Synthesis of Panoramic MRI Volumes by Registering Partially Overlapping Data Using Mutual Information

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Abstract

This paper presents a method for synthesizing panoramic MRI volume from partially overlapping MRI data. We estimated the optimal positional relationship between MRI data by maximizing mutual information of the overlapping area using a downhill simplex method. We registered MRI volumes of a hand and a forearm sharing wrist region, and merged them into panoramic MRI volume. Results of the registration and merging provided visually-consistent volumetric data of a superior limb.

1. Introduction

MRI has been used in medical fields to visualize structures and functions of a human body. It provides detailed images of internal structures by using powerful magnetic field. MRI has much greater soft tissue contrast than CT, and is free from radiation exposure. These features encourage researchers in computational biomechanics to use volumetric data of MRI to create three-dimensional finite element models of human anatomy. However, one drawback of MRI lies in its trade-off between resolution and field of view (FOV) that make us difficult to get wider high-resolution volume at a time [1]. The objective of this research is to establish a method for registering partially overlapping MRI volumes to synthesize wider volumetric data from local volumes with higher resolution.

The simplest solution for this purpose is to obtain local images under consistent coordinate system. Yokota et al. synthesized whole body volume in this manner [2]. They utilized a subject-specific mold to make a whole body immovable, and captured successive MRI images with the same longitudinal. Once the acquisition is completed, we can synthesize a whole body volume by stacking all the images. However, this method stresses subjects, since they have to remain immovable during the acquisition for more than six hours in the case of this study. The resolution of the volume is not sufficient as well, since they could not use local coils such as head coil that enhance the image quality.

On the other hand, there are several techniques to register partially overlapping data in the literature. Registering two-dimensional images into one large panoramic image, and registering local range scanner data into a geometry of a large cultural heritage [3] are good examples of this technique. The basic idea of these methods is applicable to our problem; i.e. we can synthesize wider high-resolution volumetric data from partially overlapping local volumes.

Computing a homography matrix and handling large scale data with noise [3] were main concerns in these past researches. Our problem is free from such technical issues because of three-dimensional nature of MRI data whereas we encounter two technical challenges, intensity variation in the both end of the MRI volume and deformation of soft tissue. In this paper, we propose a method for registering and merging partially overlapping MRI volumes taking account of the first issue. We adopted mutual information for measuring the similarity of overlapping area to handle the intensity variation. We registered and merged MRI volumes of a hand and a forearm with negligible skin deformation sharing wrist region. Results of the registration provide visually-consistent volumetric data of a superior limb.

2. Method

Figure 1 shows the overview of the proposed method when we have two input volumes, base data and aligned data, to be registered and merged.

Our method involves six procedures; (i) acquire two MRI volumes that have overlapping area, (ii) select at least three corresponding landmarks to compute the initial transformation matrix, (iii) resample the aligned volume by using the transformation matrix so that the resultant aligned volume has consistent voxel coordinate system with the base volume, (iv) compute similarity of the overlapping area between the base and the aligned volume, (v) update the transformation matrix, and iterate (iii) to (v) until the similarity is maximized, (vi) merge the two volumetric data using the final estimate of the transformation matrix.

Details of the transformation model, similarity measure, numerical optimization and volume merging are given in the following sections.

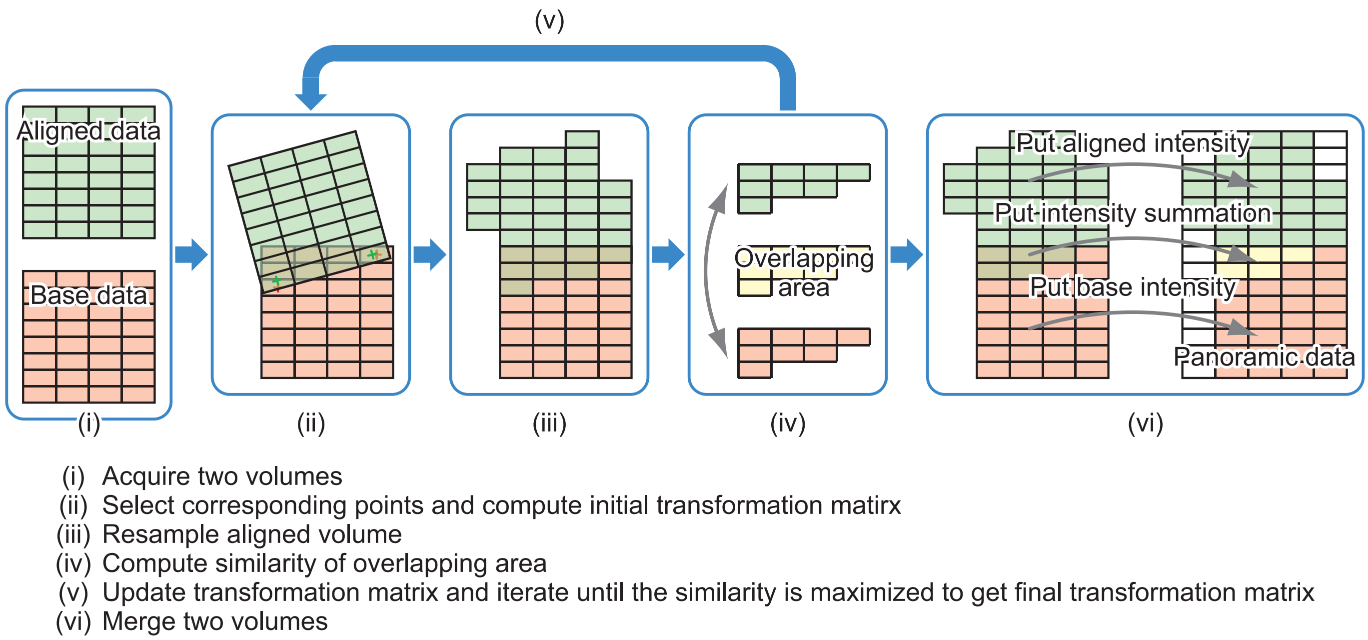

Figure 1: Outline of the proposed method showing two-dimensional case for simplicity

2.1. Transformation Model

We start by picking up set of at least three corresponding landmarks in both volumes by hand. We have developed in-house software with graphical user interface for this purpose. A homogeneous transformation matrix with the size of 4×4 is computed from these landmarks by using Horn's method [4]. The transformation model in this research has the form of

$$\begin{pmatrix} r_{11} & r_{12} & r_{13} & t_x \\ r_{21} & r_{22} & r_{23} & t_y \\ r_{31} & r_{32} & r_{33} & t_z \\ 0 & 0 & 0 & 1 \end{pmatrix}, \tag{1}$$

where r and t represents rotational and translational element of rigid-body motion, respectively. Unlike rigid model, all the parameters in this matrix are assumed to be independent during the optimization. Our transformation model, thus, has twelve degrees of freedom in total.

2.2. Similarity Measure

In prior to the computation of the similarity, we resampled the aligned volume by using the transformation matrix so that the resultant aligned volume has consistent voxel coordinate system with the base volume. Then we extract the overlapping area from both volumes to compute the similarity.

We adopted mutual information [5] for measuring the similarity of overlapping area to handle the intensity variation. SSD and NCC are also used as criterion of the similarity. However, SSD is not robust to intensity variation, meanwhile NCC only models linear relationships between template and target [6]. Mutual information is a combination of the entropy values of two volumes both separately and jointly, thus often used for comparing images or volumes in the presence of intensity variation.

2.3. Numerical Optimization

We updated the transformation matrix so that the similarity measure given in 2.2 is maximized. A downhill simplex method [7], algorithm for multi-dimensional optimization, was employed for this purpose. Since we have nine rotational and three translational parameters, the simplex is composed of thirteen points in twelve dimensional space. The initial point of the simplex is given in each row of the following matrix that has the size of 13×12

$$\begin{pmatrix} r_{11} & r_{12} & \cdots & r_{33} & t_x & t_y & t_z \\ cr_{11} & r_{12} & \cdots & r_{33} & t_x & t_y & t_z \\ r_{11} & cr_{12} & \cdots & r_{33} & t_x & t_y & t_z \\ \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \vdots \\ r_{11} & r_{12} & \cdots & r_{33} & t_x & t_y & ct_z \end{pmatrix}, \tag{2}$$

where, c is a empirically determined constant to achieve efficient convergence.

The iterative optimization was terminated when any one of the following two termination condition is met: (1) the value of mutual information increases by less than V_{min}, or (2) number of iterations increases above I_{max}. After the solution converges, we obtain final estimate of the transformation matrix.

(a) Hand

(b) Forearm

Figure 2: MRI volumes to be registered

2.4. Volume Merging

The base volume and the resampled version of the aligned volume were merged in order to get a panoramic MRI volume after the aligned volume was resampled according to the final estimate of the transformation matrix. This process is straightforward except correcting the intensity variation of the resultant panoramic volume, since the two source volumes are in the same voxel coordinate system.

Figure 1-(vi) shows the overview of the merging process. In this paper, we allocated a new blank volume enclosing the base and the aligned volumes for the panoramic data. We then put the intensity summation of two sources when they are overlapping (yellow region in this figure), otherwise put the intensity of either the base or the aligned volume depending on the position of the voxel (red and green region in this figure).

3. Experiment

3.1. Condition

Figure 2 shows partially overlapping volumes of a hand and a forearm used in this experiment. We can observe intensity variation in the top and the bottom end of the data. The hand has the size of 256×512×256, while the forearm has the size of 512×512×256. Both are stored in VTK structured points format [8].

In our experiments, we assigned following values to the constant parameters; $c = 0.0$ and $c = 1.5$ for computing the initial simplex (we have two conditions for investigating convergency of the simplex depending on the initial state), $V_{min} = 1.0$e-4 and $I_{max} = 1.0$e4 for the termination criteria. These parameters are determined empirically.

3.2. Results and Discussion

Figure 3 shows the results of the registration for the both data sets. Before the optimization both have the same mutual information; 1.6e-1 in this case. When $c = 0.0$ the registration failed. We can observe mismatching bone region in the middle of Figure 3-(a). Increase of mutual information is not significant as well, as is obvious from the plot in this figure. When $c = 1.5$ the registration succeeded. There is almost no apparent mismatch in the overlapping area, and mutual information increases to the maximum value of 2.2e-1 as expected.

The original overlapping area has strong intensity than the other region, since we do not correct the intensity variation in the volume merging; we just put the summation of the base and the aligned data. These warrant future works on improvement of the numerical convergency and correction of the intensity when merging two volume data.

4. Conclusion

In this paper, we have presented a method for synthesizing panoramic MRI volume from partially overlapping MRI data. We have registered MRI volumes of a hand and a forearm sharing wrist region, and merged them into panoramic MRI volume. Results of the registration and merging provided visually-consistent volumetric data of a superior limb. This technique will be applicable to creating wider volumetric data of a living body like whole body.

References

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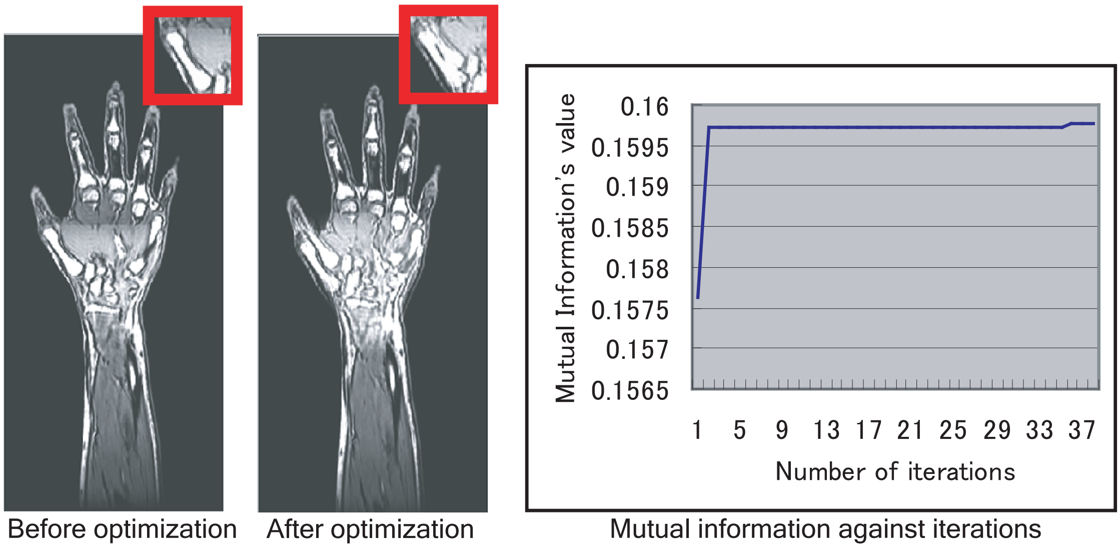
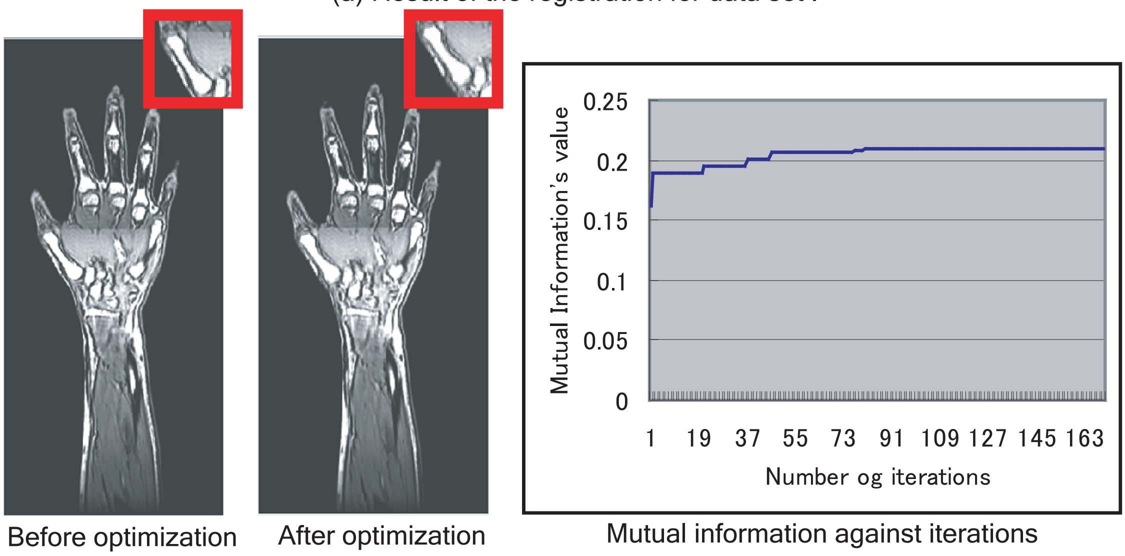


(a) Result of the registration for data set I



(b) Result of the registration for data set II

Figure 3: Synthesized panoramic MRI volumes

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