

Interpretable low-dose CT enhancement via multi-Gaussian cluster variance reduction

SHANNON, CLARE, IRELAND, May 22, 2026 /EINPresswire.com/ --
Announcing a new publication from Opto-Electronic Sciences; DOI 10.29026/oes.2026.250042.

Computed tomography (CT) has been widely applied in clinical diagnosis, biomedical research and related fields because of its ability to noninvasively acquire internal structural information from samples. However, CT imaging relies on X-ray irradiation and inevitably introduces radiation exposure while obtaining high-quality images, thereby increasing the radiation burden on patients. Consequently, how to reduce radiation dose while maintaining imaging quality has long been an important issue in the field of CT imaging.

In low-dose CT imaging, images often suffer from increased noise, blurred tissue interfaces and reduced contrast, all of which may compromise accurate clinical assessment of lesion structures. To address these challenges, researchers have developed a variety of image enhancement methods based on model-based algorithms or deep learning. Nevertheless, although many of these methods can improve image quality visually, their underlying mechanisms are often complex and lack physical interpretability. Therefore, developing an interpretable image

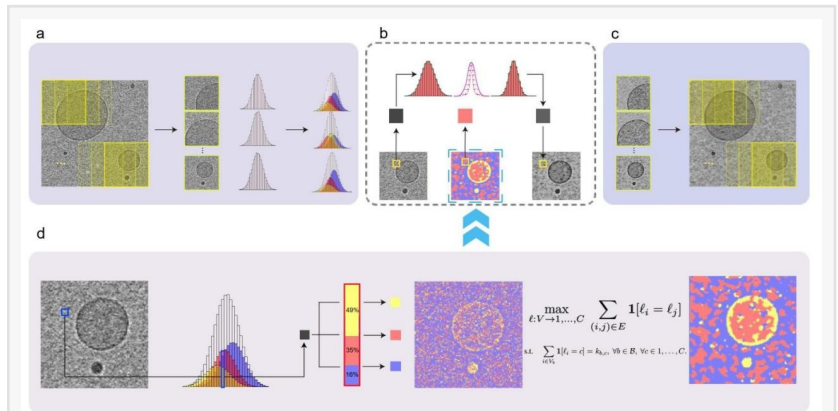


Figure 1. Workflow of the proposed mGCVR

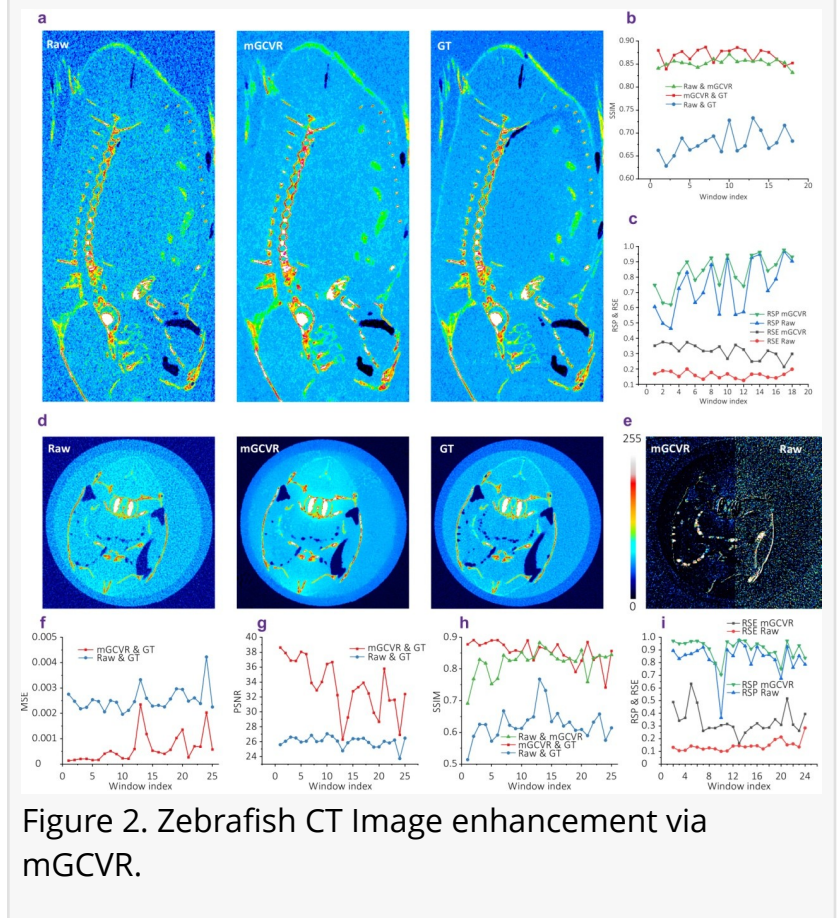


Figure 2. Zebrafish CT Image enhancement via mGCVR.

enhancement method with a clear physical basis that can effectively suppress noise and recover critical structure is crucial for advancing the application of low-dose CT.

To overcome the challenge that strong noise in low-dose CT images may obscure critical structural information, the research group of Prof. Xin Ge from Sun Yat-sen University proposed an interpretable image enhancement algorithm in the histogram domain, termed mGCVR.

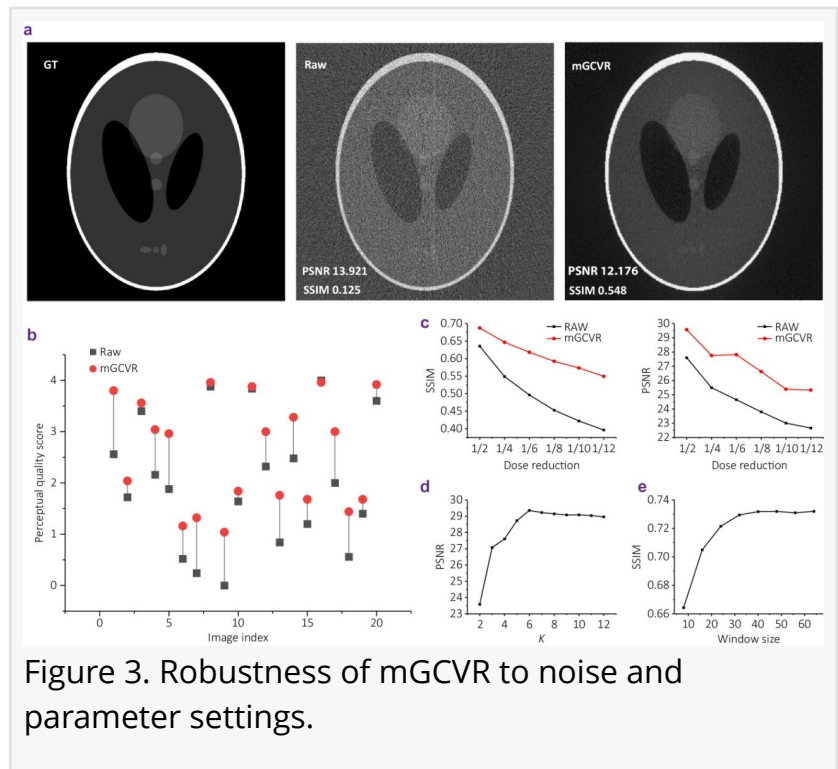
Unlike conventional model-based approaches and deep learning methods, mGCVR addresses low-dose

CT image enhancement in the histogram domain. The research group found that high-dose CT images generally present a small-variance distribution in the grayscale histogram, whereas the distribution becomes broadened due to noise interference in low-dose CT. Motivated by this observation, mGCVR introduces a multi-Gaussian modeling strategy in the histogram domain to model the grayscale distribution of the CT images. By generating label map and optimizing their shapes, the method assigns pixels to different Gaussian components and enables pixel-wise intensity adjustment for noise suppression. Finally, variance reduction is applied to each Gaussian component allowing the low-dose CT image to approximate the small-variance distribution characteristic of high-dose CT. The workflow of the proposed mGCVR is shown in Figure 1.

Using a fixed zebrafish specimen as the sample, the research group evaluate the performance of the mGCVR algorithm on a real biological specimen using multiple quantitative metrics. The experimental results demonstrate that, even under a sixfold reduction in radiation dose, mGCVR is capable of achieving globally high-fidelity CT image enhancement (Figure 2).

Furthermore, mGCVR still performs effective noise suppression capability in simulation tests under an extremely low intensity level, with the photon count reduced to only 1/80 of the ground truth (Figure 3). Experiments across diverse samples further demonstrate that mGCVR can flexibly accommodate varying noise levels and exhibits strong robustness across different scanning devices and tissue characteristics. These findings fully highlight the broad application potential of mGCVR in low-dose CT imaging and related scientific imaging applications.

Keywords: X-ray imaging, denoising, histogram-domain processing, image enhancement, low-dose CT



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Dr Ge received B.S. in Optical information science and technology in 2008, and Ph.D in Synchrotron radiation and its applications in 2013, from University of Science and Technology of China. He took postdoc training at the Chinese university of Hong Kong between 2013 to 2015 and Nanyang Technological University between 2015 to 2021, respectively. He joined the School of Science at SYSU as an Assistant Professor in 2022. His research interests are mainly focused on developing computational imaging models and building interferometric imaging instruments for various imaging applications.

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ISSN 2097-0382

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Zhang XF, Zhu YL, Huang YS et al. Interpretable low-dose CT enhancement via multi-Gaussian cluster variance reduction. Opto-Electron Sci 5, 250042 (2026). DOI: 10.29026/oes.2026.250042

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