2D image registration program using mutual information for patient alignment in proton beam therapy

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1. Introduction

Proton beam therapy provides a conformal dose distribution to a tumor volume due to the Bragg peak of a proton beam. Accurate patient alignment is required in order to ensure proper dose delivery because dose distribution in proton beam therapy is sensitive to uncertainties in patient alignment.

Generally patient alignment is performed by radiation oncologists or radiological technologists based on visual comparison between Digitally Reconstructed Radiography (DRR) generated from treatment planning CT and Digital Radiography (DR) taken during the treatment. The accuracy and required time in this approach depend on the experience and technical skills of operators. Therefore fast and accurate automatic image registration technique independent of their skills is desirable.

The purpose of this study is to develop an image registration program with Mutual Information (MI) for fast and accurate patient alignment in proton beam therapy[1]. This presentation shows preliminary results of performance verification of this program.

2. Materials and Methods

In order to calculate the displacement of DR for DRR automatically, it was decided to use image registration technique with MI in this study. MI calculated from sample image (DR) and reference image (DRR) is maximized when degree of similarity between the both images is maximized. Therefore, it means that the displacement of DR for DRR can be obtained by optimizing MI so that it has maximum value.

Procedure for the 2-dimensional (2D) image registration in this study are shown in Figure 1 and following.

① Input DRR* and DR* into self-made program.
*Image size, resolution and color depth are normalized in advance

② Calculate marginal probability distributions, $p(a_i)$, $p(b_j)$, from 1-dimension histogram of each image (a_i and b_j represent the intensity level of DRR and DR, respectively).

③ Calculate joint probability distribution, $p(a_i, b_j)$, from 2-dimension histogram of both images.

④ Calculate MI from the following equation with the size of 2-dimension histogram, bin.

$$\mathrm{MI} = \sum_{i=1}^{\mathrm{bin}} \sum_{j=1}^{\mathrm{bin}} p(a_i, b_j) \log_2 \frac{p(a_i, b_j)}{p(a_i) p(b_j)}$$

⑤ Optimize the MI with downhill simplex method to determine displacement $(\Delta x, \Delta y, \Delta\theta)$ of DR for DRR.

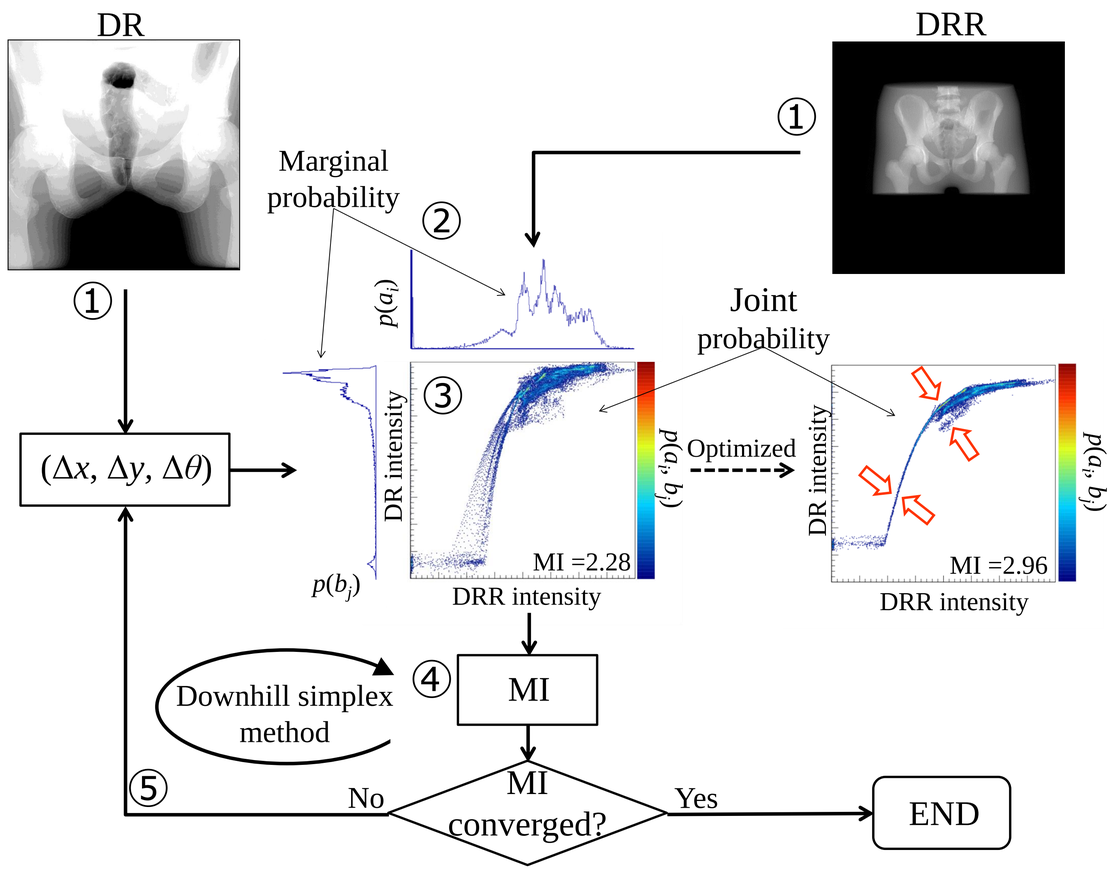

Fig.1 The procedure for 2D image registration program using MI.

DRR and DRs of pelvis phantom generated from two-directions were used as source images (i.e. coronal and sagittal planes) to verify the performance of self-made program (see Table 1). DRs were generated under x- and y-direction shift or rotation for the phantom position of DRR for the verification. Accuracy of calculated-displacement and processing time were evaluated.

Table 1 Image specifications of DRR and DR

Type	Source images			Normalized images*		
	Image size [pixel × pixel]	Resolution [mm / pixel]	Color depth [bit]	Image size [pixel × pixel]	Resolution [mm / pixel]	Color depth [bit]
DRR	512 × 512	1.0 × 1.0	16	214 × 214	1.0 × 1.0	9
DR	1536 × 1536	0.140 × 0.140	12			

*Normalized images are trimmed so that their center match center of the source images

3. Results and Discussion

Table 2 shows the results of the verifications. As an example that proper optimization was implemented, MI was maximized after calculations of 91 times in case 1 on coronal-plane (see Figure 2(a)), and its result achieve high precision of displacement without failing into localized solution by calculating MI over a wide range of displacement (see Figure 2(b)). Calculated-displacement matched correct-shifts and -rotations within 0.29 mm and 0.16° for coronal-plane, 0.61 mm and 0.38° for sagittal-plane. Processing time of the image registration in one direction were calculated within 20 seconds.

Image registration based on visually handling radiographies generally needs about 3 minutes. Therefore, it was confirmed that self-made program has acceptable performance for automatic image registration.

Table 2 Calculated displacement and processing time in all cases.

Plane	case	Actual setup error			Calculated displacement			Processing time [sec]
		x [mm]	y [mm]	θ [deg]	Δx [mm]	Δy [mm]	$\Delta\theta$ [deg]	
Coronal	1	5.0	5.0	0	5.03	4.99	-0.07	19.09
	2	0	0	2.0	0.17	0.29	1.85	15.87
	3	5.0	5.0	2.0	4.93	4.71	1.84	16.09
Sagittal	1	5.0	5.0	0	4.90	4.66	-0.14	12.63
	2	0	0	2.0	-0.38	-0.50	2.25	10.56
	3	5.0	5.0	2.0	5.22	5.61	2.38	16.81

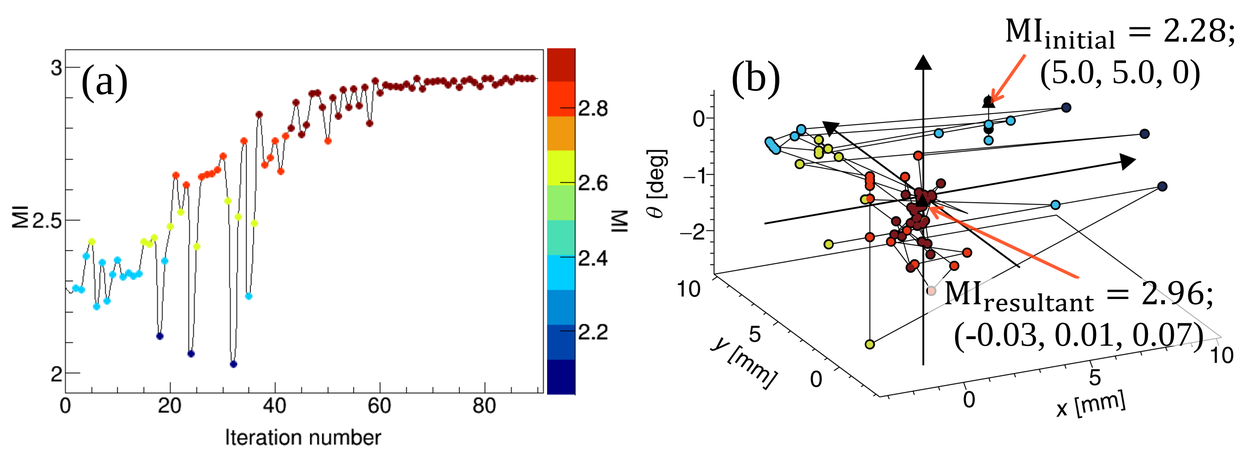

Fig.2 Trace of optimized solution in 2D image registration in case 1 of coronal-plane. Color scale represents MI. (a) MI change for iteration number, (b) Displacement for MI.

4. Conclusions

It was confirmed that performance of self-made program for 2D image registration can achieve acceptable accuracy and processing time compared with those of visually handling radiographies. We will develop 3D registration program using 2 direction images based on the verified 2D registration program for fast and accurate patient alignment as a our future work.

5. References

[1] Josien P. W. Pluim et al.: Mutual-Information-Based Registration of Medical Images: A Survey. Medical Imaging, Vol. 22, No. 8. (2003), pp. 986-1004

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