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Network-Based Scatter Suppression for Robust Rigid 2D–2D Image Registration in kV-Guided Radiation Therapy

Jiwon Park[1]; Dae Yup Han, PhD[2]; Hyesun Yang[1]; Duhee Jeon, PhD[1]; Hyosung Cho, PhD[1]

[1]*Department of Radiation Convergence Engineering, Yonsei University, Wonju, Republic of Korea*

[2]*Department of Therapeutic Radiology, Yale School of Medicine, New Haven, CT, USA*

ABSTRACT

Purpose: In image-guided radiation therapy (IGRT), patient positioning is typically estimated by rigid registration between cone-beam CT (CBCT)–derived digitally reconstructed radiographs (DRRs) and treatment kV X-ray images acquired at the same gantry angle. However, treatment kV X-ray images are heavily degraded by scattered radiation, leading to reduced contrast and degraded image similarity, which can compromise registration accuracy. This study proposes a network-based scatter suppression approach for treatment kV X-ray imaging to enhance image quality and improve the robustness of rigid 2D–2D image registration for patient positioning in IGRT, while preserving real-time clinical feasibility.

Methods: Scatter suppression was applied to treatment kV X-ray images prior to image registration. A transmission estimation network was employed to predict a pixel-wise transmission map representing scattering-induced attenuation. This transmission map was integrated into a radiographic scattering model to suppress low-frequency scatter components and enhance structural contrast. Experimental validation was performed using a spine phantom imaged on a Varian TrueBeam system. Rigid 2D–2D image registration between DRRs and kV X-ray images was conducted before and after scatter suppression, and registration performance was quantitatively assessed using a mutual-information (MI)–based similarity metric.

Results: Scatter suppression substantially improved visual consistency between CBCT-derived DRRs and treatment kV X-ray images, resulting in clearer anatomical depiction during image registration. While ground-truth positional deviations were unavailable, scatter-suppressed images yielded more stable estimates of in-plane translation and rotation. MI values consistently increased after scatter suppression, and MI maps exhibited enhanced spatial coherence across anatomical regions, indicating improved robustness of image registration.

Conclusion: The proposed network-based scatter suppression approach enhances image visibility and similarity in treatment kV X-ray imaging, leading to more robust rigid 2D–2D image registration in IGRT. These results demonstrate the potential of using learned transmission estimation for real-time scatter mitigation and reliable patient positioning under clinical on-treatment imaging conditions.

INTRODUCTION

Background: Accurate patient positioning is critical in radiation therapy, where kilovoltage (kV) X-ray imaging is routinely used to verify patient setup during treatment. In image-guided radiation therapy (IGRT), rigid 2D–2D registration between cone-beam CT (CBCT)–derived digitally reconstructed radiographs (DRRs) and treatment kV X-ray images acquired at the same gantry angle provides the positional information needed for alignment. However, treatment kV X-ray images are heavily degraded by scattered radiation, which reduces contrast, obscures anatomical structures, and lowers the image similarity between DRRs and kV images. This degraded similarity directly compromises the accuracy and robustness of the registration used for patient positioning. Similar low-frequency degradation caused by atmospheric haze has been effectively addressed in computer vision by transmission-estimation networks such as DehazeNet, which recover image clarity by modeling medium transmission. Inspired by this approach, we adapt a network-based transmission estimation framework for scatter suppression in treatment kV X-ray imaging.

Purpose: This study aims to improve the robustness of rigid 2D–2D image registration for patient positioning in IGRT by suppressing scatter in treatment kV X-ray images through a learned transmission estimation network. By enhancing structural contrast and the image similarity between DRRs and kV images, the proposed method seeks to stabilize registration under realistic on-treatment conditions where ground-truth positional deviations are unavailable, while preserving real-time clinical feasibility.

METHODS AND MATERIALS

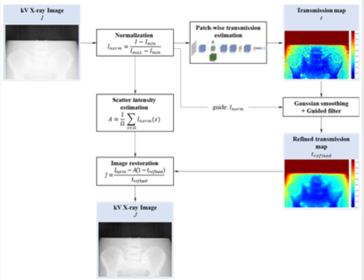

Figure 1. Simplified flowchart of the proposed radiographic restoration process using the modified DehazeNet for scatter correction in radiation therapy kV-triggered imaging.

Table 1. Experimental parameters used in this study.

Parameter	Specification
Source-to-detector distance (SDD)	1500 mm
Source-to-object distance (SOD)	1000 mm
X-ray tube voltage	110 kVp
Number of projections	40
Detector pixel size	0.388 mm
Detector dimension	397 × 297
Voxel size	0.908 mm
Voxel dimension	465 × 465 × 175

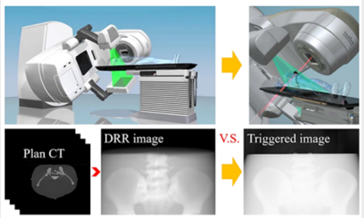

Figure 2. Workflow of patient imaging and treatment using Varian TrueBeam system. Plan CT is acquired to generate DRR images, which are then compared with kV-triggered images to verify patient alignment and ensure accurate treatment delivery.

RESULTS AND DISCUSSION

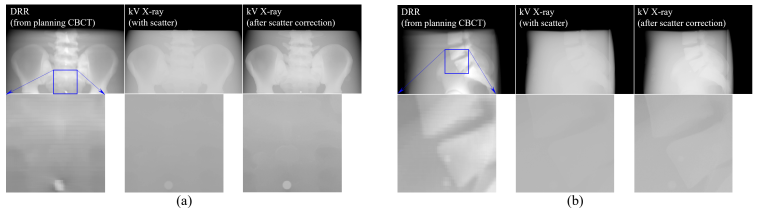

Figure 3. Comparison of CBCT-derived DRRs and treatment kV X-ray images for patient positioning: (a) AP view and (b) LAT view. For each view, the DRR from the planning CBCT (left), the treatment kV X-ray image affected by scatter (middle), and the kV X-ray image after scatter correction (right) are shown.

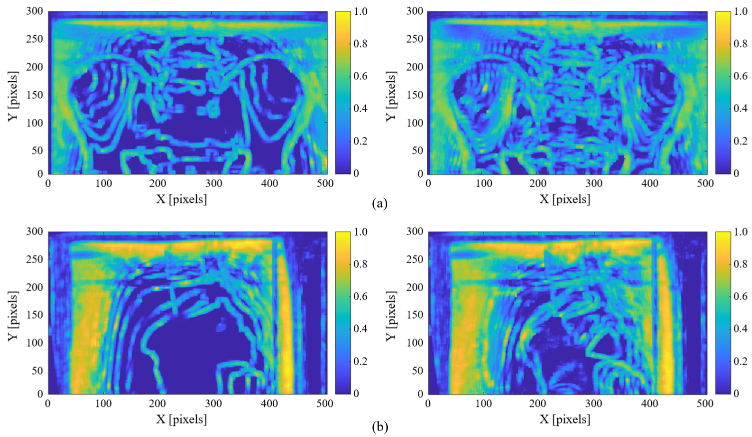

Figure 4. MI maps corresponding to the (a) AP and (b) LAT views shown in Fig. 1, evaluated before and after scatter correction. MI maps quantify the local similarity between CBCT-derived DRRs and treatment kV X-ray images, where values closer to 1 indicate higher image similarity. After scatter correction, MI values increase and exhibit improved spatial coherence, indicating enhanced registration reliability.

CONCLUSIONS

- This study presents a network-based scatter suppression approach for treatment kV X-ray imaging, in which a learned transmission estimation network predicts a pixel-wise transmission map that is integrated into a radiographic scattering model to suppress low-frequency scatter and enhance structural contrast.
- Scatter suppression markedly improved visual consistency between CBCT-derived DRRs and treatment kV X-ray images and increased the mutual-information (MI)–based similarity, with MI rising from 0.513 to 0.532 for the AP view and from 0.480 to 0.489 for the LAT view, accompanied by improved spatial coherence of the MI maps.
- By enhancing image similarity under realistic on-treatment conditions where ground-truth positional deviations are unavailable, the proposed method yields more robust rigid 2D–2D image registration and demonstrates the potential of learned transmission estimation for real-time scatter mitigation and reliable patient positioning in IGRT.

CONTACT

[name]	Jiwon Park
[organization]	Department of Radiation Convergence Engineering, iTOMO lab
[address]	Yonsei University, Wonju, 26493, Republic of Korea
[email]	sampark1017@yonsei.ac.kr
[phone]	+82 – 10 – 2189 – 1017