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A Graphical Model for the Cardiac Multi-dipole Sources

Shiqin Jiang, *Member, IEEE*, Jiaming Dong, Ming Chi, and Weiyuan Wang

***Abstract*—A multi-dipole graphical model, which is constructed by MCG measurements based on equivalent current dipole (ECD) model or equivalent magnetic dipole (EMD) source model, has been developed. This model can be used in place of the existing heart-torso model for dipole source localization or source estimation. Simulation results are presented, which indicate that the multi-dipole graphical model can effectively approximate the detected MCG.**

I. Introduction

In order to investigate human cardiac electromagnetic activity, the issue of how to reconstruct bio-magnetic or bioelectric source from detected MCG data has to be addressed.

The volume conductor model, such as boundary element model (BEM), was reported [1]. The method uses the magnetic resonance imaging (MRI) data and assigns different conductivity value to each compartment, i.e., the conductivity of the tissue is assumed to be isotropic and piecewise homogeneous. After that, for both research purposes and clinical application, a simple model is proposed upon which one can describe more easily the varying magnetic field and conductivity properties of the tissue [2].

In recent study, we have developed a graphical model (GM), which can be used to describe the activity magnetic field between detected MCG data and cardiac electromagnetic sources. This method avoids the complexity of calculating volume conduction, tissues profiles and eliminates the need for MRI data.

Furthermore, we proposed two multi-dipole source models known as the double magnetic dipole source model (DMD) and the dual current dipole source model (DCD), respectively. The multi-dipole graphical model can be constructed by MCG measurements based on these source models.

Compared with the single dipole source model (SCD), the double magnetic dipole model is more suitable for experimental implementation. The DCD can be used to research the method of constructing multi-dipole source models.

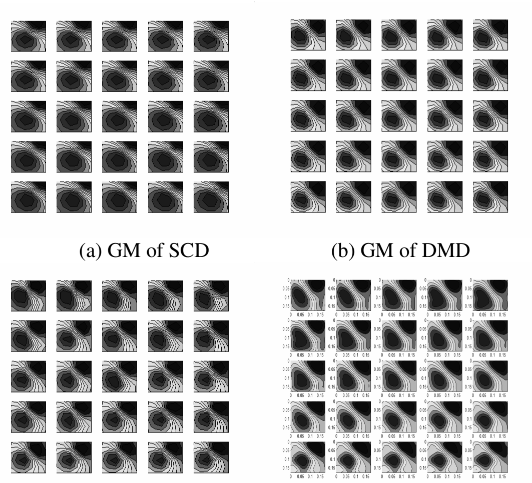
Although the solution of electromagnetic inverse problem is complicated due to the ill-posedness, or the non-linearity of the problem, particularly, the inherent dynamical variety, our method combined with the Nelder-Mead algorithm (NM) has been preliminarily proved to be effective in parameter estimation [3].

II. Principle of the Method

A. Graphical model

The graphical model is represented by a set of magnetic field maps (MFM), which is reconstructed by MCG measurements based on the source model. It can be used to describe the activity process and the variation of the cardiac magnetic field distribution over the body surface. Three graphical models in terms of different source models are shown in Figure 1. Each graphical model includes 25 magnetic field maps with a time interval of 4ms during 100ms in ST-T segment.

The procedure for model construction is illustrated in Figure 2. It is implemented by three steps: initial values choice, source estimation, and GM construction in terms of source parameters which is estimated by applying the NM algorithm. Finally, the GM is optimized by a target function.



(a) GM of SCD (b) GM of DMD

(c) GM of DCD (d) MFMs of detected MCG

Fig. 1. Three graphical models and the MFM of the detected MCG

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Shiqin Jiang is now with the School of Electronics and Information Engineering, Tongji University, Shanghai, CO 200092 China (phone: 8621-65708334; e-mail: sqjiang@mail.tongji.edu.cn).

Jiaming Dong is now with the School of Electronics and Information Engineering, Tongji University, Shanghai, CO 200092 China (e-mail: feixuxi@163.com).

Ming Chi is now with the School of Electronics and Information Engineering, Tongji University, Shanghai, CO 200092 China (e-mail: 0520080153@smail.tongji.edu.cn).

Weiyuan Wang is now with the School of Electronics and Information Engineering, Tongji University, Shanghai, CO 200092 China (e-mail: w.weiyuan@hotmail.com).

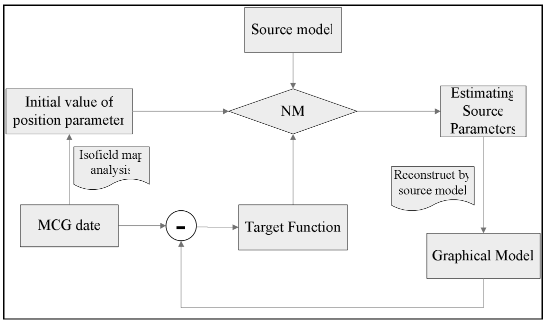


Fig. 2. Schematic diagram for the GM construction

B. Double magnetic dipole source model

We have developed a kind of simplified double magnetic dipole source model which uses a pair of magnetic dipoles as shown in Fig. 3. The magnetic moments of the double dipole are perpendicular to the measuring plane and pointing in opposite directions of each other. They have the same effect as an equivalent current dipole, and the model has eight parameters, more than the SCD model. The advantage of the double magnetic dipole is suitable for experimental implementation. We have successfully used the model for the dipole source localization [3].

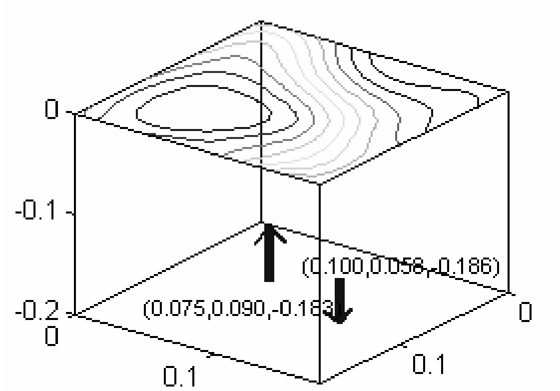
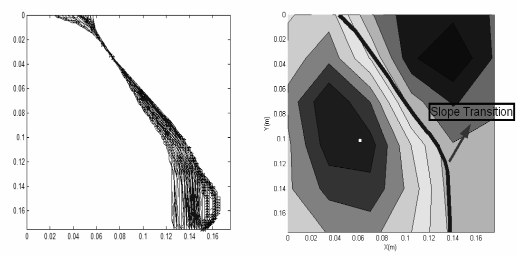


Fig. 3. Schematic illustration of the double magnetic dipole

C. Dual current dipole source model

The dual current dipole source model has been developed to investigate the method for constructing multi-dipole sources [4]. From Fig. 4 (a) and (b), we noted that in general the slope of the magnetic field zero line (MFZL) of the magnetic field map in the ST-T segment is mutative. Each MFZL of those magnetic field maps can be roughly divided into a number of linear subsections according to the inflexion points of the MFZL. Thus, we assume that there exists a current dipole which locates at the middle of the subsection of the MFZL for constructing a multi-dipole source model. The simulation results III are presented to demonstrate the accuracy improvements for the graphical model by means of this method.



(a) (b)

Fig. 4. (a) All MFZLs in ST-T segment
(b) The inflexion point of the MFZL

III. SIMULATION RESULTS

In terms of two evaluation criteria, a comparison performance among three graphical models which are shown in Fig. 1, is given in Figs. 5 and 6, respectively.

Two evaluation criteria, RMSE (Root Mean Square Error) and GOF (Goodness of Fit) are defined as followings:

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(B_{zi} - B_{si})^2} \tag{1}$$

$$GOF = \sqrt{1 - \frac{\sum_{i=1}^{N}(B_{zi} - B_{si})^2}{\sum_{i=1}^{N} B_{zi}^{\ 2}}} \tag{2}$$

where B_Z is the detected magnetic field, B_S is the reconstructed magnetic field, and N is the number of measuring points.

From Fig. 5 and Fig. 6, we can see that compared with the SCD model, two graphical models for DCD and DMD have smaller RMSE (less than 30 PT) and better GOF (better than 0.97).

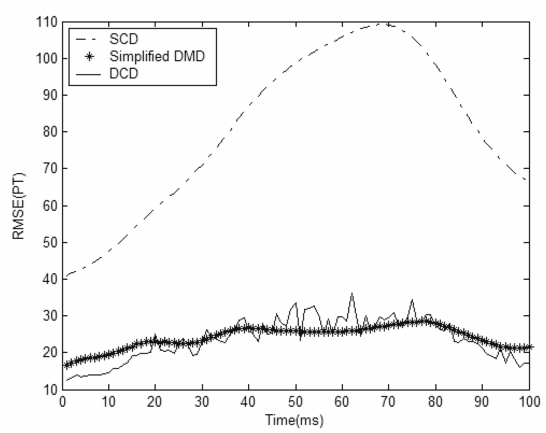


Fig. 5. RMSE curves of the three GMs

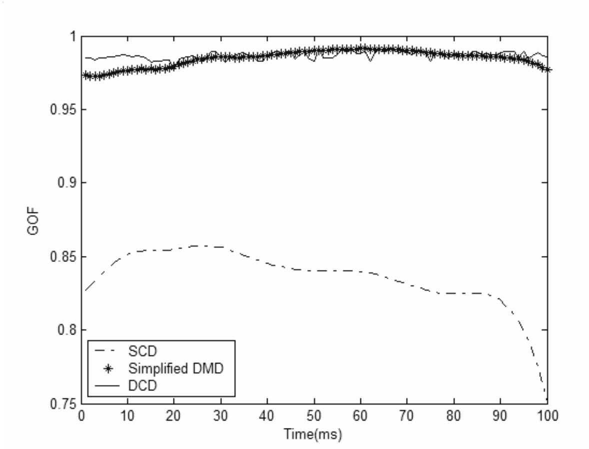


Fig. 6. GOF curves of the three GMs

IV. CONCLUSION

In this paper, two multi-dipole graphical models have been proposed for the investigation of the cardiac electromagnetic activity. The initial value choice of parameters estimation is important, because the accuracy of graphical models depends on the accuracy of sources estimation. Despite the simulation and the comparison results indicate that the multi-dipole graphical model is better than the single current dipole graphical model, how to improve the accuracy of the graphical model still is a problem that remains to be solved.

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