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 Figure 1.

![Fig. 1 The workflow of the registration process](image-url)
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 Figure 2.

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 Figure 3).

![Figure 3](image-url)
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° and -45° separately with a 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 Table 1:

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

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.

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 0° and 90° separately with a 0° 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 anly angles of 0° and 90°. The fixed images and moving images are shown in Figure 4.

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:

![Fig. 3](image3.jpg)

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Fig. 4 The fixed images and moving images: (a) fixed DRR image at 0°; (b) fixed DRR image at 90°; (c) moving x-ray image at 0°; (d) moving x-ray image at 90°
planned isocenter error of 0.066 mm along the three axes of lateral, longitude and vertical. We observed that the positioning errors were 0.068 ± 0.070 for Y, 0.072 ± 0.098 for Z, 0.154 ± 0.176 mm along the lateral, longitudinal and vertical axis, respectively. Positioning errors discussed in this paper are focused on the translation results which were magnitude shifts 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 1 mm, 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 ± 0.2 s, we used double threads programming method proposed in our IGRT prototype system. Since it simulate two fixed images and six shifted images to test 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.

### 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 lateral 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 ± 0.176 mm along the lateral, longitudinal and vertical axis, respectively. Positioning errors discussed in this paper are focused on the translation results which were magnitude shifts 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 1 mm, 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 ± 0.2 s, we used double threads programming method proposed in our IGRT prototype system. Since it simulate two fixed images and six shifted images to test 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.

### REFERENCES


