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Space Power Method for Human Heart Diagnosis

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Abstract – **Recently, it has shown that the medical diagnosis of human heart is reduced to searching for the defect positions of electrical conducting path in the human heart. The electrical conducting path searching in the human heart is one of the inverse source problems which is difficult to get unique solutions. This paper proposes an approach to identifying the electrical conducting paths in the human heart by measuring both of the local magnetic and electric fields. As a result, it is revealed that our method makes it possible to show the distinguished differences between the normal and abnormal human hearts.**

I . INTRODUCTION

With the developments of modern SQUID flux meter, the magnetocardiography (MCG) and magnetoencephalography (MEG) are intensively studied for the medical applications of human heart's and of human brain's functional operation, respectively. Particularly, the signals of the MCG are relatively large compared with those of the MEG so that the MCG may be considered as one of the most effective methodologies for the human heart diagnosis. A method of the MCG diagnosis is to plot the current density vector arrow map taking the rotation of measured magnetic field normal to the body surface above the human heart. According to the previous investigations, it has been clarified that the method of current density vector arrow map is quite effective to the human heart diagnosis [1]. On the other side, the electrocardiography (ECG) is currently used as a quite popular and standard method for the human heart diagnosis [2].

In this paper, we develop an approach to identifying the electrical conducting path in the human heart by employing both of the MCG and ECG. The conducting path in the human heart is estimated by a correlative analysis after solving the inverse source problems. Previously, we proposed the sampled pattern matching (SPM) method for solving the inverse problems in biological as well as non-destructive systems, respectively. In this paper, we apply the SPM method to estimate the conducting path from the locally measured electric or magnetic fields. Details of the SPM method are described in Refs.[3-8].

At first, a three dimensional current density distribution in the human heart is estimated by an inverse approach to a MCG. Secondly, a three dimensional electric field distribution in the human heart is estimated by an inverse approach to an ECG. Finally, a correlative analysis between the estimated three dimensional current density and electric field distribution is carried out. This correlative analysis is a power density distribution searching in the human heart. As a result, this correlative approach shows the distinguished differences between the normal and abnormal human hearts.

II . CORRELATIVE APPROACH TO MEDICAL DIAGNOSIS OF HUMAN HEART

A. Electrical Activity of the Human Heart

The pattern of heart activation is both regular and repetitive. It begins at the sino-atrial (SA) node and spreads in a well-defined manner to the rest of the heart. Since mechanical contraction of each muscle fiber is electrically initiated, the consequence of normal activation is the coordination and co-operation of all cardiac fibers so that the entire heart efficiently contracts and pumps. Therefore, electrical abnormalities will cause mechanical abnormalities. An important property of the signal heart cell is its sensitivity to electrical stimuli from neighboring cells. A transthreshold stimulus will initiate a stylized phasic response that is equivalent to time-varying source of electrical motive force. Consequently, the cell participates in the propagation of the electrical impulse because its own activity is able to excite its neighboring cells. Currents generated by an active cell extend throughout the body. Thereby, the electric potentials as well as magnetic fields appear on the body surface that arise from a superposition of the fields from active cellular sources. The regular problem concerning human heart is to evaluate the electromagnetic fields in the heart with given electromotive force and medium properties. Each body surface potential signal constitutes an ECG, also each magnetic field signal normal to the body surface constitutes a MCG.

B. Electrical Conducting Paths

The electrical activity initiating the heartbeat takes place at the SA node. This region of the heart is located at the endocardial surface of the right atrium at the junction of the superior vena cava. The cells in this region do not remain at rest but slowly depolarized until threshold is reached whereupon self excitation is carried out, i.e. known as pacemaker's operation. These are responsible for initiation of the heartbeat through excitation of their neighbors. The concatenation of activity works contiguously until all tissue has been excited. Atrial activity is conducted to the ventricles only through specialized tissue constituting the atrioventricular

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(AV) junction. This tissue has a very slow propagation velocity. Once the electrical impulse arrives at ventricular exit, it propagates at an elevated velocity through the conduction bundles of His and a network of Purkinje fibers that transport the electrical impulse to many endocardial sites in the left and right ventricles and the septum. Functionally, the AV delay serves to separate in time atrial from ventricular contraction. The conduction tissue is characterized by its relative high velocity of 2m/s, in contrast to the 0.5m/s of ventricular muscle; it is characterized for conduction and contains little contractile elements. The consequence of excitation of many endocardial sites at nearly the same time is broad depolarization waves throughout the ventricles leading to a uniform and sequenced muscular contraction.

C. Simulation of Conducting Path Estimation

As described above, the conducting system of the human heart may be regarded as one of the materials having larger conductivity compared with the other parts so that we consider a simplified model, i.e. a rectangular prism which is composed of the two materials. One has a large conductivity and the other has a small conductivity. Further, frequency of the electrical pulse exciting the movement of heart muscle is relatively low, i.e. about 1Hz. The propagation of the electric pulse is as described above. Therefore, the system is assumed to an electrostatic system, which is governed by a following Poisson equation:

$$\nabla\cdot(\kappa\nabla\phi) = -\rho, \tag{1}$$

where κ, ϕ and ρ denote the conductivity, electric potential and the space-charge distribution, respectively. Equation (1) is discretized by the finite element method (FEM) for the target rectangular prism. Imposing the boundary conditions, i.e. there are the positive space-charges in one of the elements and the negative space-charges in the other elements, we have a following system equation:

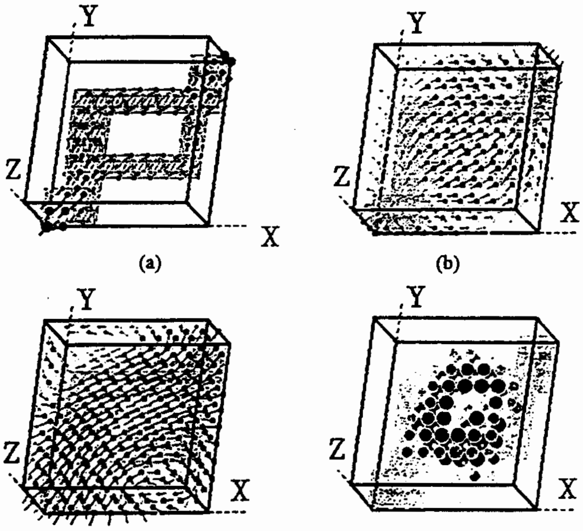
$$C\mathbf{X} = \mathbf{Y}, \tag{2}$$

where C, **X** and **Y** are the system matrix, potential vector and input vector determined by the space-charge, respectively.

After solving (2), a current density **J** distribution in a rectangular prism is obtained by means of the following Ohm's law:

$$\mathbf{J} = -\kappa(\nabla\phi). \tag{3}$$

This current density **J** distribution yields the electric field or magnetic field on the surface above the human heart. The accompanying electric potentials on the top surface of this rectangular prism correspond to an ECG. Taking a gradient of the electric potentials yields an electric field vector arrow map [9]. Similarly, the magnetic fields on the top surface of this rectangular prism correspond to a MCG.



(a) (b) (c) (d)

Fig. 1. Simulated results. (a) Exact conducting path, (b) 3D electric field distribution estimated from the electric field on the top surface, (c) 3D current density distribution estimated from the magnetic field on the top surface, (d) 3D power density distribution obtained by taking the inner product between 3D electric field [Fig. 1(b)] and current density distributions [Fig. 1(c)].

Fig. 1 shows an example of the conducting path estimation problems in a rectangular prism. Fig. 1(a) shows an exact current density distribution in a conducting path. Fig. 1(b) shows an electric field distribution in the rectangular prism estimated by the SPM method from the electric field on the top surface. Fig. 1(c) shows a current density distribution in the rectangular prism estimated by the SPM method from the magnetic field on the top surface. The electric potentials and magnetic fields on the top surface were calculated by the FEM. Finally, taking an inner product between the estimated 3D electric field and current density at each position yields a power density distribution in the rectangular prism shown in Fig. 1(d). Obviously, the results in Figs. 1(b) and 1(c) include a large amount of ambiguity. However, as shown in Fig. 1(d), it is found that the power density distribution in Fig. 1(d) provides the global position of the electrical conducting path. Comparison with Figs. 1(a) and 1(d) suggests that the power density distribution corresponds to the global conducting path. Thus, it is possible to estimate the global conducting path by our method.

D. Application to the Human Heart Diagnosis

We apply this correlative method to the practical human heart diagnosis. Fig. 2 shows a result of a normal human heart at QRS:34.0[ms]. Figs. 2(a) and 2(b) show the estimated electric field and current density distribution in the rectangular prism, respectively. These 3D electric field and current density distribution were estimated by means of the SPM method [3-8]. Fig. 2(c) shows a power density distribution obtained by taking an inner product between 3D electric field [Fig.2(a)] and current density distribution [Fig.2(b)].

In order to estimate the entire conducting path in the human heart, the most intensive estimated point at each QRS time was plotted on a model of human heart. Figs. 3(a), 3(b), 3(c) and 3(d) show the estimated electrical conducting paths for the normal heart, the right bundle branch block (RBBB), the left bundle branch block (LBBB) and the Wolf-Perkinson-White (WPW) syndromes, respectively. Obviously, distinguished difference among the conducting paths of the normal and the syndromes can be observed. Thus, we have succeeded in realizing a method of the human heart diagnosis.

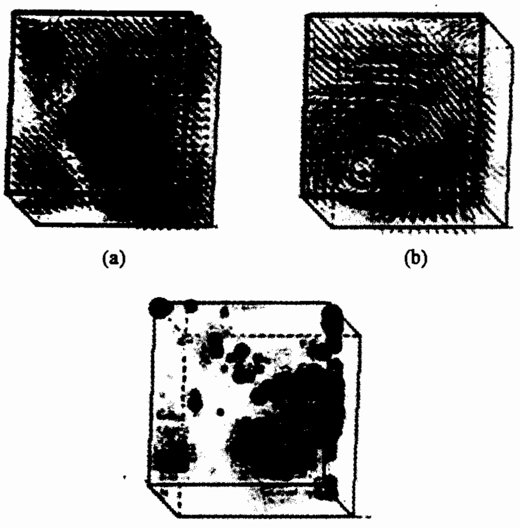
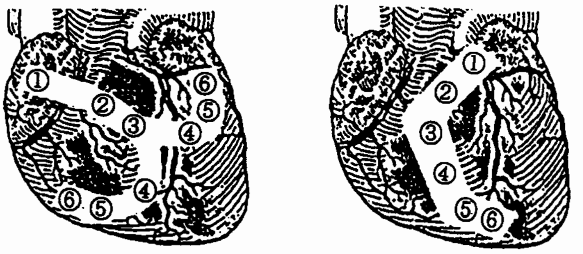
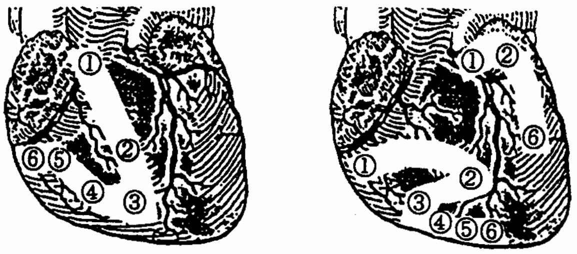


Fig. 2. Estimated results of a normal human heart at QRS:34.0[ms]. (a)3D electric field distribution estimated by the SPM method from the ECG, (b) 3D current density distribution estimated by the SPM method from the MCG, and (c) electric power distribution obtained by taking the inner product between the electric field [Fig. 2(a)] and current density [Fig. 2(b)] distributions.



QRS [ms]:
①16.0, ②22.0, ③28.0,
④34.0, ⑤40.0, ⑥46.0
(a)Normal

QRS [ms]:
①10.0, ②30.0, ③50.0,
④70.0, ⑤90.0, ⑥110.0
(b)RBBB syndromes



QRS [ms]:
①10.0, ②30.0, ③50.0,
④70.0, ⑤90.0, ⑥110.0
(c)LBBB syndromes

QRS [ms]:
①0.0, ②10.0, ③20.0,
④40.0, ⑤60.0, ⑥80.0
(d)WPW syndromes

Fig. 3. Estimated electrical conducting paths in a human heart for the normal, RBBB, LBBB and WPW syndromes, respectively.

Ⅲ. CONCLUSION

As shown above, we have developed the correlative analysis of human heart diagnosis based on the MCG and ECG approach. By means of the simulation, it has revealed that the electric power density distribution corresponds to a global electrical conducting path. Further, we have applied the correlative analysis to the practical human heart diagnosis and showed that each of the heart syndromes has the distinct electrical conducting path in the heart. Thus, we have revealed the usefulness of our correlative analysis for the human heart diagnosis.

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