Parameter estimation method of the biological tissue equivalent circuit model for local EIT

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Abstract— **Tissue impedance in beta dispersion region is expected to offer useful information for tissue structures, physiological states and functions. In short, electrical impedance tomography (EIT) is a technique that can reconstruct image of electrical impedance spatial distribution non-invasively in a biological tissue. Therefore, EIT is able not only to present information of tissue structure as well as existing X-ray computer tomography (CT), magnetic resonance imaging (MRI), ultrasound, and other medical imaging methods but also to give useful information of tissue function for diagnosis. However, there are several problems to achieve the practical use of EIT, which are an inverse algorithm for estimating parameters, and electrode configuration and so on.**

In our recent studies, we has proposed a new configuration of the electrodes, called "divided electrode", for a high-speed measurement of bio-impedance in a cross section of a local tissue.

The purpose of this study is to fundamentally investigate parameter estimation algorithm of the spatial distribution from measured impedance data. In this study, the cross section of the tissue was represented by spatial distributed equivalent circuits of tissue structure known, and their parameters were estimated by inverse algorithm. Models take account of tumor and contact impedance caused when measuring it. Estimation of impedance parameter is carried out by use of the Gauss-Newton method. As a result of the evaluation computer simulations, it is found from that the proposed method is very useful and practical as a new local tissue EIT technology.

Keywords— **divided electrode, bio-impedance, parameter estimation, Gauss-Newton method**

I. Introduction

Density distribution and density boundary information obtained by such as X-ray CT, MRI and ultrasound, are well used for recent medical tissue diagnosis. On the other hand, EIT has focused as a new method to obtain a tissue structures, and physiological functions and states of the tissue [1], [2]. It has obtained current and voltage measurements around the surface of a body as a result of applied a weak alternating current. The measurements are analyzed by various data restructuring algorithms, and they express it as 2-D or 3-D images of the electric impedance distribution in a living tissue. Though many researches have been reported [3], [4], [5], [6], [7] to realize the EIT for practical use, there remain several problems to be solved. The problems are inverse problem algorithm for estimating parameters, and electrode structure and arrangement for practical use.

So far bio-impedance information has been applied to macro measurement of lung functions [8], blood circulation functions [9], the amount of body composition [10], the amount of body fat, etc. However, these measurement methods attach a lot of electrodes to the body surface in general, and the measurement area is wide as well as a past medical imaging diagnosis device.

Incidentally, we examined usefulness of bio-impedance for diagnosis of tumor [11], [12], [13], [14], [15] and for estimation of subcutaneous structure [16], [17]. They focused on the local tissue, and measurement electrode and bio-impedance space distribution estimation has been studied. Based on these results, because bio-impedance not only makes to the image but also physiological states can be estimated if it is EIT restricted to the local tissue, it is considered that a more accurate diagnosis can be done by simultaneous using an existing medical imaging diagnosis device.

In our recent studies, a new configuration of the electrode, called "divided electrode", was proposed for a short time measurement of bio-impedance in a cross section of a local tissue [18], [19]. The cross section of the tissue was represented by space distributed equivalent circuits, and their parameters were estimated by inverse algorithm [20], [21], [22]. In this study, the possibility of estimating the parameter value of some layer structure models by using divided electrode is confirmed. These are models by whom tumor in tissue and contact impedance caused when measuring it are considered.

II. Methods

A. Divided electrode

Up until now measuring method of EIT has only attached around the body a lot of electrodes, and small alternating currents has applied to some of the electrodes. The response voltage is measured, and the process repeated for numerous different configurations of applied current. However, attaching a lot of electrodes to the surface of a body scarce the reproducibility of the measurement and the simplicity of measurement clinically. Moreover, it is very difficult for the current distribution to obtain the cross-sectional image the line like X-rays-CT with extension in three dimensions.

In this study, we used the divided electrode as a measurement electrode. Fig. 1(a) shows top view of the divided electrode. The voltage electrodes arranged at the center are divided into B parts $(v_1, v_2, \cdots, v_B)$. Moreover, the current electrodes arranged on both sides of the voltage electrodes are also divided into A parts $(i_1, i_2, \cdots, i_A)$. Then, the guard electrodes are arranged at the top and bottom with both sides (i_{A+1}, i_{A+2}) of the current electrodes. Currents flow from all the currents and the guard electrodes at the same time. At this time, the currents flow into the section S of the center without spreading as shown in Fig.1 (b), because guard currents hold down the measurement current from the both sides. Thus, the two-dimensional impedance distribution can be obtained [18], [19]. Therefore, unlike previous multi electrodes method, divided electrode is realized high-speed and high-resolution measurement.

B. Equivalent circuit model

Equivalent circuit is used as the model considered on the cell level. This is considered that each cell is expressed in an equivalent circuit, much they gather, and the biological tissue is constituted. In the case of a uniform living tissue, an equivalent circuit on tissue level is express by intracellular and extracellular resistances R_i, R_e and cell membrane capacitance C_m in beta dispersion.

Moreover, the cross section of layered tissue as shown in Fig.2 can be expressed in the two-dimensional distributed equivalent circuit. In this model, three parameters circuits are connected in the shape of a lattice. The electrodes are point electrodes.

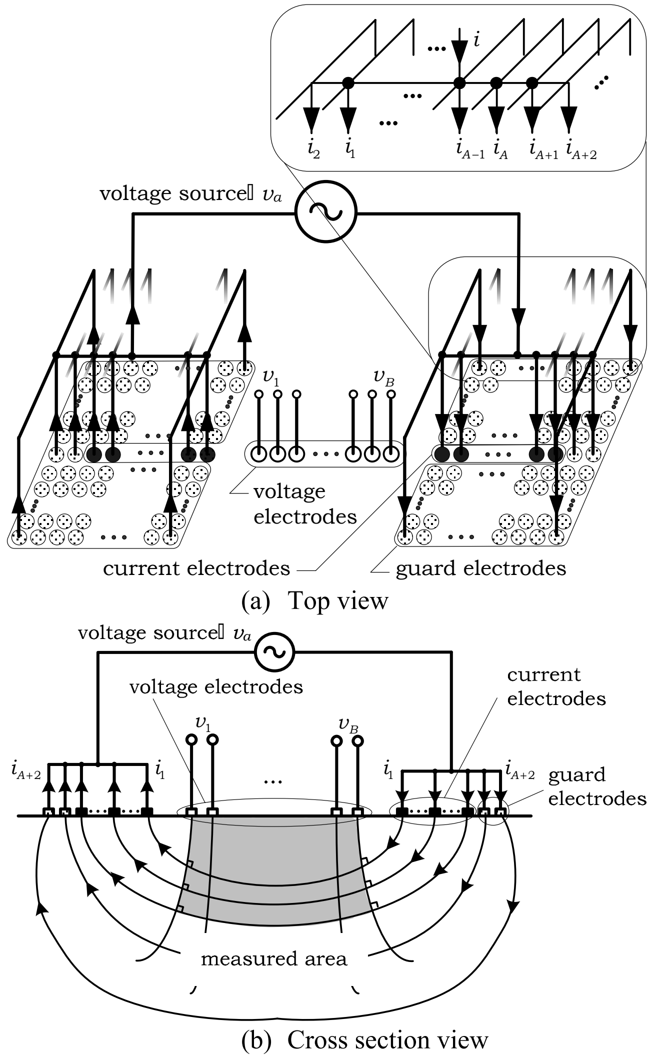

Fig. 1 Divided electrode

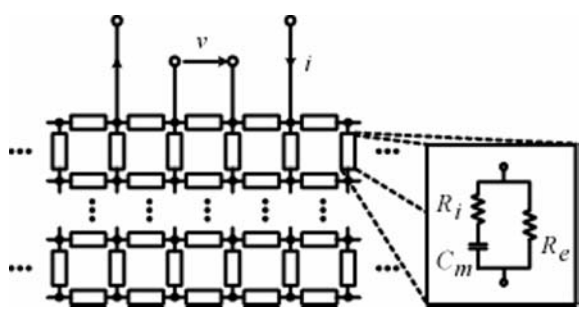

Fig. 2 Equivalent circuit model

C. Estimation method

In this subsection, parameter estimation method of equivalent circuit that adapts measured impedance data because of a minimum error is described. As mentioned above, impedance data $\mathbf{Z_D}$ of C are measured by the divided electrode consists of current electrodes of A part, voltage electrodes of B part. Moreover, if measurement frequency are set with $\omega_j(j=1\ldots\mathrm{U})$, it describe the following an estimate method of each parameter. Measured impedance $\mathbf{Z_D}$ can be expressed as following:

$$\mathbf{Z_D} = \left[Z_D^{(1)}(\omega_1), \cdots, Z_D^{(1)}(\omega_U), Z_D^{(2)}(\omega_1), \cdots, Z_D^{(C)}(\omega_U) \right]^T \quad (1)$$

On the other hand, the model connected to N equivalent circuits of three parameters in Fig.2 is considered. Parameter vector $\mathbf{p}$ is expressed as:

$$\mathbf{p} = \left[R_e(1), R_i(1), C_m(1), \cdots, R_e(N), R_i(N), C_m(N) \right]^T \quad (2)$$

where T is transposed matrix. And circuit model impedance $\mathbf{Z_M}$ is expressed as:

$$\mathbf{Z}_M(\mathbf{p}) = \begin{bmatrix} Z_M^{(1)}(\mathbf{p}, \omega_1) \\ \vdots \\ Z_M^{(1)}(\mathbf{p}, \omega_U) \\ Z_M^{(2)}(\mathbf{p}, \omega_1) \\ \vdots \\ Z_M^{(C)}(\mathbf{p}, \omega_U) \end{bmatrix} \quad (3)$$

The error $\varepsilon(\mathbf{p})$ of circuit model impedance $\mathbf{Z_M}$ and impedance data $\mathbf{Z_D}$ is defined by:

$$\varepsilon(\mathbf{p}) = \mathbf{Z}_M(\mathbf{p}) - \mathbf{Z}_D \quad (4)$$

To get the solution $\varepsilon(\mathbf{p})$ which equals 0, the Gauss-Newton method is used, i.e., $\delta\mathbf{p}$ is the change in parameter is given by:

$$-\frac{\partial \varepsilon\left(\mathbf{p}^{(t)}\right)}{\partial \mathbf{p}} \delta\mathbf{p}^{(t)} = \varepsilon\left(\mathbf{p}^{(t)}\right) \quad (5)$$

then,

$$\mathbf{X}\delta\mathbf{p} = \mathbf{Y} \quad (6)$$

$$\mathbf{X} = \left[\frac{\partial \varepsilon\left(\mathbf{p}^{(t)}, \omega_1\right)}{\partial \mathbf{p}}, \cdots, \frac{\partial \varepsilon\left(\mathbf{p}^{(t)}, \omega_U\right)}{\partial \mathbf{p}} \right]^T \quad (7)$$

$$\mathbf{Y} = \left[\varepsilon\left(\mathbf{p}^{(t)}, \omega_1\right)^T, \cdots, \varepsilon\left(\mathbf{p}^{(t)}, \omega_U\right)^T \right]^T \quad (8)$$

X is $U \bullet C \times 3N$ matrix and Y is U-dimensional vector here. X can be obtained from the numerical analysis of the circuit in Fig.2. Therefore, calculation of the least squares method of Eq. (6) expressed with Eq.(9) obtained $\delta\mathbf{p}$, which is parameter change from the initial model corresponding to measurement impedance.

$$\delta\mathbf{p} = \left(\mathbf{X}^T \overline{\mathbf{X}} + \overline{\mathbf{X}^T} \mathbf{X} \right)^{-1} \left(\mathbf{X}^T \overline{\mathbf{Y}} + \overline{\mathbf{X}^T} \mathbf{Y} \right) \quad (9)$$

III. Results and conclusions

In order to evaluate the usefulness of the proposed method, parameters of the two-dimensional distributed equivalent circuit model were estimated by using the computer simulations. As for two-dimensional distributed equivalent circuit model, a variety of circuit models were hit on but four simple layered structural models named model4 from model1 was used. Measurement area of this electrode is local tissue and breast is modeled here. Actual tissue is in the order of the skin, fat, the mammary gland, and muscle. Layer structure model composed of fat, the mammary gland, and the muscle as shown in Fig.3 is used because of the skin is thin when it sees relatively. The characteristic from model1 to model4 is described as follows. Model4 is shown in Fig.3 as one example.

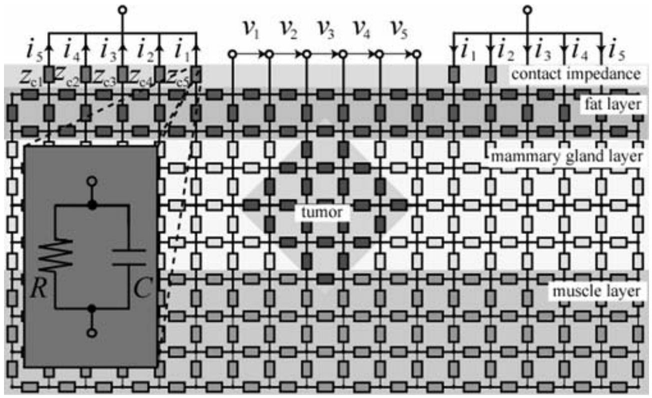

Fig. 3 Three-layered structure model with tumor considering contact impedance (Model4)

- Model1 is three layer structure model composed of fat, the mammary gland, and the muscle.
- Model2 has a tumor in the center of the second layer in model1.
- Model3 considered the contact impedance in model1. The contact impedance is impedance that influences the measurement result when we measure impedance of living tissue. Generally, when we measure impedance of living tissue, electrode paste is painted in order to increase conductivity. Then, contact impedance is about few [kΩ/cm^2][23]. Contact impedance consists of 2 parameters as shown in Fig.3.
- Model4 considered the contact impedance in model2.

The number of circuit elements totaled about 300 elements for calculation time reason.

Five current electrodes (from i_1 to i_5) and five voltage electrodes (from v_1 to v_5) are arranged at equal intervals, respectively. Measurement frequency points are 10 in range of 0 to 100kHz. At this time, the number of measurement data is 5×5×10=250. Here, because tissue in the direction of the electrode axis is uniform in layer structure model, the guard electrode located in the center part of right and left both edges of measured electrode shown in Fig.1 is not considered. Each parameter is estimated from 250 data using moderate initial values.

The parameter values are estimated correctly. Each relative error of estimated parameters are about 0.00% or less. And the error curve is collectively shown in Fig.4.

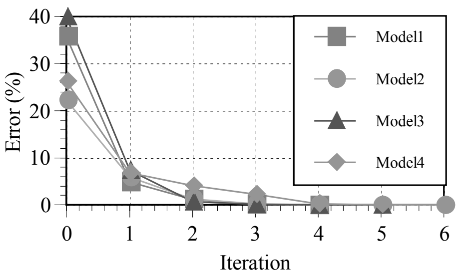

Fig. 4 Estimated result (error curve)

According to the results of the evaluation computer simulations, it is found from that the proposed method is very useful and practical as a new local EIT technology.

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