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Automatic 2D/2D Registration using Multiresolution Pyramid based Mutual Information in Image Guided Radiation Therapy

Jing Jia, Shanqing Huang, Fang Liu, Qiang Ren, Gui Li, Mengyun Cheng, Chufeng Jin and Yican Wu

***Abstract*—**Medical image registration is the key technology in image guided radiation therapy (IGRT) systems. On the basis of the previous work on our IGRT prototype with a biorthogonal x-ray imaging system, we described a method focused on the 2D/2D rigid-body registration using multiresolution pyramid based mutual information in this paper. Three key steps were involved in the method : firstly, four 2D images were obtained including two x-ray projection images and two digital reconstructed radiographies (DRRs) as the input for the registration ; Secondly, each pair of the corresponding x-ray image and DRR image were matched using multiresolution pyramid based mutual information under the ITK registration framework ; Thirdly, we got the final couch offset through a coordinate transformation by calculating the translations acquired from the two pairs of the images. A simulation example of a parotid gland tumor case and a clinical example of an anthropomorphic head phantom were employed in the verification tests. In addition, the influence of different CT slice thickness were tested. The simulation results showed that the positioning errors were 0.068±0.070, 0.072±0.098, 0.154±0.176mm along three axes which were lateral, longitudinal and vertical. The clinical test indicated that the positioning errors of the planned isocenter were 0.066, 0.07, 2.06mm on average with a CT slice thickness of 2.5mm. It can be concluded that our method with its verified accuracy and robustness can be effectively used in IGRT systems for patient setup.

***Keywords*—**2D/2D registration , image guided radiation therapy , multiresolution pyramid , mutual information

I. Introduction

THE essence of radiation therapy is to kill tumor cells and in the meanwhile to protect the surrounding normal tissues. With the development of medical imaging equipment, images are becoming increasingly important in radiation therapy. The current image-guided radiotherapy (IGRT) systems are mainly used in the clinical patient setup before each treatment verification and patient positioning during radiotherapy verification to correct target deviations caused by various reasons. It uses images of the patient before and during radiotherapy by means of registration in order to find the displacement error so that make the proper alignment of the patient. Therefore, medical image registration technology definitely plays an important part in IGRT systems. Medical image registration is to find a spatial transform mapping on one image into another so that the corresponding points of two images in both spatial location and anatomical structure will be exactly the same [1]. It can be divided into three categories[2] including marker based , segmentation based and intensity based registration according to the features employed in registration techniques. And it can also be classified as 2D/2D registration, 2D/3D registration, 3D/3D registration in accordance with the spacial dimensions of images[3].

Based on the IGRT prototype system developed by our team [4]-[12], we compared two x-ray images of an orthogonal angle with two digital reconstructed radiographs (DRRs) with the same angle that were derived from previous 3D CT data of the patient to determine the positioning error. A method focused on the 2D/2D rigid-body registration was proposed using multiresolution pyramid based mutual information to accomplish the registration. Firstly, the process of our method was presented. Then tests were done to prove its accuracy and robustness. And the results and conclusions were given in the final part of this paper.

II. Material and Method

Our method involved three key steps: firstly, two pairs of 2D images were obtained as input of the registration containing two x-ray simulator images and two digital reconstructed radiographies (DRRs) . Secondly, every two images of each pair were registered using multiresolution pyramid based mutual information by means of the ITK registration framework. And translations got from each pair were then used to determine the final couch offset through coordinate transformation. The flow chart of the whole process is shown as follows in Figure1.

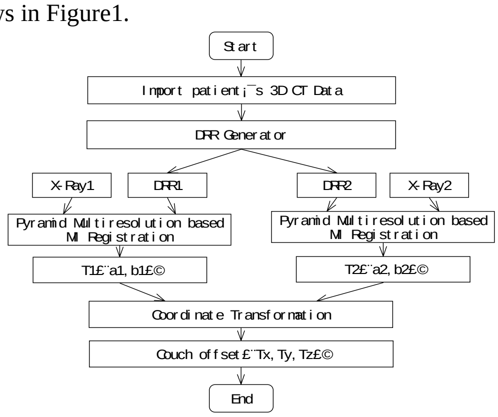


Fig. 1 The workflow of the registration process

Jing JIA, Fang LIU, Qiang REN, Chufeng JIN are with the School of Nuclear Science and Technology, University of Science and Technology of China, Hefei, Anhui, 230027(e-mail: jiajing@ mail.ustc.edu.cn).
Shanqing HUANG , Gui LI, Mengyun CHENG and Yican WU are with Institute of Plasma Physics, Chinese Academy of Sciences, Hefei, Anhui, 230031, China.

2.1 Acquisition of 2D images

Two x-ray images (x-ray1, x-ray2)were acquired according to their imaging parameters such as the distance between the source and the imaging plane, the angle as well as the isocenter coordinate. Corresponding DRR images (DRR1, DRR2) were generated from patient's 3D CT data with the same imaging parameters using ray casting algorithm[13]-[14]. After the location of the virtual X-ray source was first selected, the projection ray passed through the CT volume (generated by the CT tomography) to a plane perpendicular to the axis of the ray. The DRR pixel values were then the summations of the CT values encountered along each projection ray. Together the four images constitute two sets of images as (DRR1, X-Ray1) and (DRR2, X-Ray2) to be the input data in the next step.

2.2 Registration using multiresolution pyramid based mutual information

Insight Segmentation and Registration Toolkit (ITK) is an open-source, object-oriented software system for image processing, segmentation and registration[15]. The components of the registration framework and their interconnections are shown in Figure2.

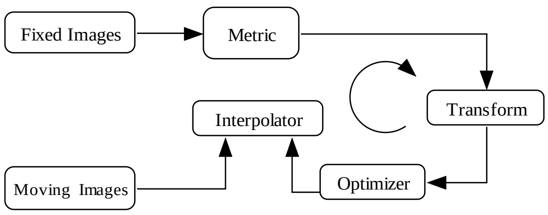


Fig.2 The basic components of the registration framework are two input images, a transform, a metric, an interpolator and an optimizer

Therefore, registration can be divided into five parts including image input, similarity measure, optimization, transformation and interpolation. With different choices of interpolation, similarity measure or optimization methods, we can achieve different registration algorithm to satisfy our practical need.

Mutual information is often used to describe the statistical correlation between the two systems or how much information a system contains in another system [16], Mutual information based medical image registration plays a very important role especially in multi-modal medical image registration [17]. However, it has the problems of a large volume of data as well as robustness issues . Therefore, pyramid multiresolution analysis was employed in the process of registration[18]-[20]. The combination of the conventional mutual information method and image pyramid algorithm makes the registration a coarse to fine process in multi-resolution, reducing mutual information the risk of trapping into a local minimum value. As to the optimization, we employed gradient descent method. It is simple and fast and has only one extreme value. In addition, other parts of the registration framework follow the choice of linear interpolation and form rigid transform.

The implementation primarily involved using the ITK class named itk:: MultiResolutionImageRegistrationMethod in accordance with the typical ITK pipeline mechanism to set the registration category [21-24].

2.3 Coordinate transformation

After the process in 1.2, two translation parameters were obtained as T1 (a1, b1) and T2 (a2, b2) in the coordinate system of DRR imaging plane. In order to get the couch offset parameters (Tx, Ty , Tz), we need to convert the coordinate system of imaging system[25-26] to that of treatment couch system (shown in Fig. 3) .

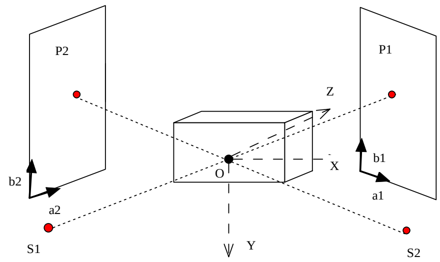


Fig.3 The coordinate system transformation in 2D/2D registration. S1 and S2 are the positions of the X-ray sources. P1, P2 are two DRR imaging planes, and a1, b1 and a2,b2 are the translation parameters obtained from each pair of images registration. The coordinate origin O is supposed to be target isocenter in the treatment

The specific procedures are as follows :

(1) Definition of the coordinate system of couch position : suppose the patient is in a supine position , then the positive direction of the X-axis is from the right hand to the left hand ; the positive direction of the Y-axis is from the person's chest pointing to the back ; the positive direction of Z-axis pointing from the human foot to head;

(2) Definition of the coordinate system of DRR imaging plane : the coordinate origin is at the lower left corner of the image with X-axis horizontally to the right and Y axis vertically upward;

(3) Offset calculation : we take two typical angles of an orthogonal imaging angles which are 45^0 and -45^0 and 0^0 and 90^0 both with a couch angle of 0^0. S1 and S2 are in the XOY plane. and the beam axis (S1O,S2O)is perpendicular to the two imaging planes P1, P2, respectively. According to the coordinate system conversion principle in computer graphics, we derived the following formula:

In the 45^0 and -45^0 case , the formula is illustrated as

$$X = -\frac{\sqrt{2}}{2}(a1+a2), \quad Y = \frac{\sqrt{2}}{2}(a1+a2), \quad Z = -\frac{1}{2}(b1+b2) \qquad \text{(a)}$$

In the 0^0 and 90^0 case , the formula is illustrated as

$$X = -a1, \qquad Y = -a2, \qquad Z = \frac{1}{2}(b1+b2) \qquad \text{(b)}$$

III. Tests and Results

3.1 Simulation test on CT images of clinical parotid gland tumor case

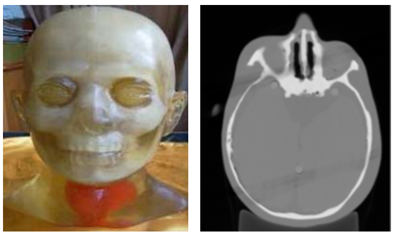
To verify the accuracy of the multiresolution pyramid based mutual information registration method in our IGRT system mentioned above. A clinical parotid gland tumor case was used which constituted by 46 CT images with a resolution of 512 * 512. Two DRR images were generated from the patient's 3D CT data as the fixed images. The parameters used during the generation process are as follows:Fixed Images: The gantry angles are 45^0 and -45^0 separately with a 0^0 treatment couch angle, the source axis distance（SAD）and the source image distance（SID）are 1000mm and 1100mm, the resolution of the DRR images is 512 * 512 with a pixel pitch of 1mm, and the coordinate center is defined to be the center of CT volume data;Moving Images: Set translations on the CT volume data first, then with the same parameters as the fixed images we got two x-ray projection images simulating the shift of the patient position during the treatment. The translation shift of the CT volume in （X, Y, Z） directions were : (5mm, 5mm, 5mm), (0mm , 5mm, 5mm), (5mm, 0mm, 5mm), (5mm, 5mm, 0mm), (3mm, 5mm, 8mm), (5mm, 15mm, 10mm). The results are given in the following Table1：

TABLE I
REGISTRATION RESULTS USING MULTIRESOLUTION PYRAMID BASED MUTUAL INFORMATION BASED ON A CLINICAL PAROTID GLAND TUMOR CASE

Standard offset（mm）	Translation after registration（mm）	Absolute error（mm）	Runtime（s）
(X,Y,Z)	(X,Y,Z)	(X,Y,Z)	
(5,5,5)	(5.05,4.89,4.91)	(0.05,0.11,0.09)	5.141
(0,5,5)	(0.002,4.83,4.86)	(0.002,0.17,0.14)	5.063
(5,0,5)	(4.97,0.026,4.95)	(0.03,0.026,0.05)	5.375
(5,5,0)	(5.04,4.90,0.023)	(0.04,0.10,0.023)	5.218
(3,5,8)	(3.07,4.89,7.83)	(0.07,0.11,0.17)	5.516
(5,10,15)	(5.14,9.73,14.67)	(0.14,0.27,0.33)	5.109

3.2 Clinical test on an anthropomorphic head phantom

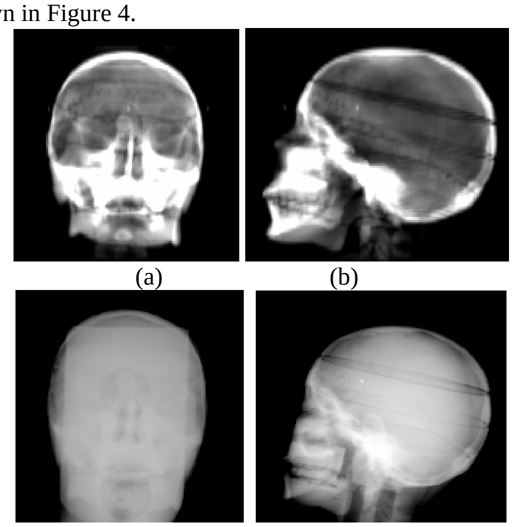
To verify the accuracy of our method mentioned above in practical use, an anthropomorphic head phantom was used in the clinical test. In the first place, we marked the isocenter of the phantom under the help of lasers; then after a CT scan, 80 CT images were obtained with a resolution of 512 * 512 and a CT slice thickness of 2.5mm.



(a) (b)

Fig. 3 The anthropomorphic head phantom used in the clinical test: (a) the anthropomorphic head phantom; (b) the CT image of the phantom

Two DRR images were generated from the 3D CT data of the head phantom as the fixed images. The parameters used during the generation process are as follows:Fixed Images: The gantry angles were 00 and 900 separately with a 00 treatment couch angle, the source axis distance（SAD）and the source image distance（SID）were 1000mm and 1900mm, the resolution of the DRR images was 512 * 512 with a pixel pitch of 1mm, and the coordinate center is defined to be the center of CT volume data;After that, the head phantom was relocated on the couch once again under the help of laser to make it in accordance with the isocenter of the accelerator. Two x-ray images were then acquired using the x-ray imaging system with the same antry angles of 00 and900 . The fixed images and moving images are shown in Figure 4.



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

Fig. 4 The fixed images and moving images: (a) fixed DRR image at 0^0 ; (b) fixed DRR image at 90^0; (c) moving x-ray image at 0^0 ; (d) moving x-ray image at 90^0

Another two different CT data sets with a slice thickness of 5mm and 10mm were obtained from the original CT data of the phantom by extracting a corresponding series of ordered CT images, that is by selecting the 1st, 3rd, 5th…79th from the CT images we formed a set of CT data with the slice thickness of 5mm and by selecting the 1st, 5th, 9th…77th from the CT images we formed a set of CT data with the slice thickness of 10mm. Repeat the same generation principles of Fixed Images mentioned above , we got the other two translation errors of the planned isocenter compared with that of the first set. The registration results of the three sets of CT image data are shown in Table 2 as follows:

TABLE II
REGISTRATION RESULTS USING THREE DIFFERENT CT DATA SETS WITH A SLICE THICKNESS OF 2.5MM, 5MM, AND 10MM BASED ON AN ANTHROPOMORPHIC HEAD PHANTOM

CT slice thickness（mm）	Translation after registration（mm）		
	X	Y	Z
2.5	0.066	0.070	2.060
5	0.772	0.980	4.435
10	0.514	1.076	8.393

IV. DISCUSSIONS

The first test employed a parotid gland tumor case to simulate two fixed images and six shifted images to test the method proposed in our IGRT prototype system. Since it involved using two orthogonal images, we chose the general gantry angles to be 450 and -450. Then Two x-ray projection images were acquired by the simulation of the patient's CT volume data under the same imaging parameters as that of corresponding DRR images but with a different shift position according to those that had been defined above. The results showed that the positioning errors were 0.068±0.070, 0.072±0.098, 0.154±0.176mm along the lateral, longitudinal and vertical axis，respectively. Positioning erros discussed in this paper are focused on the translation results which were magnitude shifs without the direction sign (±) of the deviation. The registration results showed that the accuracy of the multiresolution pyramid based method used in the 2D/2D registration module of our system can be controlled within 1mm , which at the same time also indicates the correctness of the derived formula of the coordinate transformation. And the time it took is 5.3±0.2s, we used double threads programming method in our method since the two pairs of DRR and x-ray image are independent during each own's registration.

In the second clinical test on a head phantom, we got a planned isocenter error of 0.066mm，0.07mm，2.06mm at three axes of lateral, longitude and vertical. We observed that along the vertical axis which also was the axial（Z）direction , the ttranslation error was out of the expectation range compared with the simulation test. Part of the reason for this was the CT slice thickness. Since it has been known that the CT slice thickness has an effect on the positioning errors[27]，in our test the CT slice thickness was changed from 2.5mm to 5mm and then to 10mm by selecting corresponding ordered CT images. The registration results along the Z axis were 2.06mm, 4.435mm, 8.393mm, respectively. It followed a linear increasing relationship as the CT slice thickness went on at 2.5mm, 5mm, 10mm. Apparently, the changes in Z direction were bigger than that of X and Y directions, which changed along the lateral and longitudinal axes less than 1mm at each time with a different slice thickness. Another part of reason for the big deviation in Z direction was that the head phantom which was integrated by many pieces may not be as rigid as a whole object, transparent adhesive tape was used in our test to keep the phantom together which will introduce some errors. In the future work , a rigid steel frame will be put into use in order to fixed the head phantom and also the effect of more different CT slice thickness will be tested. Besides the translation only study in this paper, six degrees of freedom including translation errors alongt three axes and three rotational errors will be taken into consideration in our future 2D/3D studies.

V. CONCLUSIONS

The 2D/2D medical image registration plays a significant role in image guided radiation therapy. A method using multiresolution pyramid based mutual information was proposed in this paper. Three key steps including the acquisition of DRR images and x-ray images, comparison of two images under the ITK registration framework as well as the calculation of coordinate transformation together completed the whole process of the 2D/2D registration in our IGRT system. The efficiency and accuracy of the method were testified in simulated images as well as in a practical clinical test on a head phantom. Conclusions can be drawn that our method with its verified accuracy and good robustness can be effectively used in IGRT systems for patient setup.

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