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Lesion Insertion in Projection Domain for Computed Tomography Image Quality Assessment

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Abstract

To perform task-based image quality assessment in CT, it is desirable to have a large number of realistic patient images with known diagnostic truth. One effective way to achieve this objective is to create hybrid images that combine patient images with simulated lesions. Because conventional hybrid images generated in the image-domain fails to reflect the impact of scan and reconstruction parameters on lesion appearance, this study explored a projection-domain approach. Liver lesion models were forward projected according to the geometry of a commercial CT scanner to acquire lesion projections. The lesion projections were then inserted into patient projections (decoded from commercial CT raw data with the assistance of the vendor) and reconstructed to acquire hybrid images. To validate the accuracy of the forward projection geometry, simulated images reconstructed from the forward projections of a digital ACR phantom were compared to physically acquired ACR phantom images. To validate the hybrid images, lesion models were inserted into patient images and visually assessed. Results showed that the simulated phantom images and the physically acquired phantom images had great similarity in terms of HU accuracy and high-contrast resolution. The lesions in the hybrid image had a realistic appearance and merged naturally into the liver background. In addition, the inserted lesion demonstrated reconstruction-parameter-dependent appearance. Compared to conventional image-domain approach, our method enables more realistic hybrid images for image quality assessment.

Keywords

Computed tomography (CT); Image quality assessment; Lesion insertion; Hybrid images

1. Introduction

Assessing CT image quality for lesion detection tasks requires the ground truth of lesion characteristics (size, contrast, texture, boundary, type, and location). Because such information is not always available with patient images, hybrid images that combine patient images with lesion models of known properties are often used. An easy and common approach to generate hybrid images is the image-domain method, which inserts the lesions into reconstructed CT images [1-3]. However, since this method inserts lesions after reconstruction, it is extremely challenging to simulate the impact of CT scan and reconstruction parameters (such as non-linear iterative reconstruction) on the lesion

appearance. As a result, lesion boundaries, which are critical for lesion detection and characterization tasks, cannot be correctly simulated using image-domain approaches. To improve the reality of the hybrid images, this study explored a projection-domain method, which inserted lesion projections into patient projections and generated hybrid images using the modified projections.

2. Methods

A flowchart of the projection-domain method is shown in Figure 1. A forward projection program was developed using Siddon's method [4]. The program can be used in all geometries of CT scanners, while the geometry of a state-of-art 128-slice scanner (Siemens Definition Flash, Healthcare Sector, Siemens AG) was used in this study. Liver lesions segmented from patient images were forward projected by the program to yield lesion projections. Because the liver lesions were in the unit of HU, the resulting lesion projections were in the unit of HU·mm. To matched the unit of commercial CT raw data, the unit of the projections was converted to μ -mm by assuming a monoenergetic beam with its energy equal to the vendor's beam hardening correction energy. In such way, the lesion forward projections could be readily combined with post-beam hardening corrections patient projections, which were decoded from commercial CT raw data with the assistance of the vendor. The patient projections with the inserted lesion projections were reconstructed with a Siemens Definition Flash scanner to yield hybrid images. This technique was applicable to various scan conditions, including axial and helical scans, 32- and 64-row collimations, and all flying focal spot modes (in-plane, z-direction, and combined).

Two experiments were performed to evaluate our projection-domain lesion insertion method. First, to verify the accuracy of the forward projection program, forward projections were computed for a digital ACR phantom that was constructed from ACR phantom images (Protocol: 71.1 keV monoenergetic beam, helical scan, pitch of 1, flying focal spot turned on both in-plane and along axial direction). The forward projections were reconstructed to acquire simulated phantom images, and then compared to physically acquired ACR phantom images (Protocol: 120 kV polychromatic beam, helical scan, pitch of 1, flying focal spot turned on both in-plane and along axial direction) in terms of HU accuracy and high-contrast resolution (Figure 2). Second, to verify the reality of the hybrid images, multiple liver lesions were segmented from patient images, rotated, and inserted back into the same patients at different locations. The inserted lesions and the original lesions were presented in pairs for visual assessment. In addition, to demonstrate the main strength of projection-domain method over image-domain method, which is the ability to reflect the impact of reconstruction parameters on lesion appearance, patient projections with inserted lesion were reconstructed repeatedly with different reconstruction slice thicknesses and kernels.

3. Results

The CT numbers measured from Module 1 of physical ACR phantom images were -82 HU (polyethylene), 868 HU (bone), 121 HU (acrylic), and -987 HU (air). The CT numbers measured from Module 1 of simulated ACR phantom images were -83 HU (polyethylene),

868 HU (bone), 121 HU (acrylic), and -987 HU (air). Overall excellent agreements within 1 HU were reached.

Figure 3 shows the bar patterns in both physically acquired and simulated ACR phantom images. The resolution of the simulated phantom images was only slightly worse than that of physically acquired images, which was expected since the forward projections were computed based on a digital phantom of limited resolution.

Figure 4 shows the forward projections of a liver lesion at various angles. The lesion was inserted into patient images, as shown in Figure 5. The lesion had a realistic appearance and merged naturally into the liver background. It also demonstrated kernel-dependent appearance. Figure 6 shows three more cases of hybrid images, with original lesions and inserted lesions presented side-by-side. Two experienced radiologists reviewed the three pairs of original and inserted lesions, and could not identify the lesions that were inserted.

4. Discussion

Hybrid images with inserted lesions are extremely valuable for the assessment of CT image quality, as they offer both anatomical complexity and knowledge of lesion characteristics. With hybrid images, observer studies can be performed to optimize the tradeoff between diagnose accuracy and radiation dose with respect to specific lesion types. To the best of our knowledge, this is the first projection-domain approach to insert lesions into commercial patient images. It not only precisely simulated the gantry geometry of a commercial CT scanner, but also provided much more realistic hybrid images for evaluations of image quality.

To improve the anatomical complexity of the hybrid images, patient projections were used in this study. However, the patient projections were decoded from commercial CT raw data with the assistance of the vendor, which is not a common research resource. A potential solution to this drawback is a reference library being developed by our group, which includes patient projections acquired on commercial CT scanners but converted into an extended DICOM format [5]. The format is open and vendor-neutral, such that the library can be assessed by public and used for CT projection related studies.

In conclusion, a framework has been developed for projection-domain insertion of lesions into commercial CT images, which can be potentially expanded to all geometries of CT scanner. Compared to conventional image-domain method, our method reflected the impact of scan and reconstruction parameters on lesion appearance.

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Figure 1.
The flowchart of the projection-domain lesion insertion.

Figure 2.
The flowchart of the forward projection geometry validation.

Figure 3.

The high-resolution bar patterns in (a) the physically acquired ACR phantom image at 120 kVp and (b) the simulated ACR phantom image. The display window setting is 200 and the level setting is 1000.

Figure 4.
The forward projections of the lesion model at various angles.

Figure 5.

(a) The patient image reconstructed with a FBP B40f kernel. (b) The hybrid image reconstructed with a FBP B40f kernel. (c) The hybrid image reconstructed with a SAFIRE I40f kernel (strength of 5).

Figure 6.

Three liver lesions were segmented, rotated, and inserted back into the same patients at different locations.