A Fully Automatic Registration Method for CARTO Electro-anatomic Map and CT Surface

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Abstract

Catheter navigation guided by the registration of CARTO electro-anatomical map (EAM) and CT surface is a hotspot for atrial fibrillation (AF) treatment. However, research on the registration algorithm is just at its beginning. Physicians now extremely rely on Carto-Merge, a piece of software, to register EAM and CT surface during AF operations. Besides, only few studies have done on the algorithm. All these methods are semi-automatic or inaccurate for catheter navigation. Therefore, in this study, we proposed a principal axes based registration (PAR) method. Using normalized eigenvector, we first extract the principal axes of each image. Then, for each of the all kinds of axial correspondence, the average distance between the CT surface and the transformed EAM is estimated, and the one with the minimum distance is chosen as the final result. PAR is fully automatic. Furthermore, compared with Carto-Merge and the stochastic approach, an automatic EAM/CT registration algorithm, the experiments on both synthetic and real data show that PAR is much more accurate. At the same time, the speed of PAR is fast. In a word, our method can satisfy AF operations well.

1. Introduction

Registration of eletro-anatomic map(EAM), the simulated atrial chamber composed of about one hundred mapping points, and CT surface, the surface segmented and reconstructed from the atrial CT slices, can help physicians observe the atrial fibrillation (AF) ablation areas carefully, and therefore get better clinical outcomes. Now physicians mostly rely on Carto-Merge, a piece of software, to register EAM and CT surface. Application of Carto-Merge is a clinical research hotspot [1]. Great attention focused on how to practice Carto-Merge efficiently [2-7]. However, little work has done on the registration algorithm [2]. To my knowledge, only several documents relate it [8, 9, 10].

In fact, the accuracy provided by Carto-Merge is not satisfactory [4]. Moreover, tiepoints are manually selected from both images, which means the physicians must be very professional [6]. Meanwhile, the method in [8] is fully done by hand. Some researchers tried to do automatic registration [9,10]. The stochastic approach given in [10] modified the work in [9]. Nevertheless, both are not accurate enough.

Thus, in this study, we proposed a fully automatic principal axes based registration method for EAM and CT surface. It is easy to operate, and what's more, more accurate than those traditional approaches.

2. Principal axes based registration for EAM and CT surface

2.1. Principal axes based registration

Principal axes based registration (PAR) was first presented in [11]. The general idea is to use the centriod of the points in image space as the origin, and the eigenvectors of the covariance matrix of these points to specify the direction of the axes of the object reference system [12]. Images are registered through aligning their principal axes.

Given A and B denote two binary images, their registration steps are as follows:

Firstly, the inertia matrices, the normalize eigenvector matrices of the inertia matrices, and the centroids of both images were calculated. The inertia matrix I is calculated as follows：

$$I = \begin{bmatrix} I_{xx} & -I_{xy} & -I_{xz} \\ -I_{yx} & I_{yy} & -I_{yz} \\ -I_{zx} & -I_{zy} & I_{zz} \end{bmatrix} \qquad (1)$$

$$I_{xx} = \sum_{x,y,z} [(y - y_c)^2 + (z - z_c)^2] \qquad (2)$$

$$I_{yy} = \sum_{x,y,z} [(z-z_c)^2 + (x-x_c)^2] \qquad (3)$$

$$I_{zz} = \sum_{x,y,z} [(x-x_c)^2 + (y-y_c)^2] \qquad (4)$$

$$I_{xy} = \sum_{x,y,z} (x-x_c)(y-y_c) \qquad (5)$$

$$I_{yz} = \sum_{x,y,z} (y-y_c)(z-z_c) \qquad (6)$$

$$I_{zx} = \sum_{x,y,z} (z-z_c)(x-x_c) \qquad (7)$$

Here (x, y, z) is the point whose value equals 1, and (x_c, y_c, z_c) is the centriod of them.

Secondly, image B was transformed to image A using the following formula:

$$B' = E_A * E_B^T * (I_B - C_B) + C_A \qquad (8)$$

Here, I denotes the inertia matrix, E is the normalize eigenvector matrix of I, and C represents the centroid. Each vector of E defines a principal axis of an image.

Actually, there are totally $P_3^3 C_2^1 C_2^1 C_2^1 = 48$ kinds of correspondence between the axes of the two images, which we called diversity problem. Hence, we can not register image A and B just using the two steps above. To solve this problem, some constraints were needed. The axes were required to be in left-handed coordinate system and the longest axis to parallel to the Z axis [11]. Some ranked the axes according to the eigenvalues [12]. And some ranked axes according to the included angles. Unfortunately, all these methods did not solve the diversity problem effectively.

2.2. PAR for EAM and CT surface

PAR is suitable for EAM and CT surface registration, for both images are closed spaces. Since EAM has only about one hundred points, we assigned EAM as the float image and CT surface as the reference image.

Considering the diversity problem, in our method, for each of the all 48 transformed EAMs, its average distance to the CT surface was estimated. The transformed EAM with the minimum distance was selected as the final registration result.

Meanwhile, for saving registration time, rigid transform was chosen. Nowadays, almost all the studies [1,8,9,10] assumed the heart to be rigid.
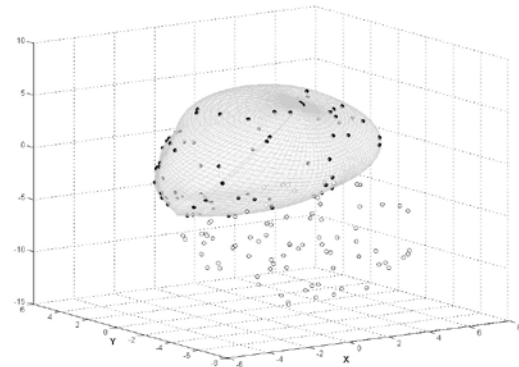
3. Experiments

Using Carto-Merge, the stochastic approach (SA)[10] and PAR, we registered the EAM and CT pair, and the registration results are compared. Experiments were done on both synthetic and real data.
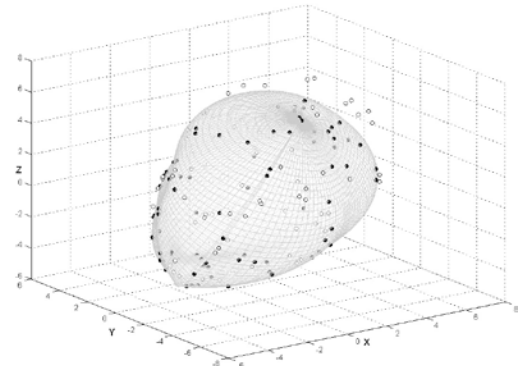
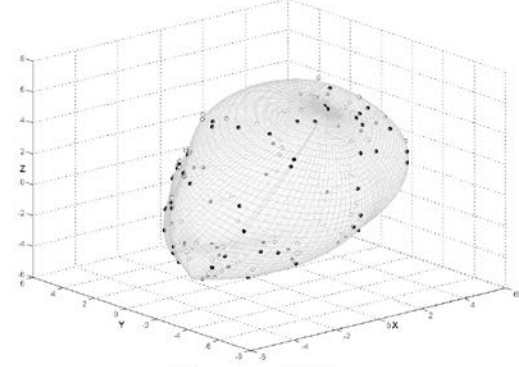### 3.1. Experiments on synthetic data
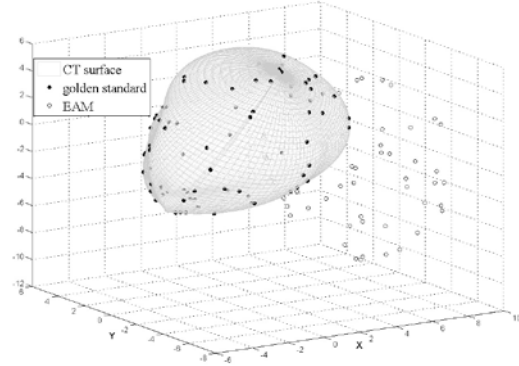
(a) before registration

(b) result of Carto-Merge

(c) result of stochastic approach

(d) result of PAR

Figure 1. Comparison of Carto-Merge, SA and PAR on a pair of synthetic EAM/CT.

Since golden standards of synthetic data are known, it is easy for us to evaluate the registration results, especially quantitatively measure the accuracy.

Figure 1 shows the registration results of Carto-Merge, SA and PAR on a pair of synthetic EAM and CT surface.

The CT surface was derived from a heart model. We first randomly selected 80 points from the CT surface, then rigidly transformed them. The transformed points were used as the EAM, and the points on the CT surface were the golden standards. By visual comparison, we note that PAR registers the EAM and CT surface much better than Carto-Merge and PAR do.

Table 1 compares the registration results of the three methods quantitatively. We can see that PAR gets the highest registration accuracy (RMSE), and SA runs fastest. PAR obtains a good balance between accuracy and speed.

Beside, the other 19 EAM/CT pairs were also registered. The mean and the standard deviation (SD) of RMES are compared in Table 2. For all the 20 image pairs, we notice that the mean and the SD of RMSE of PAR are much smaller than those of the other two approaches. That is to say, our method is much more accurate and much steadier than the others. At the same time, we also note that the registration time of PAR is tolerable.

Table 1. Registration results of the pair of EAM/CT shown in Figure 1.

	Carto-Merge	SA	PAR
RMSE	91.706	48.436	7.0558
time (s)	200.73	3.4513	19.119

Table 2. Registration results of 20 pairs of EAM/CT.

RMSE	Carto-Merge	SA	PAR
mean	78.284	33.873	11.975
SD	34.954	23.867	4.1365

3.2. Experiments on real data

Figure 2 demonstrates the registration results of Carto-Merge, SA and PAR on a pair of real EAM and CT surface.

The patient is a 74-year-old man. He acquired the CT slices on Mar. 2, 2010, and acquired the EAM on Mar. 3, 2010. The CT surface, segmented and reconstructed from the CT slices, is directly copied from a CARTO XP
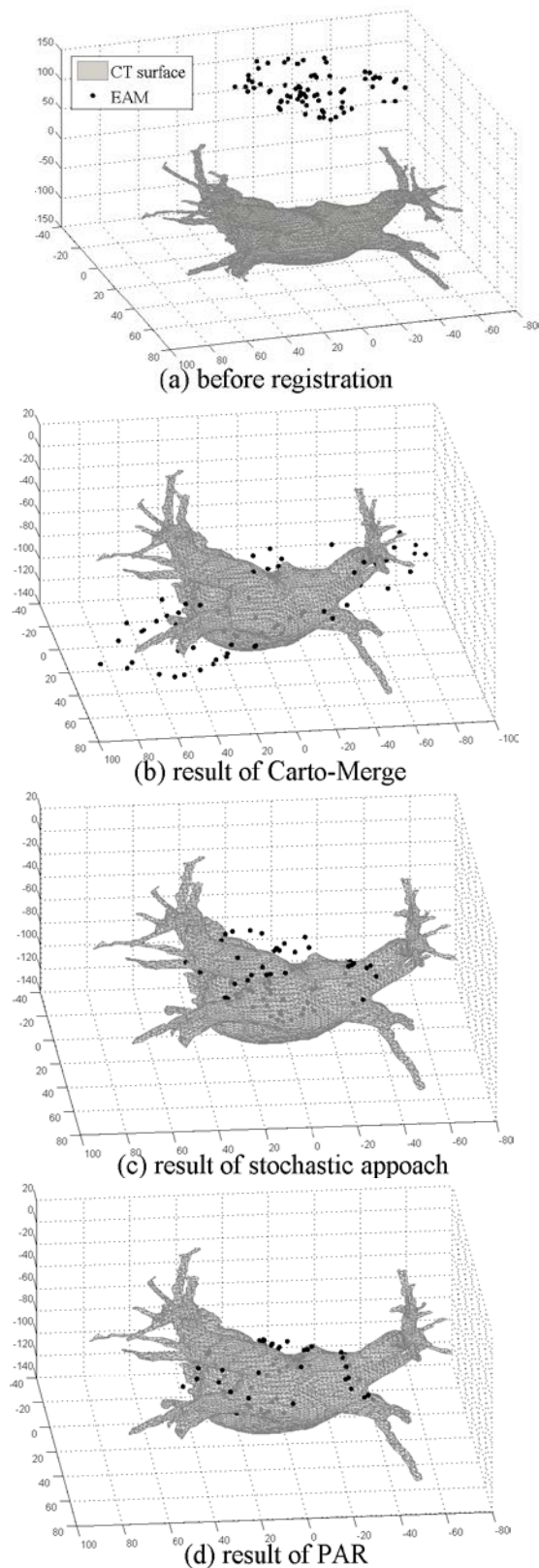

(a) before registration

(b) result of Carto-Merge

(c) result of stochastic appoach

(d) result of PAR

Figure 2. Comparison of Carto-Merge, SA and PAR on a pair of real EAM/CT

Table 3. Registration results of the pair of real EAM/CT shown in Figure 2

	Carto-Merge	SA	PAR
RMSE (mean±SD)	10.815 ±7.8371	7.6248 ±4.7326	4.6274 ±3.0144
time (s)	800.68	14.011	35.332

system. The EAM has 72 points.

From Figure 2, we notice that the registration result of PAR is the best, while the result of Carto-Merge is the worst.

Table 3 compares the registration results quantitatively. It is shown that PAR gets the most accurate result. Although PAR runs slower than SA, its speed is fast as well. Table 3 indicates that Carto-Merge is inaccurate and time-consuming.

4. Conclusions

Now physicians mostly rely on Carto-Merge to register EAM and CT surface. However, Carto-Merge is semiautomatic. Tie-points are manually selected, which means the operator must be very professional. Moreover, Carto-Merge is not accurate enough for reliable catheter navigation. Some researchers tried to do automatic EAM and CT surface registration. However, the registration accuracy is not satisfying yet. Therefore, in this study, we proposed a full automatic principal axes based registration method. Compared with Carto-Merge and the stochastic approach, an automatic registration algorithm, our method obtains much more accurate results. At the same time, its speed is fast.

Nevertheless, we found that PAR failed sometimes in the simulated experiments. It seems that the registration results are affected by the distribution of the mapping points. In the future, we will further study the relationship between PAR and the point distribution.

Acknowledgements

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