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Improved EEG Source Localization for an Isotropic Multi - Spherical Head Model

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Abstract*—Human head comprises multiple layers and tissues. The aim of this work is to investigate the effect of conductivity variation, due to presence of Gray matter and White matter in Brain, on Source Localization in Electroencephalography (EEG). Particle Swarm Optimization (PSO) Algorithm, a global optimization algorithm, has been used for finding Inverse Solution of EEG. It has been found that a five-spherical head model comprising, Scalp, Skull, CSF, Gray Matter and White Matter give better performance in source localization than a four spherical head model comprising, Scalp, Skull, CSF and Brain.

***Index Terms*— EEG, Head Models, PSO, Source Localization.**

I. INTRODUCTION

Knowledge of the electrical conductivity distribution in human body is important to many biomedical applications [1]. Various brain disease and brain function activities are reported to be dependent on conductivities of human head tissues [2] [3]. Neural activity, modeled with a distribution of current sources, within the human brain produces electrical potentials which are transmitted through various tissues of the head to the surface of the scalp. These electrical potentials can be measured by Electroencephalography (EEG) using scalp electrodes. The method of estimating the current distribution from measured EEG is known as EEG Source Localization [4] [5] [6].

EEG source localization or source analysis is done in two steps, the solution of forward problem and the inverse problem. The computation of the potential distribution, when the geometry of the sources and the medium are given is called the forward problem [7]. The inverse problem is to estimate the sources, for a given medium and a known potential distribution on a set of electrodes [7]. Since for the inverse algorithm, the solution of the forward problem has to be known, it is of prime importance to calculate the forward problem as accurately as possible in order to reconstruct the source location precisely.

II. HEAD MODELS

A number of mathematical models have been developed to generate solution of forward problem. Each forward model involves a conductivity model for the head [8]. Different head models proposed till now are: the homogeneous sphere model [9], the three sphere model [8] [10], the four sphere model [8] [11], the isotropic multisphere model [12] [14], the anisotropic multisphere model [13] [14], the five layer model [14] and the realistic head model [15].

A three layer head model comprises of brain, skull and scalp. In [8], the three layer head model is proposed. The conductivity of each layer was assumed to be isotropic. The conductivity of head is not uniform throughout. It consists of a Cerebrospinal Fluid (CSF) layer whose conductivity is quite high in comparison to other brain tissues. A four layer head model comprising, Scalp, Skull, CSF and Brain is proposed in [16].

Literature [14] indicates further classification of brain into Gray Matter (GM) and White Matter (WM) and assigning anisotropic conductivities to WM while isotropic conductivities to GM and other layers of head model.

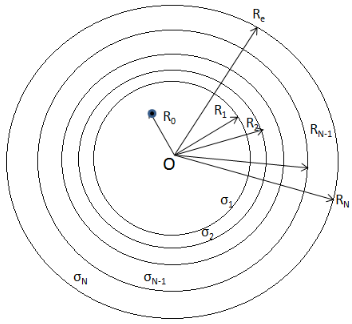

Figure 1. A Dipole within an N layer Isotropic Sphere

Sphere-shaped head models are computationally efficient in forward problem formulation and estimation, since they allow using analytical solutions. Of course, they seriously lack in geometrical adherence of the assumed shape with respect to a real human head. Modeling errors produced by the differences between the actual head and the volume conductor model affect the accuracy of the EEG forward and hence of the inverse problem solution, as the observed scalp potentials are determined not only by the location and strength of the neural generators but also by the geometry and the conductive properties of the head. Modeling errors include differences in actual head and model shape, skull thickness, and electrical conductivities of the head tissues.

In this work, multi-spherical Head Model (Fig. 1) is taken with isotropic conductivities. According to the head model, the observed potential on the N-layer sphere surface at Re [17] is given by Equation 1.

The radii and conductivity for three-spherical, four spherical and five spherical head model is given in Table 1.

Table 1
Head model parameters for three, four layer and five layer Isotropic Spheres

Head	Layer	Radii (cm)	Isotropic Conductivity (mho)

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Three Layered	Scalp Skull Brain	10 9.4 8.7	0.33 0.0042 0.33
Four Layered	Scalp Skull CSF Brain	10 9.4 8.7 8.5	0.33 0.0042 1.0 0.33
Five Layered	Scalp Skull CSF Gray Matter White Matter	10 9.4 8.7 8.5 6.7	0.33 0.0042 1.0 0.33 0.14

Forward solutions of five layer models are compared with those of four layered head model and three layered head model where it was found that Head model with 5 layers produces less error in comparison to other two models.

III. SOURCE LOCALIZATION

Several Source reconstruction methods have been developed to provide more and more accurate solutions to the inverse EEG problem. In this work, Particle Swarm Optimization (PSO) Algorithm has been used for source localization

The PSO algorithm

In PSO, a swarm of N particles is created. PSO then optimizes the problem by having these N population particles and moving these particles around in the search-space according to the mathematical formulae over the particle's position and velocity. Each particle's movement is influenced by its local best known position and is also guided toward the global best known positions in the search-space, which are updated as better positions are found by other particles. This is expected to move the swarm toward the best solutions. The PSO algorithm used in this work is described as follows:

Step 1: Initialize the swarm of particles, N, uniformly distributed in a hyperspace.

Step 2: Evaluate the fitness of each particle using its current position.

Step 3: Compare the present fitness with fitness evaluated so far. If the particle's current position is better than the previous best position, update it.

Step 4: Compare the fitness of each particle to the global best particle. Update the global best particle.

Step 5: Update each particle's velocity as [8]:

$$\overrightarrow{\boldsymbol{v_{id}}} = \boldsymbol{\chi}\left(\boldsymbol{v_{id}} + \boldsymbol{c_1}\,\boldsymbol{\epsilon_1}\,(\boldsymbol{p_{id}} - \boldsymbol{x_{id}}) + \boldsymbol{c_2}\,\boldsymbol{\epsilon_2}\,(\boldsymbol{p_{gd}} + \boldsymbol{x_{id}})\right), \quad (2)$$

where, x_{id} is a possible solution(Dipole Location) defined by the i^{th} particle location in the search space, p_{id} is its best solution and p_{gd} is the global best solution among all particles until the current iteration. χ= 0.72984, $c_1 = c_2 = 2.05$.

Step 6: Update position of each particle:

$$x_{id} = v_{id} + x_{id} \quad , \qquad (3)$$

Step 7: Move to step 2 and repeat until convergence.

IV. EXPERIMENT AND RESULT

For demonstration, we have synthetically generated EEG for head model with known dipole location. EEG is measured using 10-20 Electrode System. For implementing this, the entire work has been done in three phases:

Phase I: Development of Head models. Three, Four and Five Concentric Isotropic Layer Head models are designed.

Phase II: Designing Electrode System. Internationally accepted 10-20 Electrode System is used for forward EEG calculation.

Phase III: Design and Implementation of Source Localization Algorithm. Particle Swarm Optimization Algorithm, with N particles, has been used for Source Localization.

Starting with N=6 particles, distributed over entire head, the PSO converges to find one best dipole position after going through 50 iterations. The table below shows the result of applying PSO to a three spherical, four spherical and five spherical head model over two test locations: (i) Location (30,20,30), (ii) Dipole Location (-10,10.0).

Table 2

Original Dipole Location for two Dipoles and the Reconstructed Dipole Locations

		P	$\dot{P}$	$\grave{P}$	$\tilde{P}$
Dipole Location (1)	Rx(mm)	30	25.55	29.96	28.59
	Ry(mm)	20	29.28	20.07	20.00
	Rz(mm)	30	26.18	26.85	29.99
Dipole Location (2)	Rx(mm)	-10	-8.73	-9.31	-9.35
	Ry(mm)	10	-8.46	8.84	8.84
	Rz(mm)	0	9.84	7.29	4.45

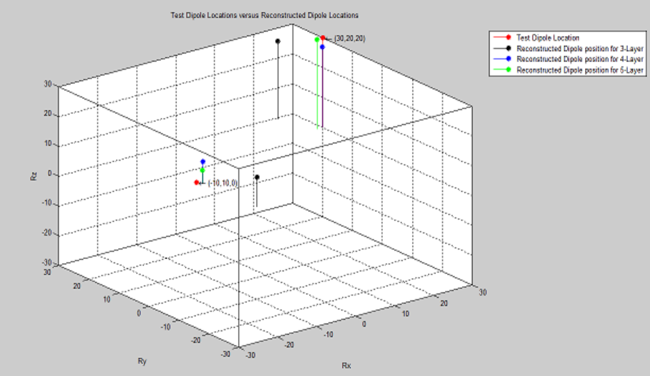

Figure 2. Original Dipole in red color with reconstructed dipole in black, blue and green color respectively for three spherical, four spherical and five spherical head models.

V. CONCLUSION

Conductivity in the head varies with different tissues and shows significant effects on source localization [15]. In this work, we have partitioned CSF into white matter and gray matter and then implemented the source reconstruction algorithm. Results have shown that when the head is modeled precisely by taking into account more layers, source reconstruction is better and more accurate. The accuracy obtained is less than 0.5mm. The reconstruction for both test dipoles shows that a five spherical head model localizes the original test dipole more accurately than a four spherical head model. The three spherical head model performs the worst in source localization amongst all. So, it is necessary to model the head as close to realistic head as possible. Even better results are expected when the conductivity variations are taken into account as within each layer also, there are tissues whose conductivity is different in transverse and tangential directions. A realistic head model with more tissues and varying conductivity when used with source construction algorithm, is supposed to perform much better source localization.

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$$V = \frac{D}{4\pi\sigma_n R_e^2} \sum_{n=1}^{\infty} \frac{2n+1}{n} \left(\frac{R_0}{R_e}\right)^{n-1} f_n \left[ncos\alpha P_n(cos\gamma) + \quad cos\beta\ sin\alpha\ P_n^1(cos\gamma)\right], \tag{1}$$

where,

$$f_n = \frac{n}{[nm_{22} + (1+n)m_{21}]}; \qquad \begin{bmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{bmatrix} = \frac{1}{(2n+1)^{N-1}} \text{x} \prod_{k=1}^{N-1} \begin{bmatrix} n + (n+1)\frac{\sigma_k}{\sigma_{k+1}} & (n+1)(\frac{\sigma_k}{\sigma_{k+1}} - 1)\left(\frac{R_e}{R_k}\right)^{2n+1} \\ n(\frac{\sigma_k}{\sigma_{k+1}} - 1)\left(\frac{R_k}{R_e}\right)^{2n+1} & \left[(n+1) + n\frac{\sigma_k}{\sigma_{k+1}}\right] \end{bmatrix}$$