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Optimized Estimation of Scattered Radiation for X-ray Image Improvement: Realistic Simulation

A. Y. Danyk[1]* and O. O. Sudakov[1]**
[1]*Taras Shevchenko National University of Kyiv, Kyiv, Ukraine*
**ORCID: 0000-0002-9201-0067, e-mail: AntonDanik@gmail.com*
***ORCID: 0000-0002-6588-1801, e-mail: saa@univ.kiev.ua*

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Abstract—Image processing algorithms for compensation of the scattered radiation influence in X-ray imaging are proposed, studied and optimized by numerical simulation. These algorithms include the scattering estimation by convolution (superposition) technique, estimation of kernel functions by Monte Carlo (MC) simulation, the determination of the optimal number and shape of kernel functions and image segmentation. The determination of the number and shape of kernel functions was performed by the MC simulation of the realistic Zubal phantom and the clustering analysis of shape features of kernel functions. Testing simulation study of the algorithms for chest images at 75 keV proves that the optimal number of kernel functions is equal to 8. This number provides the three-fold contrast enhancement without using the anti-scatter grids. The achieved contrast is about 95% of the primary image contrast that exceeds contrast enhancements achieved with anti-scatter grids. An increased number of used kernel functions provides a better image contrast and better resolution of scattered radiation image, but estimation errors also increase due to the segmentation and deconvolution errors.

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1. INTRODUCTION

Scattered radiation is one of the main sources of the contrast reduction in the X-ray diagnostics [1]. The X-ray imaging system (Fig. 1) emits X-ray photons and detects the X-ray radiation passed through the object [2], [3]. The radiation propagating inside the object may pass without interaction and may be scattered or absorbed.

The radiation passed through the object consists of the initial or primary photons that passing without interaction and of the scattered radiation. The primary X-rays that pass straight through the object contain useful information for the physician. The scattered radiation registered by detecting system is a noise that reduces the image contrast.

The radiation of the scattered X-ray photons is mainly caused by the Compton and Rayleigh processes. It is almost non-collinear with the primary radiation [4] and thus distorts the resulting X-ray image contrast and sharpness adding an extra noise and uneven background to the resulting X-ray image. The Hounsfield scale of image also becomes distorted. Such distortion leads to incorrect interpretation of images and causes artifacts on computer tomography images [5]. Hence, the scattered radiation compensation is an important task especially for medical X-ray imaging.

Application of anti-scatter grid [6] is the most common approach for the reduction of scattered radiation. Anti-scatter grid is the grid of metal plates oriented to the focus of X-ray source, and the primary radiation passes mainly through the grid. Scattered radiation is non-collinear to the primary one and is absorbed by the plates. The anti-scatter grid significantly increases the X-ray image contrast by suppressing up to 70% of the scattered radiation. At the same time, it suppresses the primary radiation by up to 30% that has to be compensated by increasing the exposure. In turn, it increases the radiation dose of patient [7].

There are various approaches for the scattering correction in X-ray imaging without application of anti-scatter grid. One class of such approaches involves the use of image processing algorithms based on mathematical models of scattering [8], [9]. These approaches are attractive because the anti-scatter grid is no more required and the patient dose is decreased significantly.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

ADDITIONAL INFORMATION

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REFERENCES

1. Z. Song, A. M. Fendrick, D. G. Safran, B. E. Landon, and M. E. Chernew, “Global budgets and technology-intensive medical services,” *Healthcare* **1**, No. 1–2, 15 (2013). DOI: 10.1016/j.hjdsi.2013.04.003.

2. A. Assmus, “Early history of X rays,” *Beam Line* **25**, No. 2, 10 (1995). URL: https://www.slac.stanford.edu/pubs/beamline/25/2/25-2-assmus.pdf.
3. M. J. Jensen and J. E. Wilhjelm, *X-Ray Imaging: Fundamentals And Planar Imaging* (DTU, Nutech, 2014).
4. P. Monnin, F. R. Verdun, H. Bosmans, S. R. Pérez, and N. W. Marshall, “A comprehensive model for X-ray projection imaging system efficiency and image quality characterization in the presence of scattered radiation,” *Phys. Med. Biol.* **62**, No. 14, 5691 (2017). DOI: 10.1088/1361-6560/aa75bc.
5. M. V. Kononov, O. A. Nagulyak, and A. V. Netreba, “Influence of X-radiation in receiver system on reconstruction performance of projection tomography,” *Radioelectron. Commun. Syst.* **51**, No. 3, 163 (2008). DOI: 10.3103/S0735272708030084.
6. S. Webb, *Webb’s Physics Of Medical Imaging*, 2nd ed. [ed. by M. A. Flower] (CRC Press, Boca Raton, 2012). URL: https://www.routledge.com/Webbs-Physics-of-Medical-Imaging/Flower/p/book/9780750305730.
7. I. Šabic, D. Kljucevsek, M. Thaler, and D. Zontar, “The effect of anti-scatter grid on radiation dose in chest radiography in children,” *Cent. Eur. J. Paediatr.* **12**, No. 1, 75 (2016). URL: http://cejpaediatrics.com/index.php/cejp/article/view/273/pdf.
8. E.-P. Rührnschopf and and K. Klingenbeck, “A general framework and review of scatter correction methods in cone beam CT. Part 2: Scatter estimation approaches,” *Med. Phys.* **38**, No. 9, 5186 (2011). DOI: 10.1118/1.3589140.
9. W. Zhao, S. Brunner, K. Niu, S. Schafer, K. Royalty, and G.-H. Chen, “A patient-specific scatter artifacts correction method,” in *Progress In Biomedical Optics And Imaging - Proceedings of SPIE* [ed. by B. R. Whiting and C. Hoeschen] (2014), Vol. 9033, pp. 903310. DOI: 10.1117/12.2043923.
10. P. G. F. Watson, E. Mainegra-Hing, N. Tomic, and J. Seuntjens, “Implementation of an efficient Monte Carlo calculation for CBCT scatter correction: phantom study,” *J. Appl. Clin. Med. Phys.* **16**, No. 4, 216 (2015). DOI: 10.1120/jacmp.v16i4.5393.
11. K. Kim, T. Lee, Y. Seong, J. Lee, K. E. Jang, J. Choi, Y. W. Choi, H. H. Kim, H. J. Shin, J. H. Cha, S. Cho, and J. C. Ye, “Fully iterative scatter corrected digital breast tomosynthesis using GPU-based fast Monte Carlo simulation and composition ratio update,” *Med. Phys.* **42**, No. 9, 5342 (2015). DOI: 10.1118/1.4928139.
12. A. V. Netreba, S. P. Radchenko, and M. O. Razdabara, “Correlation reconstructed spine and time relaxation spatial distribution of atomic systems in MRI,” in *2014 IEEE 34th Int. Scientific Conf. on Electronics and Nanotechnology* (*ELNANO*) (IEEE, 2014), pp. 365–367. DOI: 10.1109/ELNANO.2014.6873453.
13. Y. Suleimanov, S. Radchenko, O. Lefterov, A. Netreba, S. Vasnyov, V. Sava, J. Sanchez-Ramos, L. Prockop, and R. Duara, “Magnetic resonance signal processing tool for diagnostic classification,” in *2016 IEEE 36th International Conference On Electronics And Nanotechnology* (*ELNANO*) (IEEE, 2016), pp. 175–179. DOI: 10.1109/ELNANO.2016.7493042.
14. J. Maier, S. Sawall, M. Kachelriess, and Y. Berker, “Deep scatter estimation (DSE): feasibility of using a deep convolutional neural network for real-time x-ray scatter prediction in cone-beam CT,” in *Medical Imaging 2018: Physics Of Medical Imaging* [ed. by G.-H. Chen, J. Y. Lo, and T. Gilat Schmidt] (SPIE, 2018), Vol. 10573, pp. 56. DOI: 10.1117/12.2292919.
15. A. Y. Danyk, S. P. Radchenko, and O. O. Sudakov, “Optimization of grid-less scattering compensation in X-ray imaging: Simulation study,” in *2017 IEEE 37th International Conference On Electronics And Nanotechnology* (*ELNANO*) (IEEE, 2017), pp. 316–320. DOI: 10.1109/ELNANO.2017.7939770.
16. A. Danyk, S. Radchenko, A. Netreba, and O. Sudakov, “Using clustering analysis for determination of scattering kernels in X-ray imaging,” in *2019 10th IEEE International Conference On Intelligent Data Acquisition And Advanced Computing Systems: Technology And Applications* (*IDAACS*) (IEEE, 2019), Vol. 1, pp. 211–215. DOI: 10.1109/IDAACS.2019.8924353.
17. E. D. Prilepsky and J. E. Prilepsky, “Estimation of optimal parameter of regularization of signal recovery,” *Radioelectron. Commun. Syst.* **61**, No. 9, 406 (2018). DOI: 10.3103/S0735272718090030.
18. I. A. Sushko and A. I. Rybin, “Speeding up the Tikhonov regularization iterative procedure in solving the inverse problem of electrical impedance tomography,” *Radioelectron. Commun. Syst.* **58**, No. 9, 426 (2015). DOI: 10.3103/S0735272715090058.
19. E.-P. Rührnschopf and K. Klingenbeck, “A general framework and review of scatter correction methods in x-ray cone-beam computerized tomography. Part 1: Scatter compensation approaches,” *Med. Phys.* **38**, No. 7, 4296 (2011). DOI: 10.1118/1.3599033.
20. I. G. Zubal, C. R. Harrell, E. O. Smith, Z. Rattner, G. Gindi, and P. B. Hoffer, “Computerized three-dimensional segmented human anatomy,” *Med. Phys.* **21**, No. 2, 299 (1994). DOI: 10.1118/1.597290.
21. D. Sarrut, M. Bardies, N. Boussion, N. Freud, S. Jan, J.-M. Létang, G. Loudos, L. Maigne, S. Marcatili, T. Mauxion, P. Papadimitroulas, Y. Perrot, U. Pietrzyk, C. Robert, D. R. Schaart, D. Visvikis, and I. Buvat, “A review of the use and potential of the GATE Monte Carlo simulation code for radiation therapy and dosimetry applications,” *Med. Phys.* **41**, No. 6Part1, 064301 (2014). DOI: 10.1118/1.4871617.
22. O. Sudakov, M. Kononov, I. Sliusar, and A. Salnikov, “User clients for working with medical images in Ukrainian Grid infrastructure,” in *2013 IEEE 7th International Conference On Intelligent Data Acquisition And Advanced Computing Systems* (*IDAACS*) (IEEE, 2013), Vol. 2, pp. 705–709. DOI: 10.1109/IDAACS.2013.6663016.
23. L. Scrucca, M. Fop, T. B. Murphy, and A. E. Raftery, “mclust 5: Clustering, classification and density estimation using Gaussian finite mixture models,” *R J.* **8**, No. 1, 289 (2016). DOI: 10.32614/RJ-2016-021.