EIT)[1]-[4]. In these methods current injection and voltage measurements are performed using electrodes attached to the body surface [1]. This method has the problem of requirement of large number of electrodes in order to get good image and yet to get image with reasonable accuracy. A contactless method, known as Magnetic Inductance Tomography (MIT) using magnetic field has been devised recently[5]-[9]. But in this method sensitivity at the central area is very low than that in the peripheral area[5].

A paper describing a method of electrical imaging applying tetra polar circuit method with eddy current has been submitted to the IEEE for publication in BME transaction[10][11]. In this method a constant alternating current was used along with the eddy current.

Here, we propose a new method of electrical impedance imaging using only two electrode bands for the measurement. The eddy current is produced by an alternating magnetic field. The detail description of the method will be discussed in the next section. To calculate the conductivities from the measurement data, we use least square error minimization technique. Well known back projection algorithm is used to generate the two dimensional image. Based on this principle we developed a measurement system and performed some model experiments.

II. METHOD

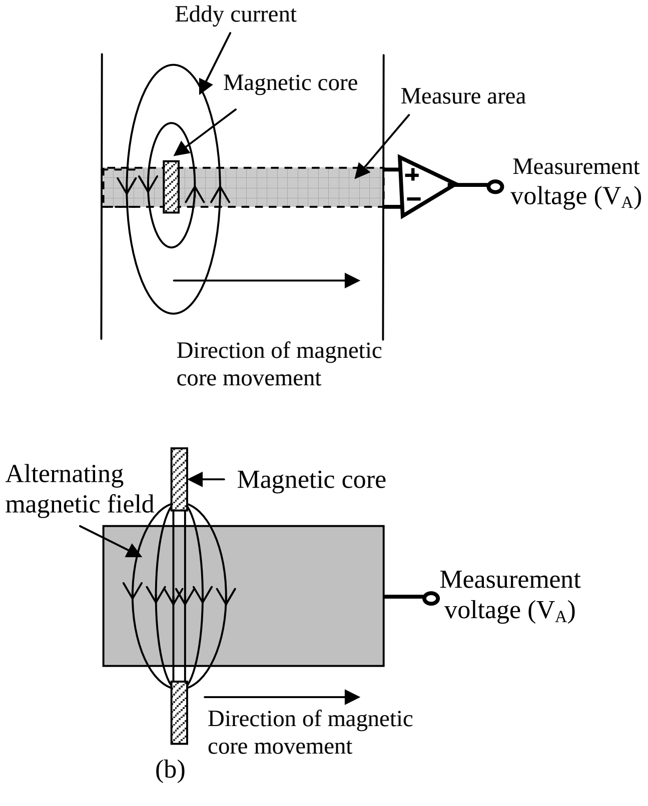

Fig. 1 Principle of the method (a) side view (b) top view

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Principle of this method is explained in Fig. 1. Two electrode bands are used at the top and the bottom of the measurement part of the body. Eddy current is produced by an alternating magnetic field. The current distribution in the subject is changed by shifting the magnetic core. During this shifting, the output voltage V_A is measured. This measured voltage V_A is used to calculate the conductivity distribution in the measurement region.

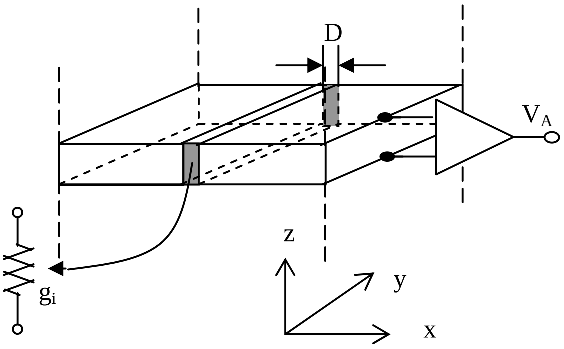
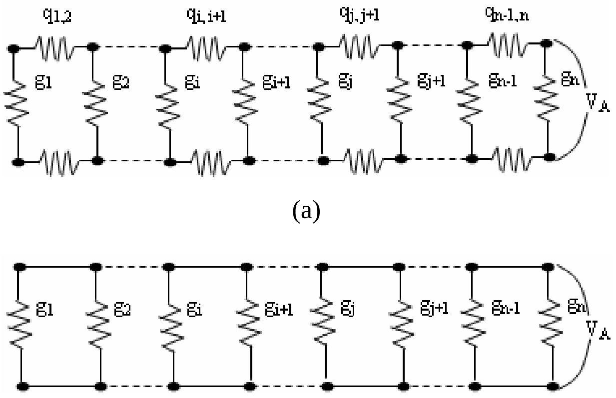


Fig. 2 Segmentation of measurement region

For the calculation of conductivity distribution, the measurement region is divided into n-segments as shown in Fig.2 and is considered as a combination of n-conductances in parallel as shown in Fig. 3 (a). Here, g_i is the average conductance of the i-th segment. The resistances between the segments are negligible and thus, the circuit can be simplified, as shown in Fig. 3 (b).



(a)

(b)

Fig. 3 Equivalent circuit of measurement region

When the magnetic field is applied by placing magnetic cores at position i on the x-axis, an electromotive force is produced in each segment as shown in Fig. 4. The electromotive force $e_{i,j}$ produced in j segment is proportional to the magnetic field intensity in the segment. We assume that the magnetic field intensity is uniform in the y and z directions in each segment. When the core position is at i , introducing a proportionality constant a, $e_{i,j}$ can be written as

$$e_{i,j} = af_{i,j}\,, \tag{1}$$

where, $f_{i,j}$ is the average value of magnetic field pattern f(x) over the segment j.

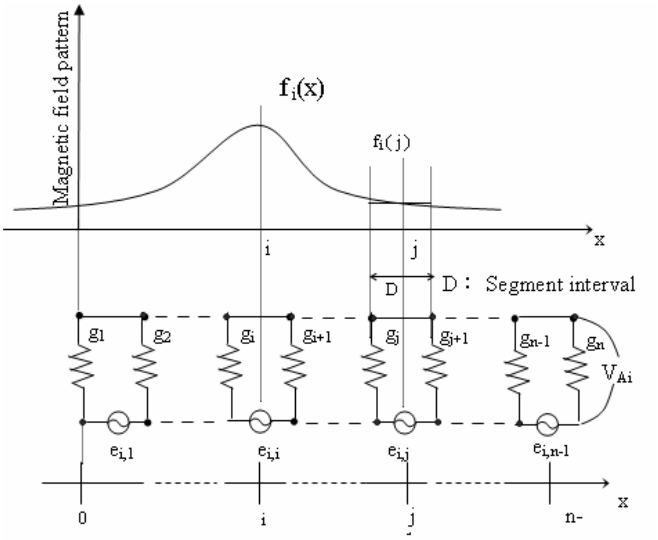


Fig. 4 Equivalent circuit with magnetic field

The eddy current $I_{i,n}$ through g_n can be calculated by applying the superposition theorem as

$$I_{i,n} = \frac{g_n}{G_{all}} e_{i,1} g_1 + \frac{g_n}{G_{all}} e_{i,2}(g_1 + g_2) + ... + \frac{g_n}{G_{all}} e_{i,n\text{-}1}(g_1 + g_2 + ...g_{n-1})$$

$$= \frac{g_n}{G_{all}} \sum_{j=1}^{n-1} e_{i,j} G_{1,j}\,, \tag{2}$$

where, $G_{1,j} = \sum_{k=1}^{j} g_k$.

Hence, the voltage V_A across g_n can be written as

$$V_{Ai} = \frac{1}{G_{all}} \sum_{j=1}^{n-1} e_{i,j} G_{1,j}\ .$$

Using (1), we get

$$V_{Ai} = \frac{a}{G_{all}} \sum_{j=1}^{n-1} f_{i,j} G_{1,j}\ .$$

$$\text{Or, } \sum_{j=1}^{n-1} f_{i,j} G_{1,j} = \frac{G_{all}}{a} V_{Ai}\ . \tag{3}$$

The left hand side of (3) can be rewritten as

$$\sum_{j=1}^{n-1} f_{i,j} G_{1,j} = F_{i,1} g_1 + F_{i,2} g_2 + ... + F_{i,n\text{-}1} g_{n-1}\,,$$

where $F_{i,m} = \sum_{k=m}^{n-1} f_{i,k}$.

Therefore (3) becomes

$$F_{i,1} g_1 + F_{i,2} g_2 + ... + F_{i,n\text{-}1} g_{n-1} = \frac{G_{all}}{a} V_{Ai} \tag{4}$$

This equation represents the relationship between the conductance of each segment and the voltage V_{Ai} when the core position is located at i. The value of G_{all}/a is constant and can be determined by proper calibration. For each core position (i=1 to i=n) we can get n similar equations. We describe these equations in matrix form as follows:

$$\mathbf{FG} = \mathbf{M}.$$

Where, G is n×1matrix of one dimensional conductivity distribution,
n is number of segments,
M is n×1 matrix of measurement data, and
F is n×n matrix determined by the magnetic field pattern.

Due to some measurement errors of V_{Ai} and magnetic field, we can not use the direct method for solving this equation. We use, therefore, the Least Square Error Minimization (LSEM) method and get one dimensional conductivity distribution of the body. Changing the direction of the measurements we get one dimensional conductivity distribution of each direction. From these distributions, we get two dimensional image of conductivity distribution using the Back Projection Algorithm.

III. MEASUREMENT SYSTEM AND EXPERIMENTS

A schematic diagram of the measurement system developed in this work is presented in Fig. 5. A saline filled glass tank is used as a phantom. The magnetic field is produced by applying an alternating driving current to a magnetic coil. The frequency of the driving current is 50 kHz.

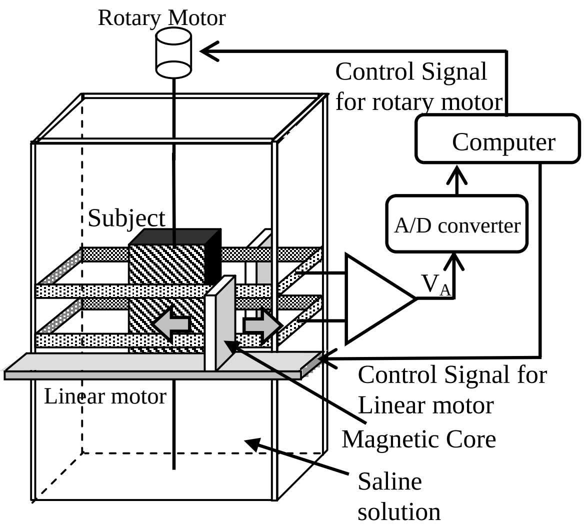


Fig. 5 Outline figure of measurement system

The voltage measurements are taken from one side of two electrode bands placed about the midway between the top and the bottom of the tank using a differential amplifier. The output from the differential amplifier, V_A, is recorded in computer memory through a 16 bit A/D converter. Shifting of the magnetic core is made by a linear motor. For the measurements from different directions, we rotate the model by a rotary motor. The linear motor and the rotary motor are operated using a computer through an appropriate interface system.

In our experiments, we use a phantom of size 8 cm long, 6 cm wide and 20 cm deep. The distance between the two voltage measurement electrodes is 2 cm. The magnetic core was shifted at 1 mm step which was equal to the segment width. Thus, each segment is 6 cm long, 0.1cm wide and 2 cm height. In two-dimensional image the segment size is 0.1x0.1 cm.

We perform measurements from the 40 equally spaced angles of a full rotation (360º) and make average of each reconstructed one-dimensional distribution with that when the object rotated 180º.

The magnetic field distribution along the x-axis is measured by using a coil of a size equal to that of one segment. As indicated by equation (4), we do not need the absolute value of magnetic field intensity but only the magnetic field pattern along the x-axis. Thus, the magnetic field intensity pattern is normalized, as shown in Fig. 6.

In our experiments the resistivities of the models are comparable to those of the human body. As very simple model, a square and a triangular shaped objects with conductivity of 1.387 mS/cm are placed separately in the saline solution of conductivity 3.403mS/cm. The both objects are made of conducting rubber. Next, we take measurements after cutting a small portion of the objects as shown in Fig.7 (shown by dotted line).

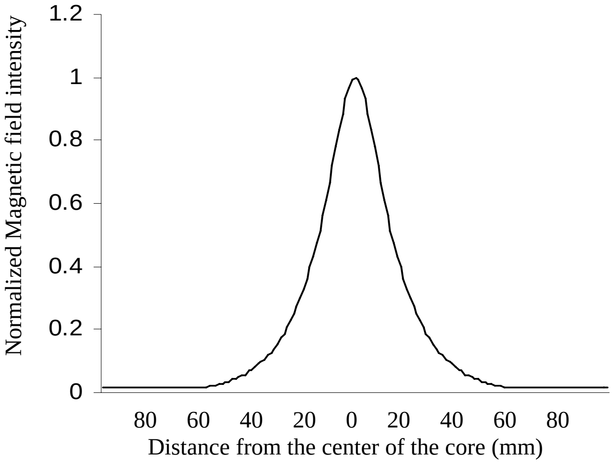


Fig. 6 Normalized magnetic field pattern

IV. RESULT

Fig. 7 shows the results using a square and a triangle objects. In this figure, the schematic outline of the original shape and size of the objects are shown in (a) and (b) with the reconstructed images shown in (c) and (d), respectively. (e) and (f) of Fig.7 show the reconstructed image after cutting a small portion of triangle and square object, respectively. As shown in Fig.7, the edges of the subjects are not as correct but the underlying shapes of objects can be estimated from the reconstructed images. The small change of subject can also be recognized in the reconstructed image as shown in Fig.7 (e) and (f).

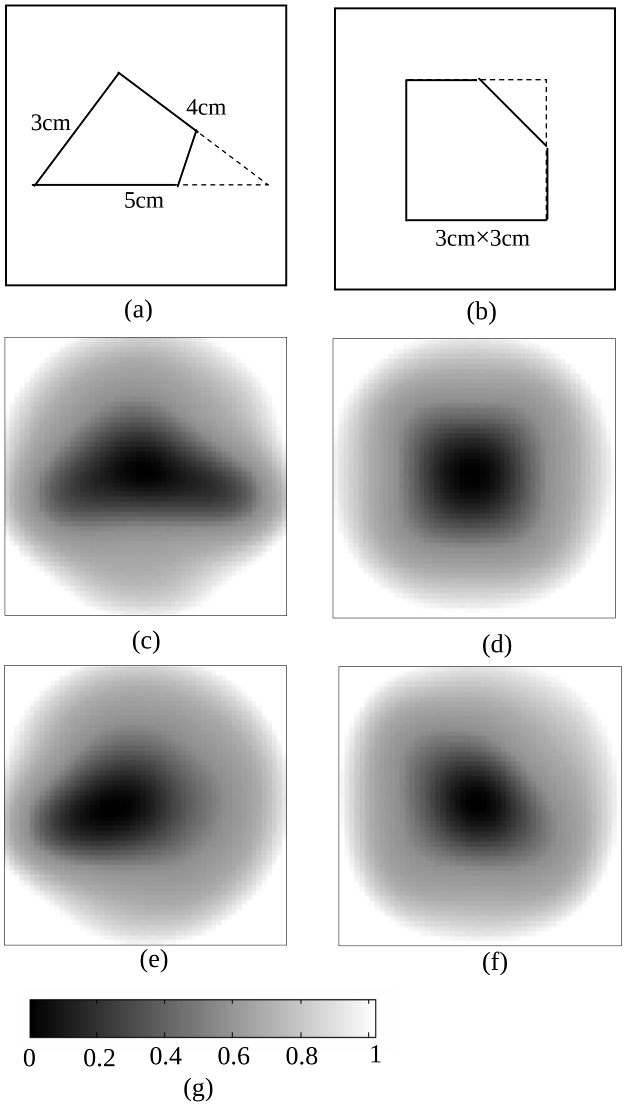


Fig. 7 Reconstructed images (a) and (b) Original shapes and sizes, (c)-(f) Reconstructed Images, and (g) color bar

V. DISCUSSION

We proposed a new method of electrical impedance imaging using eddy current. For every imaging system, there is a fundamental limit for the resolution which depends on the data points, i.e. the number of possible sensor-detector-combinations and the degree of independence between these data points. The number of independent data points is usually much lower than the number of voxels, so that the system is under-determined [7]. In our method, the spatial resolution depends on the shifting distance of the magnetic field, not on the number of electrodes, and the number of measurement is equal to the number of unknown variables.

In present, the shifting of magnetic field is performed mechanically, so the data acquisition time is about 40 minutes to get a two-dimensional image. However, it can be greatly reduced by shifting magnetic filed electrically. The data acquisition time can also be decreased by improving the data acquisition system, for example, using two current sources with different frequencies simultaneously and taking measurements from both sides.

Although, we used a small phantom in the tests, it can also be used in large case by simply scaling up the measurement system. This system can visualize only relative change of conductivity. We hope that using proper calibration technique it can recognize the absolute value. The results obtained so far demonstrate the feasibility of our method to image internal conductivity distribution of human body. However, to be used clinically, there still need improvement of measurement system, reconstruction algorithm and calibration technique.

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