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ACTIVE SOURCE LOCALIZATION INSIDE OF MULTILAYERED 3D BEM MODEL WITH THE AID OF WAVELET TRANSFORMATION

ABSTRACT *Boundary Element Method for simulation of spatially heterogeneous objects of electroencephalography is presented in this paper. The four layer spherical model (representing skin, skull, CSF layer and brain) of the real head approximated with isoparametric six nodes triangles was considered. Forward problem for active source localization was presented in this paper.*

Keywords: *boundary element method, active source localization, wavelet transformation, forward problem*

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1. INTRODUCTION

Boundary Element Method [1] (BEM) in active source localization process require construction of matrices, in which information about shape and material coefficients of the object are stored. Boundary of the object can be approximated by triangle elements of zero-order or by isoparametric elements of the second-order. Multilayered object consists of homogeneous regions, coupled by interfaces. The final system of equations for the whole object is obtained by adding the set of boundary integral equations of governing equation for each region in conjunction with compatibility and equilibrium conditions between their interfaces. Different equations and boundary conditions are used to the numerical analysis. Poisson equation with Neumann boundary conditions and internal active source (current dipole) was used in localization process. Simplified head model with an internal active source (as a group of active neurons in stimulated region of the brain) was used in presented work. Potential distribution V on the boundary of the object under consideration can be determined by BEM [3]. Those regions and its conductivities corresponds with anatomical description of a human head:

- cerebral cortex, 0.33 S/m,
- cerebrospinal fluid (CSF), 1.0 S/m,
- skull, 0.0042 S/m to 0.042 S/m,
- skin, 0.33 S/m.

2. MULTILAYERED MODEL WITH ACTIVE SOURCES

Boundary element method was used to build the multilayered numerical model. The object and internal active source was describing by integral equation:

$$\frac{1}{2}\mathbf{V}(\mathbf{r}) + \int_{\Gamma} \frac{\partial}{\partial n} G(\mathbf{r}_p, \mathbf{r}_q) \mathbf{V}(\mathbf{r}_q) d\Gamma = \int_{\Gamma} \frac{\partial \mathbf{V}(\mathbf{r}_q)}{\partial n} G(\mathbf{r}_p, \mathbf{r}_q) d\Gamma + \int_{\Omega} \text{div } \mathbf{j} G(\mathbf{r}_s, \mathbf{r}_q) d\Omega \quad (1)$$

where $G(\mathbf{r}_p, \mathbf{r}_q)$ is a Green function defined by eq. (2).

$$G(\mathbf{r}_P, \mathbf{r}_Q) = \frac{1}{4\pi r} \quad (2)$$

and r in equation (2) is equal to $r = \|\mathbf{r} - \mathbf{r}'\|$. Linear system of equations was obtained after integration.

$$\mathbf{A}\mathbf{V}(r) = \mathbf{B} \frac{\partial \mathbf{V}}{\partial n} + \frac{1}{\sigma} \mathbf{I}(\mathbf{r}_0, \mathbf{r}') \quad (3)$$

Then, after rearranging and multiplying the right hand side the final system of equations has the following form (see Fig. 1):

$$\mathbf{A}\mathbf{V}(r) = \frac{1}{\sigma} \mathbf{I}(\mathbf{r}_0, \mathbf{r}') \quad (4)$$

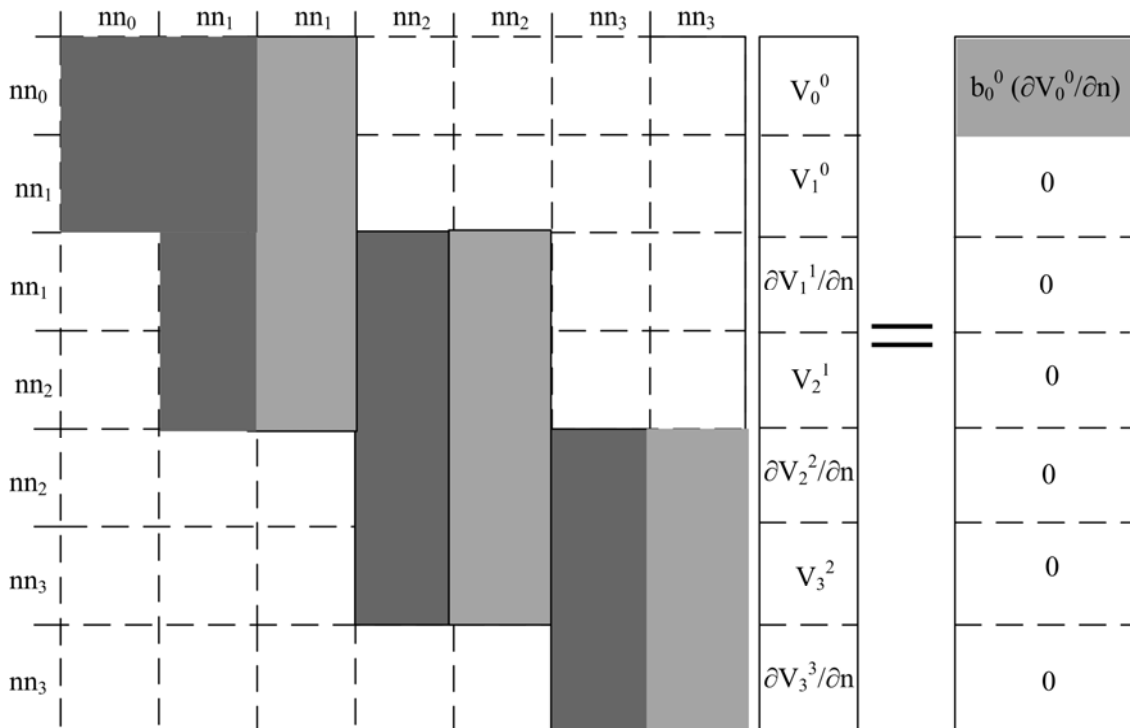


Fig. 1. System of equations with compatibility and equilibrium conditions, after rearranging

Boundary Element Method with second-order boundary elements was used in this case. The shape of the human head is more precisely approximated

by this kind of boundary elements. Four-layered (skin, skull, cerebrospinal fluid (CSF) and brain) model was investigated (Fig. 2).

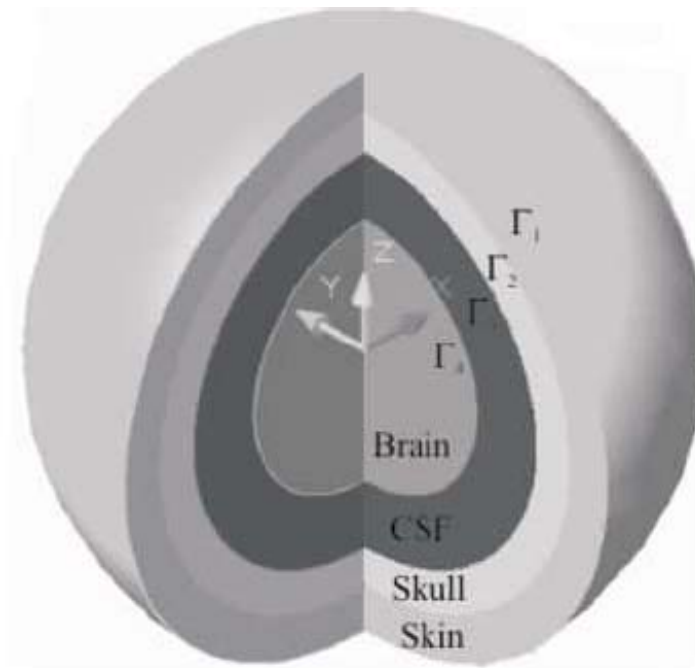


Fig. 2. Four-layered simplified head model (section)

3. ACTIVE SOURCE LOCALIZATION

In the inverse problem the dipole position was calculated by the knowledge about potentials distribution on the surface of the model. The inverse problem was solved by iterative method. Variable Metric algorithm with BFGS [4, 6] scheme was used in this case.

In our investigation influence of noise for accuracy of the active source localization was checked. The signal to noise ratio from 0 % to 15 % was used. If the signal to noise ratio was equal 15 % the active source localization was good because maximal absolute error was less than five and half millimeters (it was about 2.2 % of object dimension). If the signal to noise ratio was equal 5 percent the absolute error was less than one and half millimeter (it was about 0.6 % of object dimension). Results of experiments were presented in the table 1.

TABLE 1

Noise effect on the dipole localization accuracy

Noise [%]	δx_+ [mm]	δy_+ [mm]	δz_+ [mm]	δx_- [mm]	δy_- [mm]	δz_- [mm]
0	0	0	0	0	0	0
0.5	0.1390	0.0460	0.1260	0.1470	0.0460	0.1400
2.5	0.6830	0.2210	0.6710	0.7180	0.2210	0.7470
5	1.3300	0.4290	1.4200	1.3940	0.4250	1.5840
10	2.4330	0.8710	3.0370	2.5350	0.8570	3.4280
15	4.3680	1.2320	4.8740	4.5330	1.2060	5.4270

The trajectory of dipole displacement in iteration process is presented on the Fig. 3. The final stage was shown scaled-up.

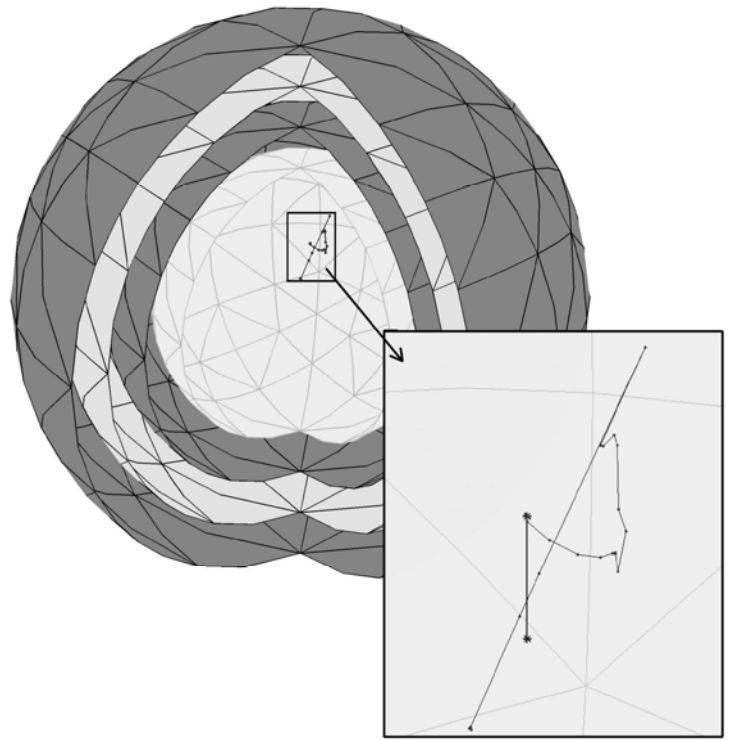


Fig. 3. Current dipole localization inside the brain in four-layered simplified head model, and localization trajectory (right-bottom corner)

Source localization for the four layer spherical model is presented on the Fig. 3. We can see four layered spherical model with starting and final (optimal) points.

4. FAST WAVELET TRANSFORM

Inverse problem was solved iteratively, so the CPU time for each iteration is crucial. In the multilayered BEM we obtained block nonsymmetric matrix and solution time increased dramatically with matrix size. Fast discrete wavelet transform (DWT) and fast wavelet transform based on binary partition techniques (BFWT), introduced in [5] was applied to make matrix sparse. In the first case matrix size must equal to 2^n , where n was integer number; $n > 0$, so we have to add additional columns and rows to fulfill this condition. The BFWT technique can be applied to matrices with arbitrary sizes. Sparsity of matrices $s = (\text{number of non-zero elements} / \text{number of elements})$ and solution time of forward problem where compared. We define S coefficient as $S = (s_t / s) 100 \%$, where s and s_t sparsity of the matrix before and after transformation adequately.

TABLE 2
Wavelet transformation comparison

matrix size	transform	solver	S [%]	time [s]
8078×8078	–	GMRES	–	352.90
	BFWT	GMRES	28.49	389.21
	BFWT	BICGSTAB	28.49	354.10
	DWT	GMRES	26.89	–
	DWT	BICGSTAB	26.89	416.00
10766×10766	–	GMRES	–	776.41
	BFWT	GMRES	22.60	630.29
	–	BICGSTAB	–	946.86
	BFWT	BICGSTAB	22.60	610.25

In the table 2 the solution times were presented. GMRES and BICGSTAB solver was compared. DWT and BFWT wasn't good for matrix which size is less then 8078×8078. When matrix size is 10766×10766 application of BFWT technique reduced solving time about 30 %.

5. CONCLUSION

Active source localization in four layer simplified head model was good, even then the signal was disturb of 15 % white noise.

When we used DWT or BFWT, in spite of the loss of information the solution is precise enough (about 2 %). Inverse problem was solved much faster after using discrete wavelet transformation, because we've got a sparse matrix.

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LOKALIZACJA AKTYWNOŚCI ELEKTRYCZNEJ
W PRZESTRZENNYCH MODELACH
WIELOWARSTWOWYCH
Z ZASTOSOWANIEM METODY ELEMENTÓW
BRZEGOWYCH I TRANSFORMATY FALKOWEJ

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STRESZCZENIE *W artykule przedstawiono lokalizację aktywności elektrycznej w przestrzennych obiektach wielowarstwowych. Do budowy numerycznego obiektu zastosowano metodę elementów brzegowych. Uproszczony. Uproszczoną czterowarstwową głowę zawierającą modele skóry, czaszki, płynów mózgowo rdzeniowych (CSF) oraz mózgu aproksymowano sześciowęzłowymi trójkątami isoparametrycznymi. Przedstawiono sposób formułowania równań oraz metodę rozwiązania zadania prostego oraz możliwość przyspieszenia obliczeń poprzez zastosowanie transformaty falkowej. W artykule pokazano wpływ stosunku sygnału do szumu (SNR) na dokładność rozwiązania zadania odwrotnego.*