Breast image registration for PET-CT and MR based on 3D surface matching

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Abstract. In this paper, we explore the PET-MRI 3D surface image registration method for the longitudinal study of cancer. Image registration gives new information to the radiologists by matching images with different modalities. The objective of this research is to develop 3D surface registration for PET/CT and **MR** images acquired by different medical imaging systems at different times. Our proposed method consists of three stages: 1) global surface matching, 2) fine adjustment stage and 3) image transformation. In this study, we perform the global registration with surface points within CT and MRI using ICP algorithm. Then we perform the fine adjusts stage using ECICP algorithm. Finally, PET image was transformed with various parameters and overlaid onto MR image.

Keywords: Breast registration, breast cancer, surface matching, PET, MRI, CT

1 Introduction

Breast cancer is one of the most common cancers for women in these days. Diagnosis of breast cancer in early stage is not only helpful to increase the survival rate of the patient but also enhancing the patient's life after the clinical treatment. To detect the breast cancer in its early stage, high performance breast imaging systems are required.

Generally, PET-CT is useful imaging system to diagnose for common cancers but the contrast of CT image for breast is not enough to detect small carcinoma lesion. Meanwhile, with the breast coil and contrast medium, the breast image of MR gives us efficient anatomical information with high contrast and resolution. Even though, the high quality image of breast MR is useful to detect the suspicious lesion in the soft-tissues but to diagnose whether the lesion is a cancer or not, it still requires the functional information such as PET images. Therefore many research groups are studying about PET-MRI system and its applications.

Recently, Korea Institute of Radiological & Medical Sciences(KIRAMS) installed MR(SIEMENS Trio Trim) and PET-CT system(SIEMENS Biograph6) for their longitudinal study of the breast cancer. Two systems are located next to each other to scan a patient sequentially with minimum time interval.

Goal of this study is to develop a 3D breast image registration algorithm for PET-CT and a standalone MR system. The algorithm is based on the surface matching

between 3D volumetric images by CT and MR. Then the optimized transformation parameters were utilized to transform the PET image, so that PET and MR images are overlaid to maximize the detection rate of the breast cancer.

2 Image registration

Image registration can be defined as a spatial mapping between two images. The goal of registration is to find the optimal transformation T : (x, y, z) —> (x', y', z') which will align one image to another. It requires a search strategy to optimize a similarity measure. This similarity measure is determined using certain features of the images.

2.1 Iterative Closet Point algorithm

The Iterative Closet Point (ICP) algorithm was used in order to registration by using breast surface point among common features which can be aquired from MRI and CT images. In the description of the algorithm, a "data" shape P is moved (registered) to be in best alignment with a "model" shape X. The data and the model shape must be decomposed into a point set if it is not already in point set form. The number of points in the data shape will be denoted N. Let Ai_x be the number of points in the model shape.

The distance metric d between an individual data point p and a model shape X will be denoted

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$$\text{x EX}$$
$$(^1)$$

The closest point in X that yields the minium distance is denoted such such that $d(f3,5;) = d(p^>, X)$, where 31 E X. Let Y denote the resulting set of closest points, and let C be the closest point operator:

$$Y = C(P, X) \tag{2}$$

Given the resultant corresponding point set Y, the least squares registration is computed

$$(Rot, trans ,X) = (P, X) \tag{3}$$

The ICP algorithm can now be stated:
a. Compute the closest points : $Yk = C(Pk, X)$
b. Compute the registration : $(Rot_k, Trans_k, X) = Q (P, X)$
c. Apply the registration : $Pk+i = Rot(P) + Trans$
d. Terminate the iteration when the change in meansquare error falls below a preset threshold $1T > 0$ specifying the desired precision of the registration : $d_k — d_{k+i} < T$

2.2 Elastic Convolved ICP method

The Elastic convolved ICP(ECICP) method is the ICP-based method. An ICP-based method estimates the rigid transformation T = [Rot trans], where Rot is the rotation matrix and trans the translation vector, by the minimizing the distance of the corresponding points. In this deformable registration, the rigid transformation is computed for each point by adding a smoothness constraint to the transformation of neighboring vertices. The error E to be minimized is represented by $E = E_d +$ where E_d is the data rerm, in witch T in Eq.(3) is replaced by the rigid transformation T_i for each point P_i and E, is the regularization term expressed as :

$$Ed = \sum_{jesz(i)} Yij(TiPt\ Yj)^2 \tag{4}$$

$$E_s = \sum_{i}\sum_{jES^-2(i)} IlAii\ °(Ti^{-T}i)Il^2{}_F \tag{5}$$

where 11 11F is the Frobenius norm of a matrix, $A_{i,/}$ is a weight of the smoothness term, and o indicates the element-wise multiplication of two matrices.

The weights y_{ij} and $A_{i,/}$ is determined for discarding an incorrect correspondence and adjusting the strength of the regularization term, respectively. Initially, both weights depend on the distance d_{ij} between p_i and p_i. The weight A_{li} is based on the Gaussian distribution as follows:

$$A_{ii} = \exp(-\ -_{2D2}) \tag{6}$$

Weight yij for the data term depends on the distance d_{py} between p_i and y_i to remove an outlier from the correspondence. Using the threshold $_{Dpy,.}$ weight $_{wpy}$ is defined based on the Tukey weight function:

$$PY \quad w = \begin{cases} \left(^1\ (-\dfrac{PY}{D}_{PY}^{\ 2})^2\right)^2 & I^d PYI < {}^D PY \\ 0 & otherwise \end{cases} \tag{7}$$

The weight for the data term is given by

$$Yij = WnightWpy \tag{8}$$

3 Discussion

Fig.1 shows the block diagram of the proposed algorithm. It is consist of three stages: preprocessing, global surface matching and fine adjustment stage. Contrast-enhanced MR image volume was used as a reference and CT volume was transformed with varying parameters to calculate similarity by surface matching.
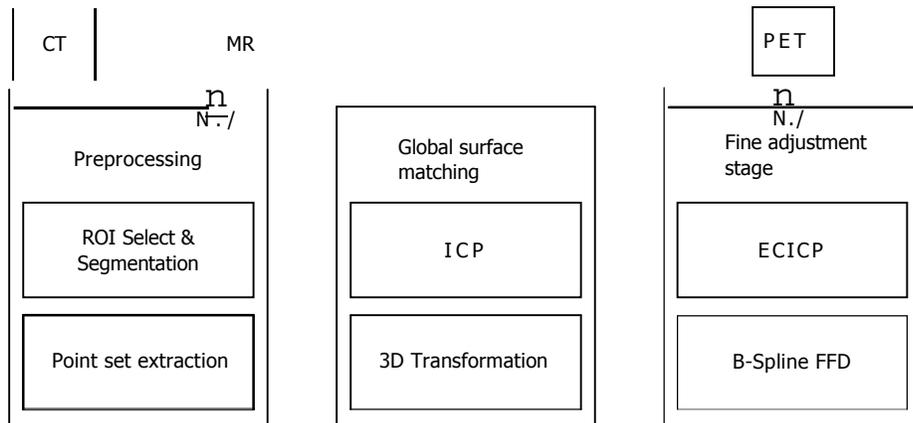

Fig. 1. Block diagram of the proposed breast registration algorithm

3.1 Preprocessing

From the abdomen CT and MR images, we segmented breast volume. Each breast region was acquired by the predetermined regional masks.

For the CT image case, a breast dedicated jig frame to hold the shape of breast was placed on the couch and patient laid one's face down during the PET-CT scan. Because jig frame's CT number is similar to the soft tissues', morphology based breast segmentation was performed.

For the surface extraction of two image volumes, the binary threshold method is conducted. From the binary image, the point-sets of surface were extracted by boundary detection, and used as a feature vector for the surface matching.

3.2 3D surface matching

In The global surface matching stage, we used ICP algorithm and affine 3D transformation. The ICP algorithm find transform parameters between point-set of CT and MRI images.

In the fine adjusts stage, using ECICP algorithm and B-spline-based free form deformation. By the result of the proposed algorithm, the obtained transformed parameters were used to B-spline-based Free Form Deformation the PET image. The transformed PET image was overlay onto the MRI image.

3.3 Result

Fig. 6 (a) shows the results of the surface matching based on ICP. Fig. 6 (b) shows the results of the surface matching based on proposed algorithm. CT image has been transformed with the final transformation parameters and overlaid to the reference MR image. Fig. 6(c) shows the registered image from MR and PET by the proposed algorithm.

(c) 11111111 Fig. 2. results of the proposed breast registration algorithm.
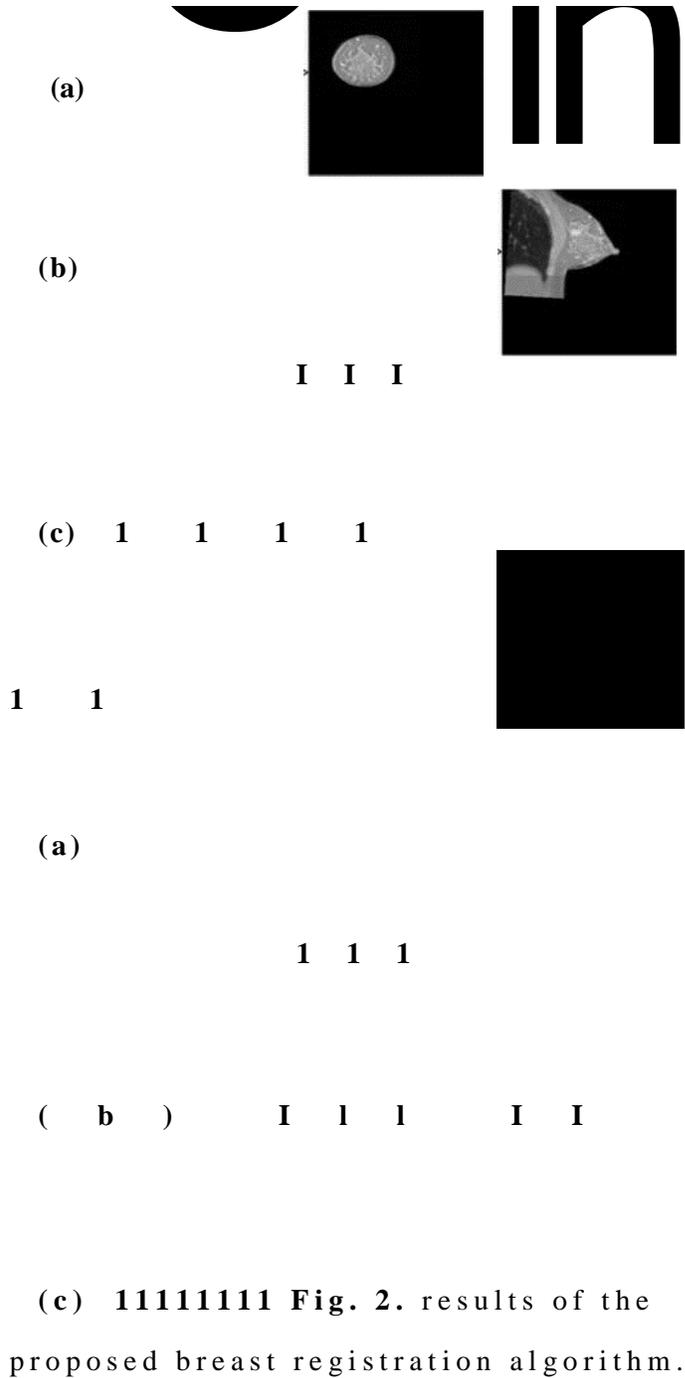
4 Conclusions

Registration of images obtained with different breast imaging modalities is the preliminary and mandatory step to combining anatomical and functional breast information. In this paper, we have presented an algorithm for non-rigid registration of 3D breast MRI and PET-CT images based on surface matching. The algorithm uses a nonrigid transformation model to describe the motion of the breast in dynamic images.

The non-rigid nature of the breast connot be sufficiently modeled by affine transformations. To caputre the anatomical variability of the breast, it will be necessary to employ non-rigid transfomation, such as elastic or fluid transformations. The proposed combination of ICP and ECICP provides a high degree of flexibility to model the motion of the breast. The proposed algorithm produced good agreement between breast surfaces of CT and MRI images.

Acknowledgements

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