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Analysis of Chaos Attractors of MCG-Recordings

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***Abstract* — By studying the chaos attractor of cardiac magnetic induction strength B_z generated by the electrical activity of the heart, we found that its projection in the reconstructed phase space has a similar shape with the map of the total current dipole vector. It is worth noting that the map of the total current dipole vector is computed with MCG recordings measured at 36 locations, whereas the chaos attractor of B_z is generated by only one cardiac magnetic field recordings on the measured plan. We discuss only two subjects of different ages in this paper.**

***Key words* — magnetocardiogram, electrocardiogram, chaos attractor, HTS-SQUID**

I. INTRODUCTION

As well known, the MCG recordings (namely the magnetic induction strength generated by the electrical activity of the heart) can be non-contact measured by using Superconducting Quantum Interference Device (SQUID) on a human heart surface. Magnetocardiogram (MCGs) can provide additional diagnosis information to that obtained from traditional ECG analysis[2-5]. However, it's lacking in a magnetocardiogram's diagnostic standard [6]. Therefore, we presented a kind of magneto-electrocardiogram (magneto-ECG) in reference [1]. It consists of a 6-lead electrocardiogram and a map of the total current dipole vector, which are obtained by calculating the MCG recordings in a 6 x 6 grid on a human heart surface.

In this paper, two subjects' magnetic field signals collected with HTS-SQUID are analyzed by means of nonlinear dynamic methods. We found that the similarity exist between the total current dipole vector map and the projection of the chaos attractor of the cardiac magnetic induction strength. It is worth noting that the map of the total current dipole vector is computed with magnetic field recordings measured at 36 locations, whereas the chaos attractor of B_z is generated by only one cardiac magnetic field recordings on the measured plan.

II. TOTAL CURRENT DIPOLE VECTOR

A total current dipole vector is assumed to be the sum of 36 individual current dipole vectors calculated at each site on the measuring plane. In Fig .1 and Fig .2, the maps of total current dipole

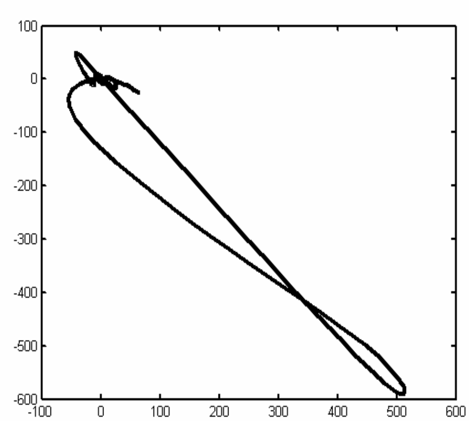

Fig. 1 A total current dipole vector map of the subject

aged 28. The abscissa indicates x-component and the ordinate indicates y-component.

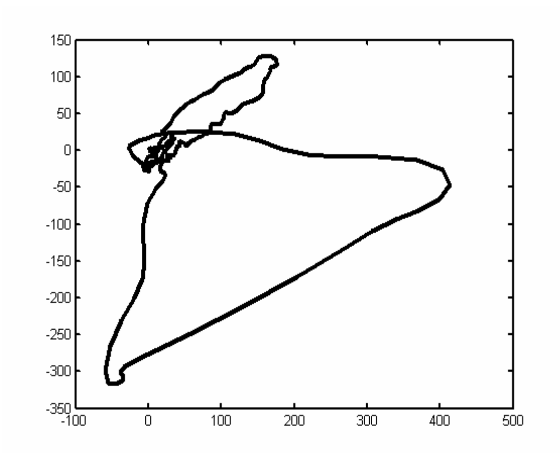

Fig 2 A total current dipole vector map of the subject aged 40. The abscissa indicates x-component and the ordinate indicates y-component.

vectors of two male subjects aged 28 and 40 are shown respectively. It is observed that the total current dipole vector maps reveal evident P-wave, QRS-wave, T-wave as the common ECG.

III. CHAOTIC ATTRACTOR OF B_z

In recent years the development of nonlinear dynamics has promoted the investigation in biomedicine field. The chaotic characteristics of ECG signals have been reported by nonlinear dynamic methods [11]. In this section we show the chaotic attractors of the cardiac magnetic induction strength.

A. Methods

According to Takens' embedding law and the reconstruction method for phase space proposed by Parkard et al., the chaotic attractor of the cardiac magnetic induction strength B_z can be calculated [7].

We denoted a discrete single variable time series $\{x_k | k = 1, 2, \cdots, N\}$ in terms of the following time delay vector:

$$\mathrm{x}_k = \{x(k)\,,\, x(k+\tau)\,,\, \cdots,\, x(k+(m-1)\tau)\} \qquad (1)$$

where the delay time τ is an integral multiple of the sampling period. m is the embedding dimension. The two parameters determine the coordinates of the reconstructed phase space.

For example, the chaotic characteristic of the 40 years old male subject's MCG recordings (N=6000) measured at the middle site (C4) on the heart surface has been analyzed.

According to the first minimum of the auto mutual information function, a delay-time, τ equaling 16, was chosen. Figures 3 show the result of the auto mutual information function computed with MCG recordings. The first minimum of the function appears at 16, which is identical with the corresponding computed value. In addition, the minimal embedding dimensions can be determined by Cao's method [9]. In figures 4, we observe an inflection point at 3 on abscissa, so its embedding dimensions equal to 3.

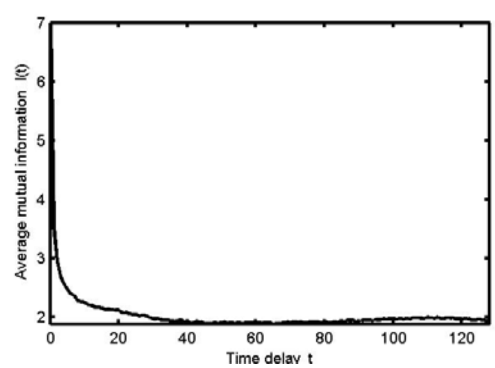

Fig. 3 The curve of auto mutual information function calculated by MCG recordings.

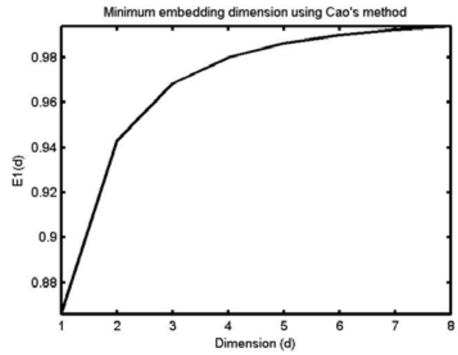

Fig. 4 The curve of minimum embedding dimension calculated by MCG recordings.

B. Results

By applying the above-mentioned method, the obtained chaotic attractor of C4 recordings is shown in Figure 5. It is very interesting that the projection of the chaotic attractor of C4 recordings bears a close resemblance to its total current dipole vector map as shown in Figure 6 and 2, which is very special. In other words, it can be seen that the two outline maps have a very similar shape, though they are obtained through two different methods. Therefore we can say that all of two figures reflect the electrical activity of one same heart. But, the relation between them needs further theoretical explanation.

In addition, it seems that two loops in different size, as shown in Figure 5 and 6, correspond to the QRS-wave and T-wave respectively. Here P-wave is not very clear.

Moreover, Figure 7 and 8 show the chaotic attractors of the MCG recordings of a 28 years old man.

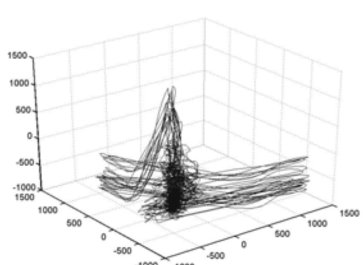

Fig. 5 The chaotic attractor of the MCG recordings of a 40 years old man.

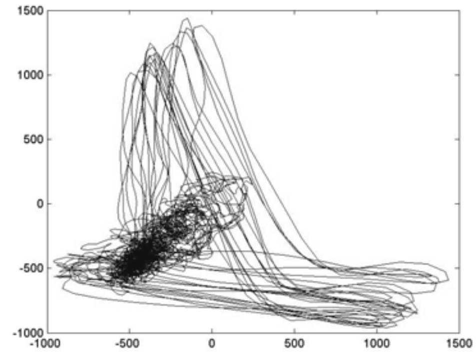

Fig. 6 The TZ-projection of the chaotic attractor of MCG recordings of a 40 years old man.

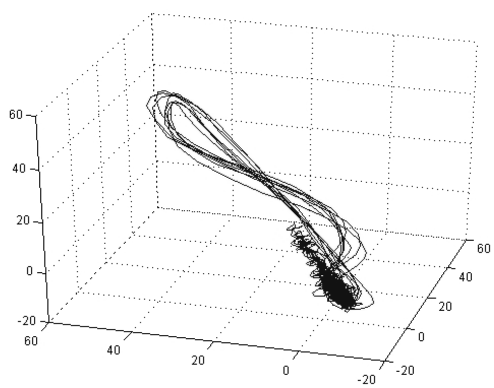

Fig. 7 The chaotic attractor of the MCG recordings of a 28 years old man.

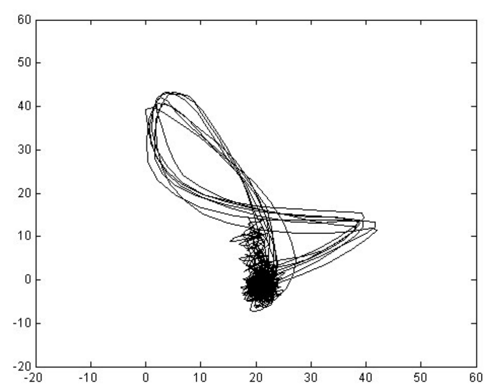

Fig. 8 The projection of the chaotic attractor of MCG recordings of a 28 years old man.

IV. CONCLUSION

The total current dipole vector maps of two subjects and their chaotic attractor of MCG recordings are analyzed in this paper.

It is shown that the total current dipole vector maps display the character of P-wave, QRS-wave and T-wave, which are similar to those of the common ECG, though they are calculated with magnetic field signals.

The total current dipole vector map and the projection of the chaotic attractor of MCG recordings have very similar shapes. It is the similarity that explains the effectiveness of two kinds of maps. Because the total current dipole vector map is computed with cardiac magnetic field signals recorded at 36 locations, whereas the chaos attractor of magnetic induction strength is generated only by recordings from the cardiac magnetic field on the centre of the measured plan.

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