A Novel Cardiac Equivalent Moving Dipole Solution

Shiqin Jiang
School of electronics and Information Engineering
Tongji University
Shanghai, P.R. China
sqjiang@tongji.edu.cn

Mingwei Shi
School of electronics and Information Engineering
Tongji University
Shanghai, P.R. China
s1000101816@gmail.com

Abstract—**We propose a novel approach for localizing a cardiac equivalent moving dipole, by which only the maximum and the minimum values measured at two magnetic field measurement sites are employed in solving the inverse problem. The numerical experiments verify that the operation speed of this approach is faster than that of the previous equivalent moving dipole solution, which applies an iterative algorithm and 36-channel measurements by a superconducting quantum interference device (SQUID) system. Its localization error depends on the interval of two sites on a measuring plane. We also show the results of two sets of magnetocardiography (MCG) data, which illustrate the feasibility of this approach for localizing a cardiac equivalent current source in ST-T segment without using a realistic torso model. Moreover, the magnetic field produced by Ohmic current is discussed.**

Keywords-biomagnetism, magnetocardiography, MCG inverse problem, signal processing

I. INTRODUCTION

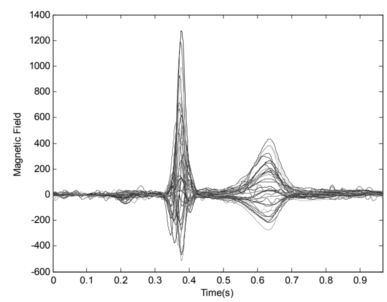
The equivalent moving dipole solution is developed in solving inverse problems of the heart and brain with the aim of imaging of bioelectrical activity. The research on the solution includes (1) Using electrocardiography (ECG) or body surface potential map (BSPM) [1-3], and (2) Using magnetocardiography (MCG) [4-6]. In terms of the solution, a equivalent current dipole is estimated by minimizing the difference between the model-generated and the measured body surface electrocardiograms or magnetocardiograms. In recent decades, many successful applications of the solution with a realistic torso model have been reported. However, the iterative algorithm used in the solution and the use of 36 or 64-channel SQUID measurements would cost quite a few minutes and require large memory space for the purpose of clinic application.

In this study, we propose a novel approach of solving MCG inverse problem with reduced SQUID measurement sites. In general, a 36 or 64-channel SQUID system is used for detecting magnetocardiac signals. However, in fact, for a set of MCG data with two-pole MCG maps, only a few measurement sites could appear the maximum and the minimum magnetic field values among 36 SQUID measurement sites during ST-T segment of a cardiac-cycle. Thus, we propose an approach of localizing an equivalent current source, using the maximum and the minimum magnetic field signals measured at two measurement sites in ST-T segment. We also notice that the site appeared the maximum or the minimum magnetic field value could change one or more times in ST-T segment, which depends on measured magnetocardiac signals.

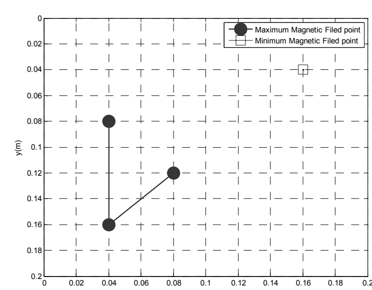
II. METHODS

A. Analysis of measuring MCG data

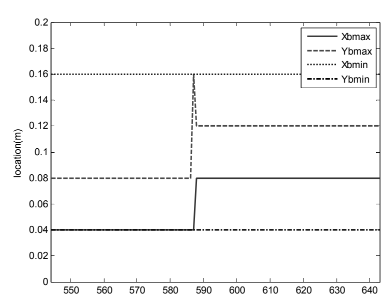
In Figure 1 and Figure 2, (a) shows MCG signals of a subject measured by a 36-channel low-temperature SQIUD



(a) MCG signals of the subject 1



(b) The site-distribution of the maximum and the minimum values in 100 ms of ST-T segment

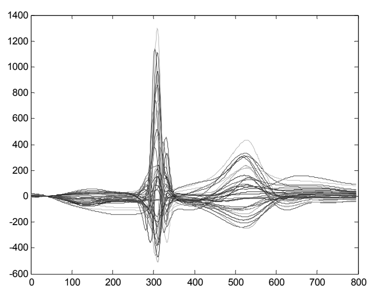


(c) X and Y coordinate-change plots of the two sites in 100 ms of ST-T segment

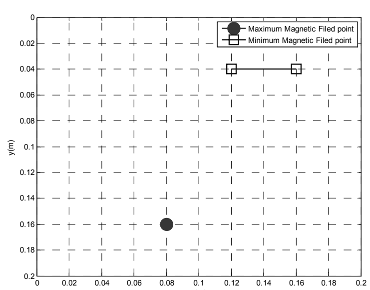
This work was supported by the National Natural Science Foundation of China (60771030), the National High-Technology Research and Development Program of China (2008AA02Z308), the Shanghai Science and Technology Development Foundation (08JC1421800), the Open Project of State Key Laboratory of Function Materials for Information, and Shanghai Leading Academic Discipline Project (B004).

Figure 1. MCG data analysis of the subject 1

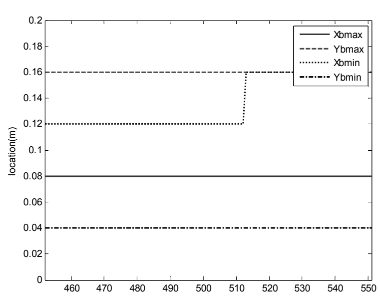
system. And (b) shows all sites of the maximum (black dot) and the minimum (square) magnetic field values among 36 SQUID measurement sites over the body surface in 100 ms of ST-T segment. The measurement plane is 20 X 20 cm and the interval of two sites is 4 cm. We can see that there are only a few measurement sites appeared the maximum and the minimum magnetic field value in ST-T segment. As well as (c) shows the X and Y coordinate-change plots of the two sites in ST-T segment. Obviously, an abrupt change of X (Xbmax) and Y (Ybmax) coordinates of the $B_{z\max}$ site appear at 586 ms in Figure 1 (c). And an abrupt change of X (Xbmin) coordinate of the $B_{z\min}$ site appears at 513 ms in Figure 2 (c). It is possible that they are related with the electrophysiology characteristic of the human heart.



(a) MCG signals of the subject 2



(b) The site-distribution of the maximum and the minimum values in 100 ms of ST-T segment



(c) X and Y coordinate-change plots of the two sites in 100 ms of ST-T segment

Figure 2. MCG data analysis of the subject 2

B. *The proposed approach*

The relationship between the measured maximum (or the minimum) magnetic field and an equivalent current dipole (ECD) is shown in Figure 3. In terms of the Biot-Savart law [7], the maximum magnetic field value $B_{z\max}$ measured at the site (x_1, y_1) (or the minimum magnetic field $B_{z\min}(x_2, y_2)$), which is perpendicular to the human chest surface, can be expressed as:

$$B_{z\max}(x_1, y_1) = f_1(d, Q) \tag{1}$$

or

$$B_{z\min}(x_2, y_2) = f_2(d, Q) \tag{2}$$

where Q is the source-moment magnitude, and d is the depth of the equivalent current dipole. When the maximum value $B_{z\max}(x_1, y_1)$ (or the minimum value $B_{z\min}(x_2, y_2)$) of the measured magnetic field are known and the location (x_0, y_0) of an current dipole is given along the line D, the depth d and the source-moment magnitude Q of an equivalent current dipole can be solved. The localization error of this approach is related to the interval of two sites. In the worst case, the localization error is 1.2 cm, when a set of simulated magnetic field data is used to calculate an equivalent current dipole. The operation time is less than 1 minute with a normally equipped computer.

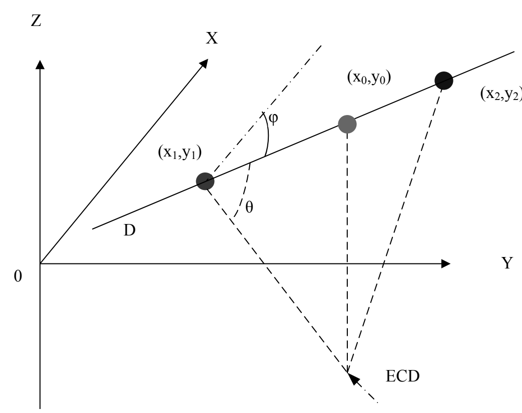
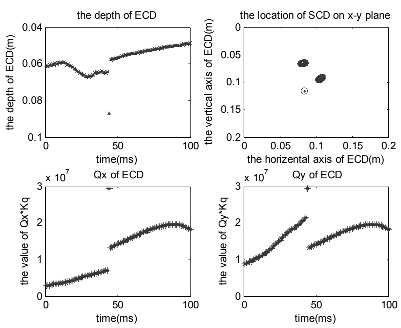


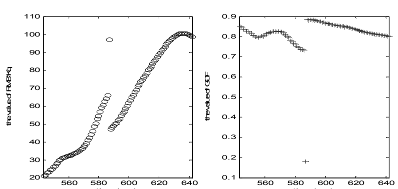
Figure 3. The sketch of a measurement site of the maximum (or the minimum) magnetic field value in a measuring plane and the location of an equivalent current dipole (ECD), where the angle between the line D and the X-axis is φ and the angle between the measurement plane and the line from (x_1, y_1) to the current dipole is θ.

III. RESULTS

Here results of two sets of MCG data in 100 ms of ST-T segment are shown to illustrate the effectiveness of the proposed approach. An equivalent current source of the subject 1 localized by five parameters is shown in Figure 4. The source depth is between 4 cm to 6 cm shown in the left top of Figure 4 (a). The location of the current source in the X-Y measurement plane is shown in the right top of Figure 4 (a). Two source-moment components are shown in the left and right bottom of Figure 4 (a), respectively. It is noticeable that all of the source parameters change at the time of 586 ms. Two evaluation index regarding the GOF (Goodness of Fit) and the RMSE (Root Mean Square Error) are shown in Figure 4 (b). Although the two indexes have no actual significant, they display a decline trend, which will be mentioned in Part IV. The results of localizing an equivalent current source of the subject 2 are shown in Figure 5. The source depth is between 5.4 cm to 7 cm. And all of the source parameters change at the time of 513 ms. Two indexes have a similar decline trend as shown in Figure 4 (b).

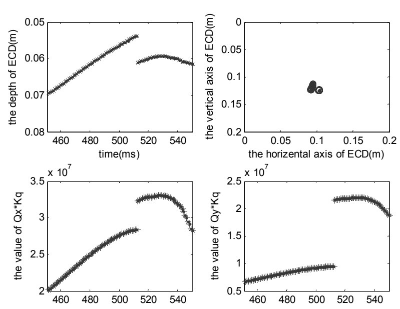


(a) The results of the subject 1

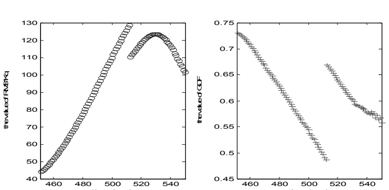


(b) The RMSE and the GOF index of the subject 1

Figure 4. The results of a set of MCG data of the subject 1



(a) The results of the subject 2



(b) The RMSE and the GOF index of the subject 2

Figure 5. The results of a set of MCG data of the subject 2

IV. Discussion

It is obviously that the detecting magnetocardiac signals at 36 sites on the measurement plane are of asymmetrical distribution. In most cases of two-pole MCG maps from a normal heart, the absolute value of the maximum magnetic field value is larger than that of the minimum value in ST-T segment. Theoretically speaking, it is caused by the current density $J = J^i + \sigma E$ in myocardial tissue based on the quasistatic approximation of the Maxwell equation, where J^i is the current density (with regard to one or more current dipoles) and σE is Ohmic current. If we assume that J^i is the current density with regard to one equivalent current dipole source, then the changes of source-parameters or two indexes in Figure 4 and Figure 5 are just related to a magnetic field variable $B_{\sigma E}$ caused by Ohmic current.

The variables $B_{\sigma E}$ calculated from the previous two sets of MCG data of 100ms ST-T segment are shown in Figure 6 and 7. The magnetic field $B_{\sigma E}$ is obtained, when a symmetrical magnetic field generated by a current dipole is removed from the measuring cardiac magnetic field. The effect of the $B_{\sigma E}$ can also be revealed from the change trend of two indexes which have an increased trend. In other words, the magnetic induction flux generated by Ohmic current increases gradually in 100ms ST-T segment. The maximum value of $B_{\sigma E}$ is about one fourth of T wave peak value. Thus, it is also a way to investigate the influence of volume conductor to cardiac source localization by using the information of the $B_{\sigma E}$.

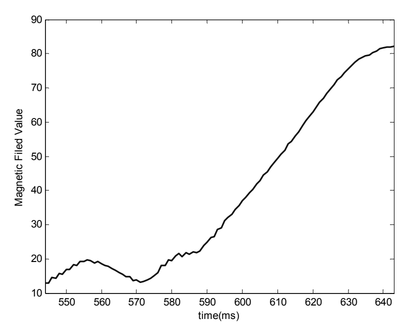


Figure 6. The variable $B_{\sigma E}$ of the subject 1

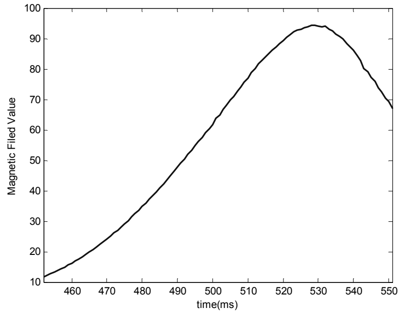


Figure 7. The variable $B_{\sigma E}$ of the subject 2

V. CONCLUSIONS

We propose a novel approach for localizing a cardiac equivalent current source in ST-T segment of a cardiac-cycle, by which a few SQUID measurement sites are required. Simulation results demonstrate that this approach is feasible. However, how to improve the localization accuracy of the approach and remove the influence of volume conductor need further research and evaluation.

ACKNOWLEDGMENT

We thank Professor Drs Yi Zhang and Xiaoming Xie for their great support during this project.

REFERENCES

[1] R. Gulrajani, F.A. Roberge and P. Savard, "Moving dipole inverse ECG and EEG solutions," IEEE Trans. Biomed. Eng. vol. 31, pp. 903-10, 1984

[2] B. He, Modeling and imaging of bioelectrical activity principles and applications. Kluwer Academic/Plenum Publisher, 2004

[3] D. Lai, C. Liu, M. D. Eggen, P. A. Iaizzo, B. He, "Equivalent moving dipole localization of cardiac ectopic activity in a swine model during pacing", IEEE Transactions on Information Technology in Biomedicine, vol. 14 (6), pp. 1318-1326, 2010

[4] A. Wilfried, N. Hannes, Magnetism in medicine Germany: WILEY-VCH, 1998

[5] Y.Q. Zheng, Z.Y. Jiang and C. Xiaogu, Magnetic imaging technology and clinical applications. People's Medical Publishing House. 2001 (In Chinese)

[6] I. Tavarozzi, S. Comani, C. D. Gratta, G. L. Romani, S. D. Luzio, D. Brisinda, S. Gallina, M. Zimarino, R. Fenici and R. D. Caterina, "Current perspective Magnetocardiography: current status and perspectives". Part I: Physical principles and instrumentation Ital Heart J pp. 375-85, 2002

[7] J. Sarvas, "Basic mathematical and electromagnetic concepts of the biomagnetic inverse problem", Phys. Med. Biol. Vol.32, pp. 11-22, 1987