IDENTIFICATION OF SKIN TISSUE PARAMETERS FROM THE IMPEDANCE MEASURED OVER THE SKIN SURFACE - SIMULATION

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ABSTRACT

A skin tissue system is considered, whose configuration is electrically modelled by a layer over the infinite half space. The problem is to estimate the layer's thickness and respective conductivity from the measured impedance between the electrodes placed on the skin surface. A simulation is taken place as the optimization problem which is to minimize the norm between the "measured" and the solution for the assumed parameters.

1 INTRODUCTION

Electrical impedance between the electrodes placed in a half space has been investigated by the charge simulation method for the grounding system evaluation [1]. The half space is considered to be inhomogeneous, consisting of conductive-dielectric media. This configuration is widely found in electrical grounding systems and also in the tissue organ in human body. The charge simulation method provides a direct boundary element formulation.

The skin tissue system is here simply modelled by a layer over the half space, as shown in Fig. 1. The problem is to estimate the layer's thickness and two conductivities from the impedance measured between the electrodes placed on the skin surface. This inverse problem is considered as an optimization problem to which the genetic algorithm is used for the parameter identification. The objective function is defined as the error norm between the measured impedance and the solution for the model with assumed parameters. The calculation is repeated to minimize the objective function.

2 CHARGE SIMULATION METHOD

2.1 Boundary Integral Expression

We consider a conductive and inhomogeneous half space field. The same approach as shown in reference [1] is used in which the original inhomogeneous conductive field is transformed into the dielectric field due to the dual relation. The last one is then transformed into the homogeneous region with charges distributed over the interface boundaries. The transformation process is illustrated in Fig. 2 (a), (b) and (c) [1].

The conductive field can thus be treated by the charge simulation method [2].

The problem under consideration is now modeled by a system as shown in Fig. 2 (c), which is in more detail shown in Fig. 3 with nomenclature.

The electric potential $\phi(P)$ and electric field strength $\mathbf{E}(P)$ at arbitrary point P are given by

$$\phi(P) = \int_\Gamma G(P;Q)\,\rho(Q)\,ds \qquad (1)$$

$$\mathbf{E}(P) = \int_\Gamma \{-\nabla_P\, G(P;Q)\,\rho(Q)\}\,ds \qquad (2)$$

where $\rho(Q)$ is the charge density at arbitrary point Q over the boundary Γ, and G is the Green's function or

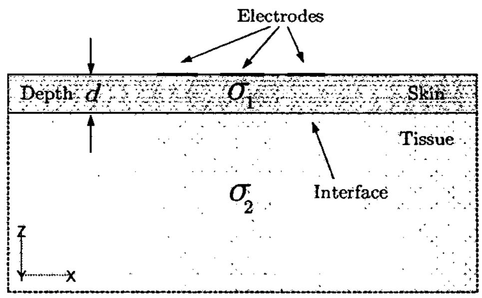


Fig. 1: Simple skin tissue system

fundamental solution defined by

$$G(P;Q) = \frac{1}{4\pi\varepsilon_0 r}, \quad r = |r_P - r_Q| = \overline{PQ} \quad (3)$$

The electric field strength at point C over the conductor surface Γ_1 is expressed by

$$\mathbf{E}(C) = \frac{1}{\varepsilon_0}\rho(C)\,\mathbf{n}(C) \quad (4)$$

where $\rho(C)$ is the charge density at C over the conductor surface and $\mathbf{n}(C)$ is the unit normal vector at C.

The two electric field strength $\mathbf{E}_1(F)$ and $\mathbf{E}_2(F)$ at point F in the figure over the boundary between the two dielectric regions (permittivity ε_1 and ε_2 originally) are expressed as

$$\left.\begin{array}{l} \mathbf{E}_1(F) = \mathbf{E}(F) + \mathbf{E}_0(F) \\ \mathbf{E}_2(F) = \mathbf{E}(F) - \mathbf{E}_0(F) \end{array}\right\} \quad (5)$$

where $\mathbf{E}_0(F)$ is the electric field strength due to $\rho(F)$ and $\mathbf{E}(F)$ is the electric field strength due to the contribution of other charges except $\rho(F)$. They are respectively evaluated as

$$\mathbf{E}_0(F) = \frac{1}{2\varepsilon_0}\rho(F)\,\mathbf{n}(F) \quad (6)$$

$$\mathbf{E}(F) = \int_{\Gamma - F}\{-\nabla_F\, G(F;Q)\,\rho(Q)\}\,ds \quad (7)$$

Referring to Fig. 2 (b), since there is no true charge over the interface between the two dielectric regions, the continuity of the electric displacement in the direction normal to the boundary implies that

$$\{\varepsilon_1\,\mathbf{E}_1(F) - \varepsilon_2\,\mathbf{E}_2(F)\}\cdot\mathbf{n}(F) = 0 \quad (8)$$

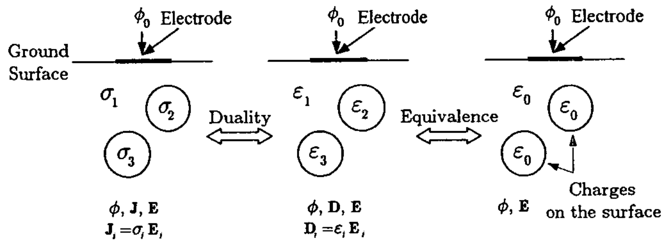
which, with the help of the expression (5), leads to

$$\left\{\varepsilon_1\left(\mathbf{E}(F) + \frac{1}{2\varepsilon_0}\rho(F)\,\mathbf{n}(F)\right) - \varepsilon_2\left(\mathbf{E}(F) - \frac{1}{2\varepsilon_0}\rho(F)\,\mathbf{n}(F)\right)\right\}\cdot\mathbf{n}(F) = 0 \quad on\ \Gamma_2 \quad (9)$$

which, also with the substitution of equation (7), leads to the expression

$$\frac{1}{2\varepsilon_0}\left(\frac{\varepsilon_1+\varepsilon_2}{\varepsilon_1-\varepsilon_2}\right)\rho(F) + \int_{\Gamma - F}\{-\nabla_F\, G(F;Q)\}\cdot\mathbf{n}(F)\,\rho(Q)\,ds = 0 \quad (10)$$

over the interface boundary surface on Γ_2.



(a) Conductive field (b) Dielectric field (c) Homogeneous field with surfaces changes

Fig. 2: Inhomogeneous half space field

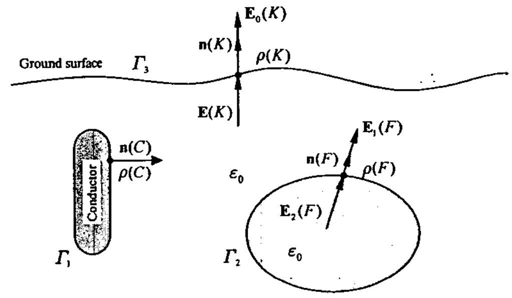


Fig. 3: Modelling of the field

2.2 Solution Procedure Method

For the numerical evaluation, the charge simulation method is used.

The boundary surface must be divided into elements for discretization. The conductor surface Γ_1 is divided into N_1 elements and other interfaces including Γ_2 and Γ_3 into N_2 elements.

The unknown surface charges placed on the elements are solved for the conductor potentials prescribed.

Equation (10) is discretized from which the linear algebraic expressions are derived

$$\begin{bmatrix} A_{ik} \\ B_{jk} \end{bmatrix}\{\rho_k\} = \begin{bmatrix} \{\phi_i\} \\ \{0\} \end{bmatrix} \quad (11)$$

where A_{ik} and B_{jk} are the components of the coefficient matrices, defined as

$$A_{ik} = \int_{\Delta s_k} G(i;k)\,ds_k \quad (12)$$

$$B_{jk} = \begin{cases} \int_{\Delta s_k}\{-\nabla_j G(i;k)\}\cdot\mathbf{n}_j\,ds_k & j \neq k \\ \frac{1}{2\varepsilon_0}\left(\frac{\varepsilon_1+\varepsilon_2}{\varepsilon_1-\varepsilon_2}\right) + \int_{\Delta s_k}\{-\nabla_j G(i;k)\}\cdot\mathbf{n}_j\,ds_j & j = k \end{cases} \quad (13)$$

i=1, 2, ⋯, $N_1 \in \Gamma_1$
j=1, 2, ⋯, $N_2 \in \Gamma_2 + \Gamma_3$
k=1, 2, ⋯, $N_1 + N_2 \in \Gamma_1 + \Gamma_2 + \Gamma_3$

where Δs_k refers to the area of the surface element k.

Triangular constant elements are employed and the evaluation of the coefficients is made using Gauss integration formula. The singularity in the second expression in equation (14) is analytically processed after the reference [3].

The electric potential and the electric field at arbitrary point P are thus calculated by

$$\phi(P) = \sum_{k=1}^{N_1+N_2} \left(\int_{\Delta s_k} G(P;K)\, ds_k \right) \rho_k \quad (14)$$

$$\mathbf{E}(P) = \sum_{k=1}^{N_1+N_2} \left(\int_{\Delta s_k} \{-\nabla_P\, G(P;K)\}\, ds_k \right) \rho_k \quad (15)$$

2.3 Input Impedance

In the previous section, we consider the dielectric field in place of the conductive field. The conductive field and dielectric field has the duality, so that

$$\mathbf{J}_i \equiv \mathbf{D}_i \qquad \varepsilon_i \equiv \sigma_i$$

That is

$$\mathbf{J}_i = \mathbf{D}_i = \varepsilon_i\, \mathbf{E}_i = \left(\frac{\varepsilon_i}{\varepsilon_0} \right) \rho_i\, \mathbf{n}_i \quad (16)$$

The total current through the conductor electrode for the potential ϕ applied to the electrodes is

$$I = \int_{\Gamma_1} \mathbf{J}_i\, ds_i = \sum_{i=1}^{N_1} \mathbf{J}_i\, \Delta s_i \quad on \quad \Gamma_1 \quad (17)$$

where Δs_i is the element surface area. The input resistance R is evaluated by

$$R = \frac{\phi}{I} \quad (18)$$

3 OPTIMIZATION AND GENETIC ALGORITHM

The objective function for the optimization is defined as

$$\epsilon = |R_{mes} - R_{cal}|^2 \quad (19)$$

where R_{mes} is the measured resistance, R_{cal} is the calculated resistance for the assumed parameters.

The genetic algorithm (GA) is here used for the optimization. The GA [4, 5, 6] is a search algorithm based on the mechanism of natural genetics and natural selection. It is known that it may converge to the global optimum without falling into the local optimum. The progress of the iterative calculation made through the following steps :

1. First an initial population is generated using random number. Each chromosome is structured with binary numbers.

2. The binary numbers are transformed to the real variable in such a way that

$$X = X_{min} + \frac{(X_{max} - X_{min})K}{2^N - 1} \quad (20)$$

   where $X_{min} \leq X \leq X_{max}$, N is the bit allocated for each chromosome, and K is the decimal number.

3. The error ϵ is evaluated for each generation.

4. The fitness $1/\epsilon$ of each chromosome in the population is evaluated.

5. Then, the next generation-population is determined out of the existing population depending on its fitness using the roulette wheel selection.

6. The reproduced individuals are crossed by using the cross-over-operator (one-point crossover) to form a new offspring.

7. The selected bits are swapped by the mutation operator. The next generation-population is thus made out.

The progress from step 2 to step 7 is iteratively repeated until the end condition is satisfied.

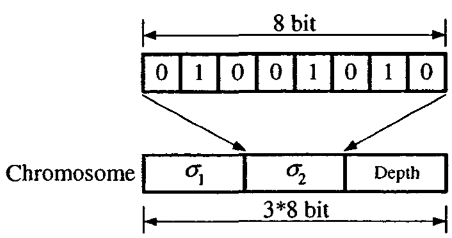
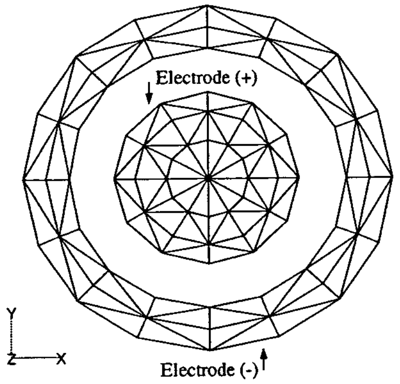
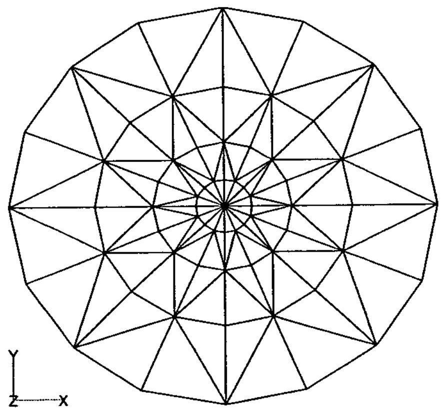


Fig. 4: Relation between chromosome's structure and parameters



Inner electrode(+) : number of elements=60
number of nodes=40, radius=0.005m
Outer electrode(-) : number of elements=64
number of nodes=51, radius=0.0075m/0.01m

(a) Element division on the electrodes



number of elements=112, number of nodes=69
domain radius=0.04m

(b) Element division on the interface boundary

Fig. 5: Surface element division

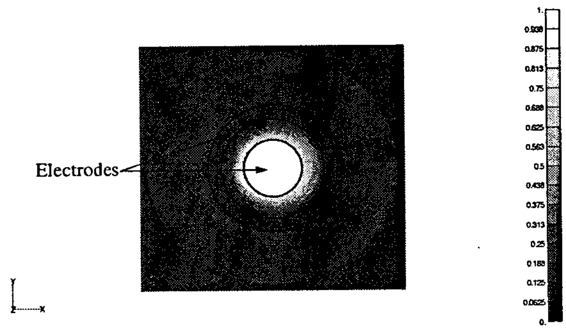
4 NUMERICAL DEMONSTRATION

The case of a layer (σ_1, d) on the half space (σ_2), as shown in Fig. 5, is considered. In the present modelling, there is only three parameters to be identified. Each chromosome is structured with binary $3 \times N$ bit, where N is chosen to be 8 (see Fig. 4). The population is chosen to be 50, the crossover rate be 0.4 and the mutation rate be 0.05. The calculation is iteratively repeated until 100th generation.

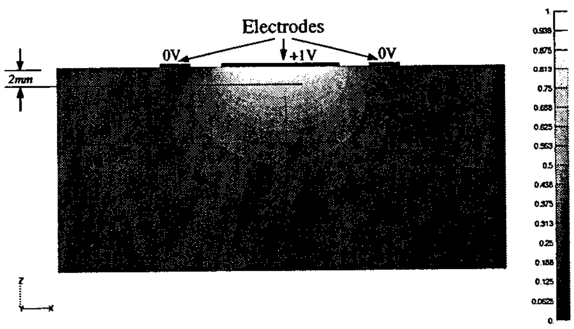
The co-axial electrodes as shown in Fig. 5 (a) are considered over the skin surface, between which the potential +1V is applied. The interface between the two media must be divided into the elements, which is shown in Fig. 5 (b). Its radius is chosen $0.04m$, 4 times as big of surface the electrode's.

For a skin tissue system, the parameters are chosen, $\sigma_1=1.0\mho/m$, $\sigma_2=1.6\mho/m$ and the skin depth d=-$0.002m$. In this case, the calculated terminal resistance is 19.549Ω. The potential distribution near the electrodes is shown in Fig. 6. When the size of outer electrode is enlarged to 0.01125m/0.015m and 0.015m/0.02m, the resistances are respectively 22.192 and 23.335Ω.

In the identification problem, the two conductivities, σ_1 and σ_2 and depth d are unknown and to be searched. The searching range of conductivities and depth are respectively from 0 to 2.04 and from 0 to 0.00408. Conversion is reached at 16th iterations by GA. Steps of the individuals and the mean square error are shown at Fig. 7 and Fig. 8. The individuals has reached the optimum values 1, 1.6 and 0.002, which are represented by the line in the figures.



(a) Top view (xy space)



(b) Cross-sectional view (xz space)

Fig. 6: Potential distribution

5 CONCLUDING REMARKS

Identification of a skin-tissue system was taken as a conductive field problem, in which a simple case was successfully demonstrated. To be more precise, the field should be considered as a conductive-dielectric field. The procedure can easily be extended to coping with this situation with a little modification, whose example will be presented at the symposium.

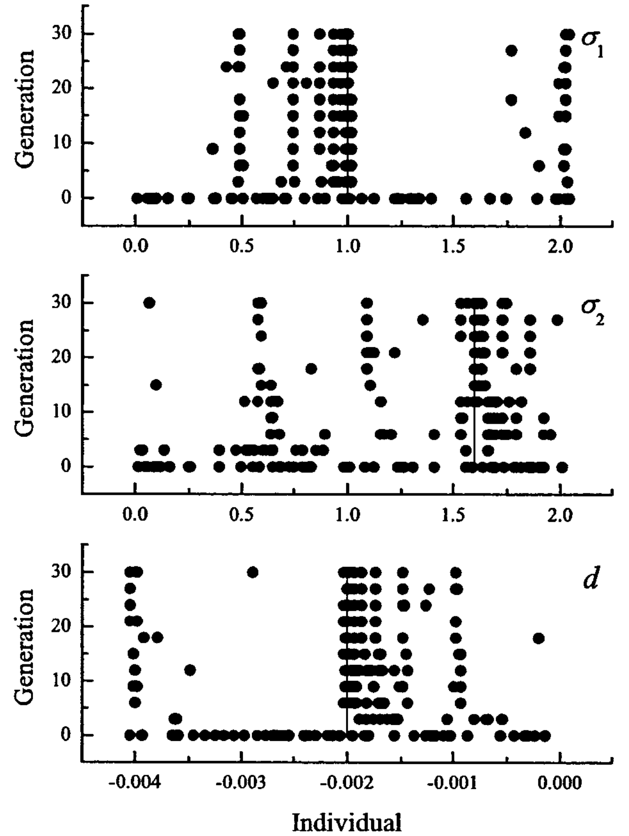


Fig. 7: The distribution of each individual

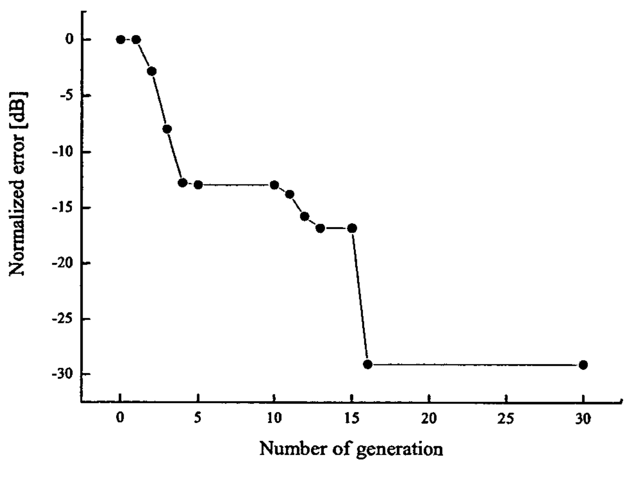


Fig. 8: Mean square error

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