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Dipole Source Localization in Magnetocardiography

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Abstract- **Dipole source localization (DSL) is complicated as it involves solving electromagnetic inverse problems in Magnetocardiography (MCG). The accuracy of the inverse solutions depends upon the adequacy of the forward model and the DSL algorithm used. We have developed two simplified models based on double magnetic dipoles source and a single current dipole source respectively. In this paper, the inverse solutions of DSL using Levenberg-Marquart (LM) algorithm and Nelder-Mead algorithm (NM) were discussed. Numeral simulations were performed using the MCG data generated from two different graphical models, which were reconstructed in terms of the parameter character of the real MCG measurements. An analysis of the average localization error in the ST-T segment at different noise levels and with different initial values was given. Our results indicated that the NM algorithm for both models works effectively in the case of initial values having 10% random noise. Furthermore, the localization accuracy less than 1 mm has been achieved in our research.**

I. INTRODUCTION

The Equivalent Current Dipole (ECD) model is widely used to characterize and localize cardiac sources in magnetocardiography. The localization accuracy of 10 - 20 mm has been reported, when comparing MCG results with those obtained at cardiac surgery, electrophysiological studies and by ECG localization [1]. Furthermore, the Boundary-Element Method (BEM) was also used to approximate the electrical conductivity profile of the human torso combining with the Magnetic Resonance Imaging (MRI) data on solving cardiac magnetic forward and inverse problems [2].

In the recent study, we have developed a new double magnetic dipoles simplified source model and a single current dipole source model. In this work, the method assumes that the human body is a semi-infinite homogeneous conductor. The bio-magnetic sources are modeled by two magnetic dipoles, the magnetic moments of which are along the vertical axis in the different direction. Figure 1 shows the magnetic field map (MFM) due to two magnetic dipoles located a distance below and perpendicular to the measuring plane. It has been considered that two simplified double magnetic dipoles are similar to a single current dipole, because the magnetic field lines of two magnetic dipoles follow circular paths perpendicular to the direction of an equivalent current dipole, which is parallel to the measurement plane. For this simplified model, a necessary condition is: one of magnetic moments should be positive, and the other should be negative mathematically. From figure 1, we can find that two magnetic dipoles relate to the surfing and the sinking at the same time respectively.

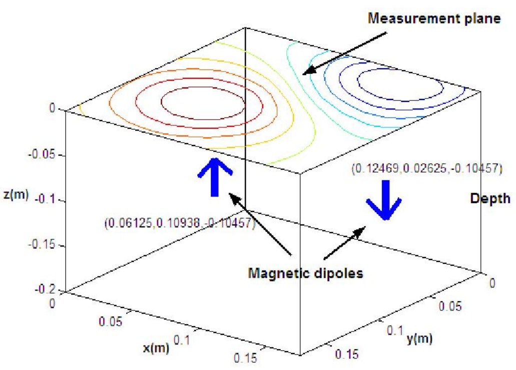

Fig. 1 Double magnetic dipoles in T peak time

To compare the double magnetic dipoles simplified source model and the single current dipole source model in the inverse solutions of DSL, a kind of graphical model was created for computer simulation. It is assumed that MCG data of the graphical model generated by a known electrical or magnetic sources in addition to ongoing background heart activity. Furthermore, the localization results with two source models using Levenberg-Marquart algorithm and Nelder-Mead algorithm are demonstrated respectively. The accuracy of localization in different noise levels and initial values is also evaluated.

II. FORWARD PROBLEM

According to Biot-Savart's law, when the magnetic field strength is measured along the axis direction of SQUID, an equivalent current dipole source model can be obtained, where 5 parameters are used for the source description [3].

However, it is assumed that the cardiac magnetic field is generated by a magnetic dipole as show in figure 2.

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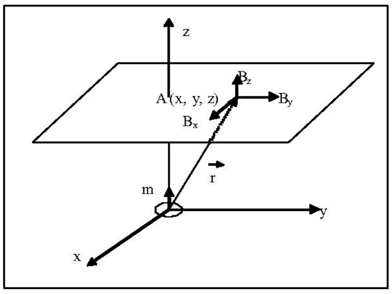


Fig. 2 Magnetic field generated by a magnetic dipole

Were m denotes the magnetic moment, which direction is along the z-axis. The magnetic field strength can be calculated by the system of equations as follows [4]:

$$\begin{cases} B_x = \dfrac{m}{4\pi} \cdot \dfrac{3xz}{(x^2+y^2+z^2)^{5/2}} \\ B_y = \dfrac{m}{4\pi} \cdot \dfrac{3yz}{(x^2+y^2+z^2)^{5/2}} \\ B_z = \dfrac{m}{4\pi} \cdot \dfrac{2z^2-x^2-y^2}{(x^2+y^2+z^2)^{5/2}} \end{cases} \qquad (1)$$

Based on Equation (1), a new double magnetic source model as mentioned above, which contains 8 parameters, has been developed by us [5]. It has more degree of freedom for the source description.

III. SIMULATION AND RESULTS

The inverse problems, using the MCG-recordings to determine the magnitude and location of the electrophysiological sources mathematically, can be solved by means of non-linear local optimization algorithms. There are two types of procedures: one is Levenberg-Marquart algorithm and the other is Nelder-Mead algorithm.

In order to achieve more reliable DSL results in a computer simulation, we created a kind of graphical model to approximate the space between the electrical source (involved volume conductors) and measuring sites.

A. Graphical model

A graphical model is a type of magnetic field map reconstructed by us using the real magnetocardiographic measurements, in which the magnetic field strength can be generated by a known electrical dipole or two magnetic dipoles. Figure 3 illustrates the approach on reconstructing a graphical model. The parameters of the source model are estimated by using the LM or NM algorithm. Then a graphical model can be reconstructed according to the parameter character.

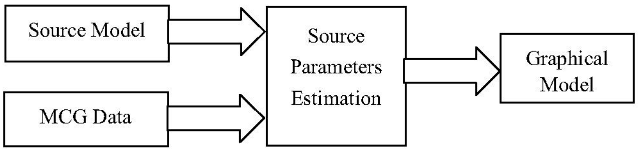
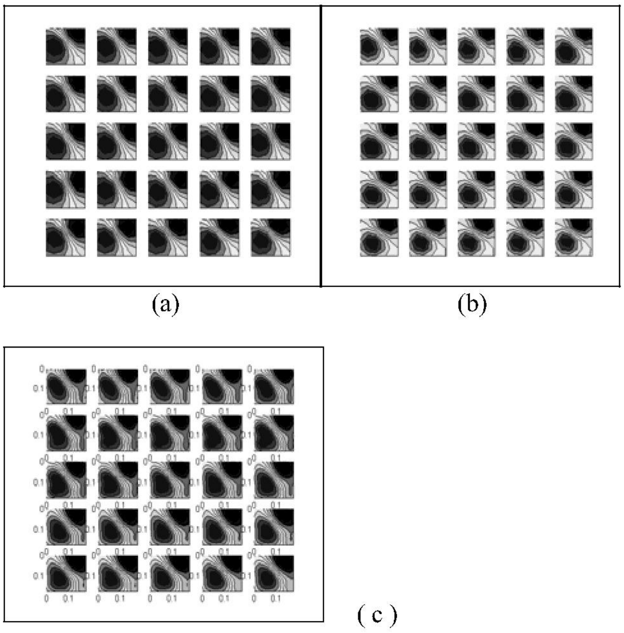


Fig. 3 Approach of reconstructing a graphical model

Two reconstructed graphical models and MFMs of MCG measurements of the subject are shown in figure 4.


(a) (b)

(c)

Fig. 4 Two graphical models and MFMs of the MCG measurements

Where (a) is the graphical model for the single current dipole, (b) is the double magnetic dipoles graphical model, (c) denotes the MFMs of MCG measurement of the subject. It can be found that the double magnetic dipoles graphical model performs better reconstruction than the single current dipole model, which can reveal the character on the measured MCG pattern with an appropriate depth.

To analyze the localization accuracy at different noise level, the additional noise is modeled using 5% and 10% uniform Gaussian white noise (GWN) separately. It is also assumed that the initial values have 10% random noise and no noise cases.

B. Single current dipole model

In the simulation of DSL with the single current dipole model, the initial values were discussed in two cases: one is the accurate value and the other is the initial value with additional 10% noises. The average localization errors in ST-T segment are listed in Table I.

TABLE I
AVERAGE LOCALIZATION ERRORS OF SINGLE CURRENT DIPOLE MODEL IN ST-T SEGMENT (MM)

Initial values Data noises	Accurate		10% random	
	LM	NM	LM	NM
No noise	1.141 e-007	0	0.7462	5.510 e-005
5% noise	6.014 e-003	8.554 e-003	0.8401	0.008365
10% noise	0.2676	0.4501	0.7799	0.01629

Table I shows that the NM algorithm performs better than the LM algorithm in the case of the initial value having 10% random noise specially. The average localization errors of two algorithms are less than 1 mm in ST-T segment.

C. Double magnetic dipoles model

Similarly, the initial values are also discussed in two cases for the double magnetic dipoles model.

The DSL results are shown in Table II, where the localization errors are the average values in 100 ms of ST-T segment.

TABLE II
AVERAGE LOCALIZATION ERRORS OF THE DOUBLE MAGNETIC DIPOLES MODEL IN ST-T SEGMENT (MM)

Initial values Data noises	Accurate		10% random	
	LM	NM	LM	NM
No noise	1.450e-007	0	0.1458	2.196e-003
5% noise	0.01892	0.02159	0.1378	0.02141
10% noise	0.03901	0.04442	0.1519	0.04462

The results of Table II indicates that the average localization errors of LM algorithm are less than that of the NM algorithm in the case of accurate initial values, but the NM algorithm is better in the case of initial values having 10% random noise. The localization accuracy of two algorithms also is all less than 1 mm in ST-T segment.

IV. CONCLUSIONS

The results of Table I and II show that the double magnetic dipoles simplified source model is useful to solve the cardiac DSL problem. Furthermore, the double magnetic dipoles graphical model performs better reconstruction than the single current dipole model, which can reveal the character on the measured MCG pattern with an appropriate depth.

A kind of graphical model is suggested, which is reconstructed with real MCG measurements. This model can be used to approximate the space between the electrical sources (involved volume conductors) and the middle measuring sites corresponding to the linear part of the zero magnetic field line only.

The localization errors, influence of different noise level and initial values based on two types of source models and two localization algorithms are discussed. The results indicate that the NM algorithm for both models works effectively in the case of initial values having 10% random noise. Furthermore, the localization accuracy less than 1 mm has been achieved for both models and algorithms in a computer simulation.

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