Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 22-23, 2025

Dual-energy subtraction efficiency of various X-ray detection materials

Junho Lee[a], Seungjun Yoo[a], Seokwon Oh[a], Seongbon Park[a], and Ho Kyung Kim [*]
[a] *Computational X-ray Imaging Laboratory, School of Mechanical Engineering, Pusan Nat'l Univ., Busandaehakro 63beon-gil, Busan 46241*
[*] *Corresponding author: hokyung@pusan.ac.kr*

***Keywords: Dual-energy imaging, Dual-energy subtraction efficiency, X-ray detector, Chest radiography**

1. Introduction

Chest radiography is one of the most widely utilized imaging modalities for the diagnosis and monitoring of thoracic diseases due to its accessibility, cost-effectiveness, and relatively low radiation dose. However, conventional chest radiographs often present challenges in differentiating overlapping anatomical structures, such as bones and tissues, which can obscure critical pathological findings. To overcome these limitations, dual energy imaging (DEI) has emerged as a significant advancement in chest radiography [1].

DEI employs two different X-ray energy levels to acquire separate image sets, enabling material decomposition based on their unique attenuation properties. By selectively reducing the relative contrast of non-relevant regions and background structures, DEI enhances the visibility of areas of interest [2].

DEI can be performed using different imaging techniques. The double-shot method utilizes energy integrating detectors (EIDs) based on materials such as Cesium Iodide (CsI) and Amorphous Selenium (a-Se), whereas the single-shot method employs photon counting detectors (PCDs) based on Silicon (Si), Gallium Arsenide (GaAs) and Cadmium Telluride (CdTe) or multi-layer sandwich detectors.

To investigate and compare the upper-limits of DEI performance of various detector materials, the p-Trac function of MCNP (Version 5, RSICC, Oak Ridge, TN) was used to acquire images, which were then evaluated using the dual-energy subtraction efficiency (DSE) metric as defined in IEC 62220-2-1:2023 [3].

DSE is calculated based on the contrast-to-noise ratio (CNR) of tissue-subtracted images normalized to radiation dose, enabling the quantitative evaluation of a detector's DEI performance.

2. Methods and Materials

2.1 Simulation geometry

The simulation geometry for DSE evaluation follows the standardized setup defined in IEC 62220-2-1:2023 to ensure consistent performance measurement of digital X-ray imaging detectors. The test device used for performance evaluation is a phantom that simulates chest radiography, incorporating cylindrical protrusions made of acrylic (Ac) and aluminium (Al). Ac and Al represent soft tissue and hard tissue, respectively, with cylindrical protrusions of varying thicknesses, ranging from

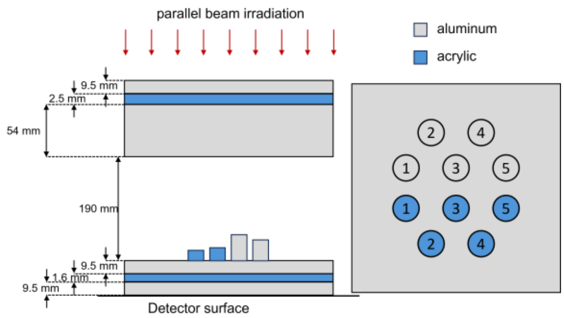

Fig. 1. Geometry of the DSE simulation, consisting of a phantom designed to simulate chest radiography.

cylinder identification numbers 1 to 5, as shown in Fig.1. To acquire dual-energy imaging (DEI) data, the high-energy spectrum was set to 120 kVp (2.0 mm Al, 0.5 mm Ag), while the low-energy spectrum was set to 60, 70, 80, and 90 kVp (2.5 mm Al).

2.2 Tissue-subtracted images

Tissue-subtracted images are generated using high-energy and low-energy X-ray images to enhance the visibility of specific anatomical structures while minimizing the contrast of unwanted tissues. To achieve this, multi-spectral primary data is first acquired, representing different X-ray absorption spectra. This data can be obtained using either a single-exposure or multi-exposure imaging technique [4]. The acquired high-energy image (I_h) and low-energy image (I_l) are then used to compute soft-tissue images (I_s) and hard-tissue images (I_b), where Al contrast is minimized in the former, and Ac contrast is minimized in the latter.

$$I_s = \frac{I_h}{(I_l)^{w_s}}, \tag{1}$$

$$I_b = \frac{I_h}{(I_l)^{w_b}}, \tag{2}$$

To optimize tissue-subtracted images, appropriate subtraction weights must be determined to effectively remove the contrast of specific tissues. The weight for soft-tissue subtraction (w_s) is designed to minimize Al contrast, while the weight for hard-tissue subtraction (w_b) is designed to minimize Ac contrast. These weights are computed based on the mean pixel values in the regions of interest (ROI) of the third cylinder feature.

$$w_s = \frac{ln\left(\frac{\overline{I_h(F_3^{Al})}}{\overline{I_h(B_3^{Al})}}\right)}{ln\left(\frac{\overline{I_l(F_3^{Al})}}{\overline{I_l(B_3^{Al})}}\right)}, \tag{3}$$

$$w_b = \frac{ln\left(\frac{\overline{I_h(F_3^{Ac})}}{\overline{I_h(B_3^{Ac})}}\right)}{ln\left(\frac{\overline{I_l(F_3^{Ac})}}{\overline{I_l(B_3^{Ac})}}\right)}, \tag{4}$$

For example, $\overline{I_h(F_3^{Al})}$ represents the mean pixel value of the third Al feature ROI in I_h, while $\overline{I_l(B_3^{Ac})}$ denotes the mean pixel value of the third Ac background ROI in I_l.

2.3 DSE

DSE is a quantitative metric used to evaluate the effectiveness of dual-energy imaging in suppressing unwanted anatomical structures while preserving the contrast of target tissues. It is computed by analyzing the CNR of specific tissue features in tissue-subtracted images and normalizing this value to the total air kerma (K_a) used during image acquisition.

To calculate DSE, the first step is to determine the dual-energy contrast (DEC), which represents the CNR for each feature in the test device. This is done using two independent acquired tissue-subtracted images. Each value of the DEC is given by

$$DEC_{s,b}^{Ac,Al}(i) = \frac{\left|\overline{I_{s,b}^{(1)}\left(F_i^{Ac,Al}\right)}+\overline{I_{s,b}^{(2)}\left(F_i^{Ac,Al}\right)}-\overline{I_{s,b}^{(1)}\left(B_i^{Ac,Al}\right)}-\overline{I_{s,b}^{(2)}\left(B_i^{Ac,Al}\right)}\right|}{\sqrt{2}\sqrt{var\left(I_{s,b}^{(1)}\left(F_i^{Ac,Al}\right)-I_{s,b}^{(2)}\left(F_i^{Ac,Al}\right)\right)+var\left(I_{s,b}^{(1)}\left(B_i^{Ac,Al}\right)-I_{s,b}^{(2)}\left(B_i^{Ac,Al}\right)\right)}}, \tag{5}$$

Once the DEC values are determined for all features, they are normalized by K_a to compute the final DSE values for both I_s and I_b. The DSE is given by

$$DSE_s = \left\{\frac{DEC_s^{Ac}}{\sqrt{K_a}}, \ \frac{DEC_s^{Al}}{\sqrt{K_a}}\right\}, \tag{6}$$

$$DSE_b = \left\{\frac{DEC_b^{Ac}}{\sqrt{K_a}}, \ \frac{DEC_b^{Al}}{\sqrt{K_a}}\right\}, \tag{7}$$

3. Preliminary Results

Fig. 2 shows images generated from simulations using a 2-mm-thick CdTe detector material, typically used in PCD. Fig. 2(a) shows I_l acquired with an energy range of 20 to 60 keV, while Fig. 2(b) depicts I_h, containing photons with energies above 60 keV. Fig. 2(c) represents a tissue-subtracted image in which the contrast of soft tissue is suppressed, preserving the contrast of Al, which corresponds to hard tissue. In an ideal DEI, the contrast of Ac should be eliminated; however, some residual contrast remains.

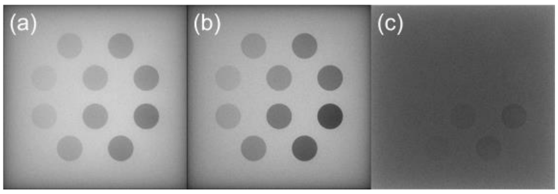

Fig. 2. Simulated images under the CdTe 2mm PCD condition: (a) I_l (20-60 keV), (b) I_h (>60 keV) and (c) Tissue subtracted image with suppressed soft-tissue contrast.

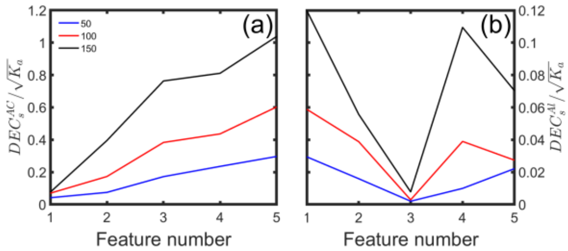

Fig. 3. DSE_s graphs for CdTe 2mm PCD with pixel pitches 50, 100, and 150 μm.

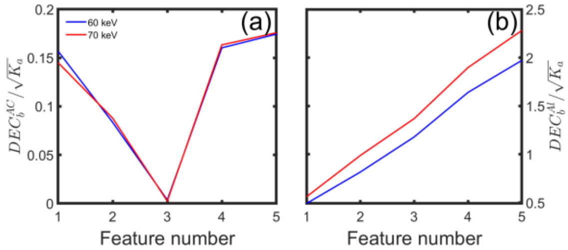

Fig. 4. DSE_b graphs for CdTe 2mm PCD with high-energy thresholds of 60 and 70 keV.

Fig. 3 presents the corresponding DSE_s results, illustrating the impact of detector resolution (pixel size) on DSE. While the DEC of soft tissue increases with larger pixel pitch, the DEC of the suppressed material also increases. Therefore, an increase in pixel pitch does not necessarily indicate an improvement in DSE.

Fig. 4 presents the DSE_b graphs with the low-energy threshold fixed at 20 keV and the high-energy threshold set to 60 keV and 70 keV. The contrast of soft tissue remains similar under both threshold conditions, whereas the contrast of hard tissue is higher when the threshold is set to 70 keV. In this case, using a 70 keV threshold demonstrates better DSE performance.

4. Conclusion

This study presented preliminary results on the evaluation of DSE under various detector conditions using simulations. The findings demonstrated that detector resolution and energy threshold selection significantly influence DSE performance. While a larger pixel pitch improves the CNR of soft tissue, it also increases the contrast of suppressed materials, indicating that a higher pixel pitch does not always lead to better subtraction efficiency. Additionally, the comparison between high-energy thresholds of 60 keV and 70 keV showed that the 70 keV threshold enhances hard-tissue contrast, highlighting the importance of optimal energy threshold selection for improving DSE.

This study serves as a foundation for further investigation into DSE optimization across various detector technologies, including both PCDs and EIDs. Future work will focus on expanding the analysis to different detector types and optimizing the selection of detector parameters to further enhance DSE performance.

ACKNOWLEDGEMENTS

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (RS-2024-00340520).

REFERENCES

[1] J. E. Kuhlman, J. Collins, G. N. Brooks, D. R. Yandow, and L. S. Broderick, Dual-energy subtraction chest radiography: what to look for beyond calcified nodules, Radiographics, Vol. 26, No. 1, pp. 79-92, 2006.

[2] H. Shin, S. Yoo, S. Oh, J. Lee, and H. K. Kim, Detective quantum efficiency of a double-layered detector for dual-energy x-ray imaging, Journal of Instrumentation, Vol. 18, No. 11, pp. C11005, 2023.

[3] IEC, Medical electrical equipment – Characteristics of digital X-ray imaging devices – Part 2-1: Determination of dual-energy subtraction efficiency – Detectors used for dual-energy radiographic imaging; IEC 62220-2-1, International Electrotechnical Commission, 2023.

[4] J.-T. Ho, R. A. Kruger, and J. A. Sorenson, Comparison of dual and single exposure techniques in dual-energy chest radiography, Medical Physics, Vol. 16, No. 2, pp. 202-208, 1989.