Nonlinear Phenomena in Electromagnetic Fields
T. Furuhashi and Y. Uchikawa (Editors)

AN ESTIMATION OF THE CURRENT DISTRIBUTIONS IN HUMAN HEART BY THE FACTOR ANALYSIS

H. Saotome, K. Kitsuta, S. Hayano and Y. Saito

College of Engineering, Hosei University, Koganei, Tokyo 184, Japan

Abstract

In order to enhance the accuracy of human heart diagnosis, this paper applies a generalized factor analysis to the magnetocardiogram. As a result, it is revealed that the current distribution remarkably depends on the heart condition. Thus, we have succeeded in working out a novel approach of human heart diagnosis. It is demonstrated that various human heart conditions reflect the current distributions in the heart.

1. INTRODUCTION

The inverse problem is one of the most important problems in the medical applications, because most of the medical diagnosis can be reduced to solving the inverse problems. It is well known that any neural activity in the biological systems accompanies the electric charge movements, and this leads to a magnetic field distribution on the surface of biological body. Particularly, the magnetic field distribution measured on the heart is called the magnetocardiogram (MCG) [1]. Depending on the heart operating conditions, the MCG exhibits the distinct pattern so that the MCG analysis is intensively studied for the heart diagnosis [2]. Furthermore, the relationship between the operation and activation current flow in the human heart has been measured and confirmed by a group of the anatomists.

In the present paper, we propose a generalized factor analysis to enhance the accuracy of human heart diagnosis This new method is now applied to the MCG. As a result, it is revealed that the current distribution remarkably depends on the heart condition. Thus, we have succeeded in working out a novel approach of human heart diagnosis. Several examples demonstrate that various human heart conditions directly reflect the current distributions in the heart.

2. A GENERALIZED FACTOR ANALYSIS

2.1 Basic equations

Most of the magnetostatic field problems are reduced to solving a following equation assuming the Coulomb gauge $\nabla \cdot A = 0$:

$$(1/\mu)\nabla^2 A = -J, \tag{1}$$

where μ, A and J are the permeability, vector potential and current density, respectively. The magnetic field H is related with the magnetic flux B as well as vector potential A by

$$H = (1/\mu)B = (1/\mu)\nabla \times A = \nabla \times \int [J/(4\pi|r|)]dv, \tag{2}$$

where r is a distance between the field H and source J points. In (2), the volume V containing the current density J is subdivided into a large number of subdivisions V_i, i=1~m, also the number of field points is denoted by n, then (2) reduces into

$$U = \sum_{i=1}^{m} \alpha_i d_i \tag{3}$$

where

$$U = [H_1, H_2, \cdots, H_n]^T, \tag{4}$$

$$d_i = \{1/(4\pi)\}[n_i \times a_{1i}/r_{1i}^2, n_i \times a_{2i}/r_{2i}^2, \cdots, n_i \times a_{ni}/r_{ni}^2]^T, \tag{5}$$

$$\alpha_i = J_i V_i, \quad i=1\sim m, \quad m>>n. \tag{6}$$

In (5), n_i is a unit vector in the direction of J_i; $a_{1i}, a_{2i}, \cdots, a_{ni}$ are the unit vectors from the source point i to the field points 1,2,⋯,n; $r_{1i}, r_{2i}, \cdots, r_{ni}$ are the distances from the source point i to the field points 1,2,⋯,n, respectively. Further in (6), α_i, i=1~m, is a magnitude of the current dipole P_i, also the condition m>>n is always satisfied because the field H can be measured in the limited points. Equation (3) is a system equation [2].

2.2 Generalized factor analysis

According to the condition m>>n, it is obviously difficult to obtain a unique solution of (3). Namely, the number of equations n is smaller than the number of unknowns m. Thus, we apply a factor analysis to estimate the current distribution pattern from (3) [3].

Equation (3) can be decomposed into

$$U = \sum_{i=1}^{m} \{\beta_i d_i + \sum_{j\neq i}^{m} \{\beta_j (d_i + d_j) + \sum_{k\neq i,\, k\neq j}^{m} \{\beta_K (d_i + d_j + d_k) + \cdots \}\}\}. \tag{7}$$

Physically, the 1st, 2nd and 3rd solution groups on the right hand in (7) give the one, two and three pairs of the north (N) and south (S) magnetic poles normal to a plane surface, respectively. This means that the factor analysis should be carried out only to the 1st solution group but also the other remaining solution groups. After applying the factor analysis to all of the groups in (7), summation of their results will yield a general factor distribution pattern. In order to evaluate a particular factor distribution, the practical factor analysis is carried out in the following way.

At first, we calculate

$$\gamma_i = [U/|U|]^T [d_i/|d_i|], \quad i=1\sim m, \tag{8a}$$

then we can get the 1st factor distribution. If the γ_h takes the maximum value in the 1st factor distribution, then the 2nd factor distribution taking d_h as a pilot pattern is calculated by

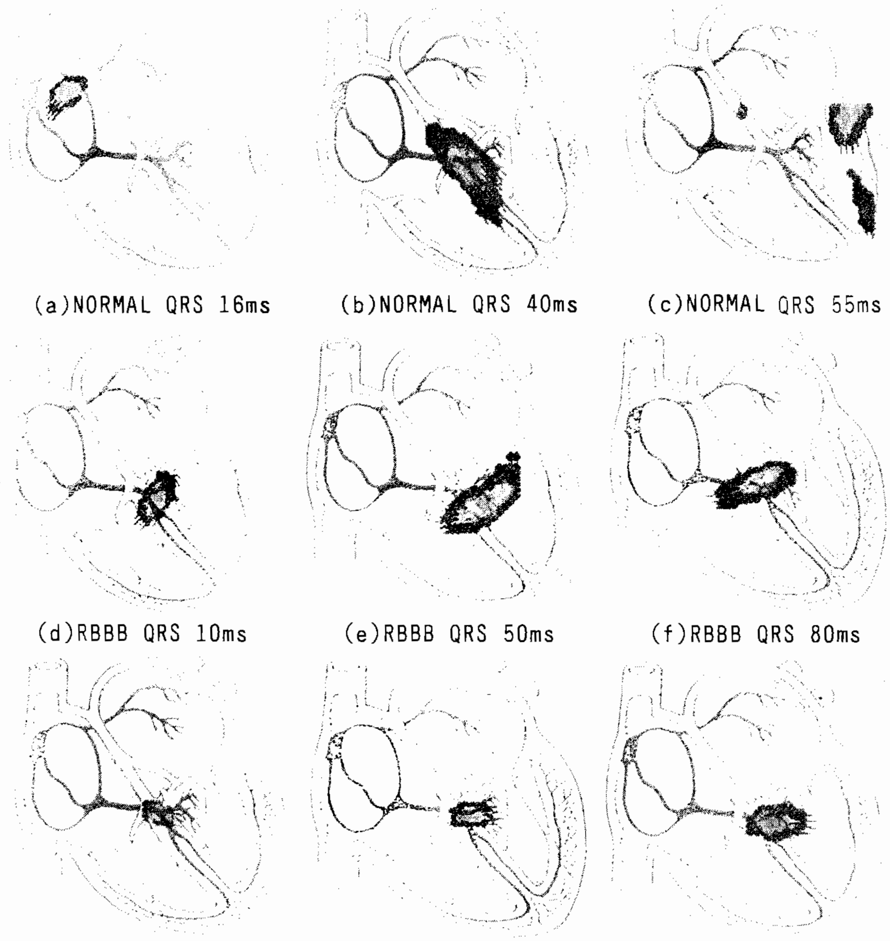
$$\gamma_{ih} = [U/|U|]^T [(d_h + d_i)/|d_h + d_i|], \quad i=1\sim m, \quad i\neq h. \tag{8b}$$

Similar process is continued up to the peak value of γ. Thereby, the generalized factor distribution γ_i', i=1~m, of (3) becomes

$$\gamma_1' \simeq [\gamma_1 + \gamma_{1h} + \cdots], \tag{9a}$$
$$\gamma_2' \simeq [\gamma_2 + \gamma_{2h} + \cdots], \tag{9b}$$
$$\cdots\cdots\cdots\cdots$$
$$\gamma_h' \simeq [\gamma_h + 1 + 1 + \cdots], \tag{9c}$$
$$\cdots\cdots\cdots\cdots$$
$$\gamma_m' \simeq [\gamma_m + \gamma_{mh} + \cdots]. \tag{9d}$$

This gives a particular factor distribution depending on the field vector U in (4), and corresponds to the normalized current distributions [4,5].

2.3 Examples



(a)NORMAL QRS 16ms (b)NORMAL QRS 40ms (c)NORMAL QRS 55ms

(d)RBBB QRS 10ms (e)RBBB QRS 50ms (f)RBBB QRS 80ms

(g)LBBB QRS 20ms (h)LBBB QRS 50ms (i)LBBB QRS 80ms

Fig.1. The results of the generalized factor analysis. (a)-(c):Normal healthy heart. (d)-(f):Right bundle branch block syndrome. (g)-(i):Left bundle branch block syndrome.

Figure 1 shows the most dominant parts of the factor distributions. Figures 1(a)-1(c) show the results of normal healthy heart, where Fig.1(a), 1(b) and 1(c) show the current flows from the sino-atrial node to antioventicular node at QRS 16ms, from the bundle of His conduction bundle to the left as well as right bundles at QRS 40ms and ending in the ramifying Purkinje fiber network at QRS 55ms, respectively.

Figures 1(d)-1(f) show the results of abnormal heart exhibiting the right bundle branch block syndrome. Obviously, abnormal condition can be observed by considering the current flow to the right direction from the intersection of right and left bundle branches in heart at any QRS time.

Figures 1(g)-1(i) show the results of abnormal heart exhibiting the left bundle branch block syndrome. Obviously, abnormal condition can be observed by considering the current flow to the left direction from the intersection of right and left bundle branches in heart at any QRS time.

3. CONCLUSION

As shown above, it is difficult to estimate the exact current distributions in the human heart by means of MCG. But it is possible to estimate the unique current distribution patterns by the generalized factor analysis. Thus, our generalized factor analysis which is in essence similar to the sampled pattern matching method successfully provides a large number of important information to the human heart diagnosis.

4. REFERENCES

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