NON-LAYERED HUMAN HEAD MODEL FOR EEG

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Abstract - **The paper suggested a new method in human head modelling by directly considering and studying the head as a inhomogeneous subject consisting of many small homogeneous meshes. Therefore the inherent head tissue inhomogeneity which is widely ignored in the existing models is included. An approach is derived to handle the resulting complexity. The simulation results have shown promising applications in EEG.**
Keyword - **Head Model, EEG, Inhomogene**

I. INTRODUCTION

The bioelectric fields produced in the human head can be mathematically described by Maxwell equation. In the frequency range of the EEG signals (0-100Hz) the volume conductor can be considered purely resistive, so that a quasi-static approximation is justified [1]. For the electrostatic problems in dielectric volume conductors, an electric field, E, can be described as

$$\nabla(\sigma\nabla V) = \nabla Ji = -Isv \quad \text{in } \Omega \qquad (1)$$

with $V=V_0$ on S_{cut}

$$\sigma(\nabla V)n = 0 \quad \text{on surface of } \Omega \qquad (2)$$

where I_{sv} is internal current source per unit volume, and Ω bounded volume domain.

One important parameter in above equations is σ which represents the tissue conductivity of human head. It is a scalar while the tissue is isotropic and a 3×3 symmetric matrix while anisotropic. Obviously, the conductivity of the tissues at each point plays a key role in solving this field potential problem since the conductivity of biological tissues determines current flow within tissue and is directly related to the potentials measured on the scalp. Actually, a lot of effect has been made to measure the bio-conductivity even since the discovery of bio-electric events. The data appeared in the literature as early as 1902 for animal tissues and 1932 for human tissues [1]. L. A. Geddes and L. E. Baker later compiled and published these data in 1967 [2]. Recently further studies have been done. Law described the procedures for measuring the conductivity of human skull tissue and concluded that the conductivity of human tissues varies with location even for the same type of tissue. At best the conductivity of tissues can only be estimated [3]. Y. Wang *et al* found that both the measurement instruments and the measured tissue samples affect the measurement accuracy and the measurement error would be even bigger in vivo since it usually involve large tissue size [4].

For the above problem an analytic solution is available only while the domain Ω is simple and homogeneous. In the human head case, some numerical techniques must be employed since the complicated head structure and inhomogeneity. One of the most common used numerical technique is Finite Element Method (FEM).

In the computation of EEG using FEM, the human head is modelled by a large number of elements; each represents a different area of the head with its own unique conductivity. Not only do the elements representing different tissues have unique conductivities, but also do the elements representing the same type of tissue. The latter is due to the complex composition of the tissue. For instance, the elements in the brain may have different conductivities, since they may contain different proportions of blood vessels, white matter, grey matter, *etc*. Experimentally measured values of conductivity for grey matter increase as a function of the measuring signal frequency (*e.g.*, $0.33(\Omega m)^{-1}$@5Hz, $0.43(\Omega m)^{-1}$@5kHz, *etc*.). White matter has conductivity $1.76(\Omega m)^{-1}$@5Hz, and has been shown to be anisotropic with the ratio of conductivities varying between 5.7-9.4 [3]. The conductivity of the CSF surrounding the brain is generally accepted to be $1.0(\Omega m)^{-1}$. In the skull's case, the element conductivity may differ for elements composed purely of cancellous bone or compact bone, or some combination of the two. Its resistivity varies between 1360Ω-cm and 21400Ω-cm, with a mean of 7560Ω-cm and a standard deviation of 4230Ω-cm. All models reported in the literature use the value of $0.33(\Omega m)^{-1}$ for the scalp conductivity [1]. No allowance has been made for the conductivity of the underlying muscle (0.0076-$0.52(\Omega m)^{-1}$), or subcutaneous fat (0.02-$0.07(\Omega m)^{-1}$) [4]. With such widely varying values of conductivity, it is impossible (or at least not easy) to measure and set an exact conductivity for each element.

II. METHODOLOGY

Given that the conductivities of the elements for the same tissue are relatively close in comparison with those for different tissues, the conductivities of the elements in a tissue can therefore be assumed to follow a distribution as:

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\frac{(x-\mu)^2}{\sigma^2}} \qquad (3)$$

where μ is the mean conductivity and σ is the standard deviation. The curve of *f(x)* is symmetric with respect to $x = \mu$ because the exponent contains $(x-\mu)^2$. Changing μ corresponds to translating the centre of the curve to another position. σ^2 is the variance. For small σ^2, the conductivities of the elements within a tissue are tightly centred around the mean, and for $\sigma^2 = 0$, all conductivities are the same – as assumed in the current literature. Conversely, with increasing

0-7803-7944-6/03/$17.00©2003 IEEE.

σ^2, the conductivities of the elements are more widely distributed. From the assumption given in equation (3), a set of statistical parameters (namely, μ and σ) can be derived for a tissue type from the limited data available for that tissue in the literature. For example, the skull has the most scattered distribution, its mean resisitivity and standard deviation are 7560 cm/s and 4230 cm/s. Therefore, the standard deviation assumed to be 4230/7560=50% of the mean. CSF is a type of liquid. Its conductivity is commonly considered as constant anywhere. Obviously, it is reasonable to let its standard deviation to be zero. As for the brain cases, their means are commonly accepted as 0.33 s/m and the standard deviation are set to 30% of their means based on the available data. Then, a range of conductivity values – the *pseudo conductivities* – can be generated to fit the Normal distribution which is specifically defined by μ and σ. These pseudo conductivities are allocated to the component elements belonging to that tissue. Then the human head is considered as a totally inhomogeneous conductor. Their conductivity values are different point from point, but very close within a small range, for example, in a small mesh. Therefore, the small mesh can be considered as homogeneous. The whole head model is an inhomogeneous one but consists of small homogeneous meshes. The conductivity values of the meshes are interpreted from the data measured at the points close to the mesh. For example, the values for the meshes in brain will be estimated using the conductivity values of grey matter, white matter and blood. To simplify the computation and save memory, the meshes can only be set with the values in a given range and in a digital form. For example, the meshes in the skull will get their resistivities in range of $\mu \pm \sigma$, that is between 7560 - 4230 and 7560 + 4230. The values will appear as discretized number such as 7550, 7555, 7560 *etc*., that is there are only limited values available. To make our model more comprehensive, it can be re-described as: The model consists of N meshes and P nodes. Each mesh can have any one of the M values as its conductivity. There are P1 internal nodes and P2 marginal nodes and P1+P2=P. If a current dipole is put in a mesh of the model and we want to find the potentials at all the nodes, then it can be considered as an EEG problem.

To test the above model, a set of simulation studies are carried out. Firstly, a sphere head model is supposed. The radius of the model is 10cm and it consists of 12482 tetrohedral meshes. The conductivity of the meshes are 0.25 s/m, 1.0 s/m and 1.75 s/m. According to our head model method, though there are only three conductivity values available, there will be 3^{12482} possible set parameters for the model. Obviously, it is impossible to carry out computation for each case. To demonstrate the feasibility of our approach, a head model is selected randomly to represent the true head. There are 7568 meshes with conductivity of 1 s/m, 4310 meshes with conductivity of 0.25 and 352 meshes with conductivity of 1.75. They make 60.2%, 34.2% and 5.6% contribution to the model conductivity respectively.

The computation begins with a homogeneous sphere model with conductivity of 1. The model is adjusted gradually close to the supposed true one by including more and more inhomogeneous meshes in each computation. To evaluate the performance of these computations, the statistic parameters root mean square error (R_{rms}), relative error (R_{rel}) and maximum error (R_{max}) are employed. The comparisons are done among the values evaluated from these simulations. The results obtained are shown in table 1.

The potential to use this model is tested in the following study. First, a sphere head model with radius 10cm and conductivity 0.33 s/m is used. Next is a three-sphere model with radii 0.087/0.092/0.1m and conductivities 0.33/0.0042/0.33s/m for brain, skull and scalp respectively. A head model with pseudo conductivity is taken as the true model. The pseudo conductivity of this model is derived based on the assumption that their mean conductivities μ are 0.33/0.0042/0.33s/m, and STD σ 30%/50%/30% of their means for brain, skull and scalp respectively. The statistical results from these computations are listed in table 2.

III. RESULTS AND CONCLUSIONS

The possible way to construct individual head model is explored in the paper. The simulation results confirmed that it is a promising way although there are a lot of work to be done in the future. The current problem is how to include more measured location-related data into our model and reduce the number of model data sets. Another trend is to explore the efficiency of annealing algorithm in our problem.

Table 1 Evaluated Performance

	HomO.	Inhomo. I	Inhomo. II	True
R_{rel}	106.6%	91.7%	60.2%	0
R_{rms}	0.0016	0.0014	0.0009	0
R_{max}	0.0069	0.0065	0.0033	0

Table 2 Evaluated Performance

	Homo.	3-Sphere	True
R_{rel}	90.63%	72.2%	0
R_{rms}	0.0019	0.0011	0
R_{max}	0.0044	0.0031	0

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