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Original paper

Integrated Digital Tomosynthesis for patient positioning of image-guided radiation therapy

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ABSTRACT

Purpose: Digital Tomosynthesis (DTS), originally developed for diagnostic applications, has been recently introduced to image guided radiotherapy (IGRT). Due to limited scan range, DTS was featured by anisotropic spatial resolution. A new approach, integrated DTS (IDTS), was developed to improve image resolution of DTS for patient positioning in IGRT.

Materials and methods: For registration purpose, both on-board IDTS (O-IDTS) and reference IDTS (R-IDTS) were required. O-IDTS was generated from cone-beam (CB) projections acquired in two narrow scan ranges separated by 90°. R-IDTS was generated from digitally reconstructed radiographs (DRR) computed from planning CT in the same two narrow scan ranges. Target offsets were determined by registration of O-IDTS and R-IDTS. The reconstruction algorithms of DRR and IDTS were implemented on general purpose graphics processing unit (GPGPU) for acceleration purpose. IDTS approach was evaluated by phantom and patient cases.

Results: Comparing with DTS, IDTS provided high-resolution images in both coronal view and sagittal views. The image resolution of IDTS in axial view was significantly improved compared to that of DTS, but still inferior compared to that of cone-beam computed tomography (CBCT). Reconstruction accuracy and registration accuracy for all cases were high which was within 1 mm. Reconstruction performance of IDTS using general purpose graphics processing unit (GPGPU) can be substantially improved, thus competent for daily clinical use.

Conclusions: IDTS can provide high-resolution images in coronal and sagittal views with fewer CB projections. Image registration based on IDTS was simple and reliable compared to DTS. IDTS is potentially a useful imaging tool for fast patient positioning in IGRT.

1. Introduction

The intensity-modulated radiation therapy (IMRT) and volume modulation radiotherapy (VMAT) have been widely used for external beam treatment of radiation oncology. Positioning accuracy of treatment target is crucial because of the high treatment plan conformity of IMRT and VMAT. 2D megavoltage (MV) portal imaging technique was used earlier in patient positioning. It was gradually replaced by 2D kilovoltage (kV) imaging technique because MV image has low tissue contrast. With the introduction of 2D kV imaging system, 3D cone-beam computed tomography (CBCT) emerged and became the major tool for routine patient positioning in image-guided radiotherapy (IGRT) [1,2]. A large amount of 2D cone-beam (CB) projections are required to generate CBCT. These projections need large gantry rotation and require considerable imaging dose to patient.[3–5] The accumulated imaging dose to normal tissue is higher for a typical IMRT treatment plan consisting of 30 fractions [6–8]. Several approaches were proposed to lower the imaging dose of CBCT scan, such as low mAs per projection, partial scan mode, and iterative reconstruction technique, etc [9,10]. However, the image quality and reconstruction efficiency of CBCT were compromised with these techniques.

Recently, there has been a growing interest of using DTS for patient positioning of IGRT. DTS has several advantages including small gantry rotation, shorter scan time, and less imaging dose. However, DTS has anisotropic spatial resolution because of limited scan range [11–15]. Typically, four DTS data sets with images reconstructed at coronal or sagittal views were required [16,17]. One on-board DTS (O-DTS) data set, called coronal O-DTS, was reconstructed from CB projections with scan ranges centered at 0° or 180°. Another O-DTS data set, called sagittal O-DTS, was reconstructed from CB projections with scan ranges centered at 90° or 270°. Correspondingly, two sets of Reference DTS (R-DTS),

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called coronal R-DTS and sagittal R-DTS, were generated from DRRs with the same scan centers and ranges. Target offsets in lateral and longitudinal axes were determined by registration of coronal O-DTS and coronal R-DTS, while target offsets in longitudinal and vertical axes were determined by registration of sagittal O-DTS and sagittal R-DTS [18–20]. Note here that two registration courses were required in DTS-based patient positioning procedure which has low efficiency for daily clinical use.

In this study, we propose a new approach, called integrated DTS (IDTS), to improve the current DTS reconstruction technique which only offers high-resolution images in a single view (such as coronal view). The IDTS images were reconstructed from fewer CB projections with high-resolution in both coronal and sagittal views. Using IDTS technique, only one registration is needed to determined target offsets in three dimensions. The remainder of this paper was organized as follows. In section 2, first of all, DTS-based patient positioning procedure was described. Secondly, IDTS based patient positioning procedure was explained. Thirdly, the implementation of DRR and IDTS reconstruction algorithms on GPGPU was introduced. In section 3 the results of phantom and clinical cases were analyzed and reported. Finally, the advantages and disadvantages of the new IDTS approach were discussed in section 4.

2. Materials and methods

2.1. DTS-based patient positioning procedure

To determine target offsets in three dimensions using DTS approach, two registrations were required because DTS only provided high-resolution images in a single view. In the first registration, coronal O-DTS and coronal R-DTS were used. As an example, the scan center (0°) and scan range (20°) of coronal DTS was demonstrated in Fig. 1a, and the high-resolution plane of coronal DTS was illustrated in Fig. 1b. Target offsets in lateral and longitudinal axes were determined by registration of coronal O-DTS and coronal R-DTS. In the second registration, sagittal O-DTS and sagittal R-DTS were used. As an example, the scan center (270°) and scan range (20°) of sagittal DTS was demonstrated in Fig. 1c, and the high-resolution plane of sagittal DTS was illustrated Fig. 1d. Target offsets in longitudinal and vertical axes were determined by registration of sagittal O-DTS and sagittal R-DTS. The target offsets in three dimensions were obtained by averaging the results of the two registrations mentioned above. Both O-DTS and R-DTS were reconstructed using classical FDK algorithm [21–24]. Before DTS reconstruction, CB projections were pre-processed by logarithmic transformation and DRRs were computed from planning CT based on ray-casting algorithm.

In general, DTS-based patient positioning procedure consisted of nine steps: (1) Acquiring CB projections by on-board kV imaging system; (2) Generating coronal O-DTS from CB projections with scan center 0° and scan range 20°–40°; (3) Computing corresponding DRRs from planning CT; (4) Generating coronal R-DTS from DRRs with the same scan center and range; (5) Registering coronal O-DTS with coronal R-DTS to determine target offsets in lateral and longitudinal axes; (6) Generating sagittal O-DTS from CB projections with scan center 270° and scan range 20°–40°; (7) Generating sagittal R-DTS from DRRs with the same scan center and range; (8) Registering sagittal O-DTS with sagittal R-DTS to determine target offsets in longitudinal and vertical axes; (9) Averaging results from two registration courses to obtain target offsets in three dimensions. Note that the scan center could be 0° or 180° for coronal DTS and 90° or 270° for sagittal DTS for clinical use.

2.2. IDTS-based patient positioning procedure

To generate IDTS, two CB scans which centered at 0° and 270° were required as illustrated in Fig. 1e. IDTS was reconstructed from the two sets of CB projections instead of one set of CB projections as DTS. As CB projections acquired from two scan ranges separated by 90° were used, IDTS approach results in high-resolution images in both coronal and sagittal views as shown in Fig. 1f. The scan range of CBCT and high-resolution CBCT images in three views were demonstrated in Fig. 1g and h for reference. The image resolution of IDTS (Fig. 1f) was comparable in coronal view and superior in sagittal view compared to coronal DTS (Fig. 1b). The image resolution of IDTS (Fig. 1f) was comparable in sagittal view and superior in coronal view compared to sagittal DTS (Fig. 1d). The image resolution of IDTS in axial view was significantly improved

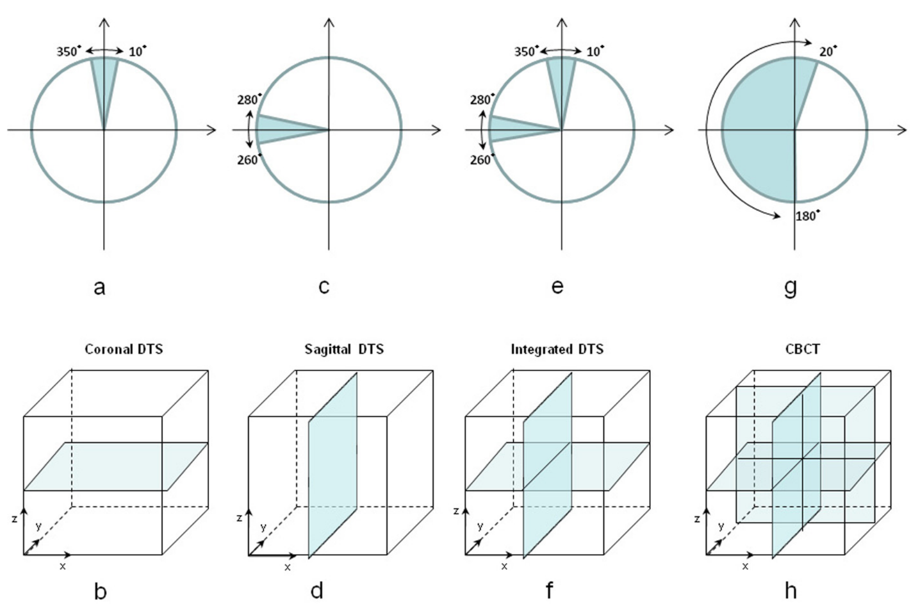

Fig. 1. The illustrations of scan ranges and high-resolution views of DTS, IDTS, and CBCT. (a) The scan range of coronal DTS. (b) The high-resolution view of coronal DTS. (c) The scan range of sagittal DTS. (d) The high-resolution view of sagittal DTS. (e) The scan ranges of IDTS. (f) The high-resolution views of IDTS. (g) The scan range of CBCT. (h) The high-resolution views of CBCT.