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Noise Reduction in Low-Light Spinal Images using CNN-Based Spinal Net Approach

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ABSTRACT: Spinal imaging plays a crucial role in diagnosing medical conditions such as spinal cord injuries, disc degeneration, and tumors. Techniques like MRI and CT scans provide detailed images, but achieving high quality often requires longer scanning time or higher radiation exposure. To address this, low-light or low-dose imaging methods are used, which reduce risk but introduce noise, low contrast, and loss of fine details.

To overcome these challenges, this project proposes a deep learning-based approach using a Convolutional Neural Network (CNN) called SpinalNet. The model is designed to effectively remove noise while preserving important anatomical structures. It uses a gradual feature input mechanism and residual learning, allowing the network to focus on noise removal instead of reconstructing the entire image.

The performance of the model is evaluated using image quality metrics such as PSNR (Peak Signal-to-Noise Ratio) and SSIM (Structural Similarity Index). Results show significant improvement in image clarity and detail preservation. This enhances diagnostic accuracy and also helps in reducing scan time and radiation exposure, making it suitable for real-world healthcare applications.

KEYWORDS: Low-light spinal imaging, Noise reduction, Convolutional Neural Network (CNN), Image denoising, PSNR & SSIM, Deep learning.

I. INTRODUCTION

Spinal imaging is essential for diagnosing a wide range of neurological and musculoskeletal disorders, with techniques such as Magnetic Resonance Imaging (MRI) and Computed Tomography (CT) providing detailed insights into spinal structures. High-quality imaging is crucial for identifying abnormalities like disc herniation, nerve compression, and spinal deformities. However, achieving such quality often requires longer scan times or higher radiation doses, which can lead to patient discomfort, increased costs, and potential health risks. To mitigate these issues, low-dose or low-light imaging techniques are commonly adopted in clinical practice.

Despite their advantages, low-light or low-dose imaging methods introduce significant noise and reduce image clarity, making it difficult to visualize fine anatomical details. The presence of complex noise patterns, such as Rician noise in MRI and Poisson noise in CT images, further complicates the enhancement process. Traditional denoising approaches, including Gaussian filtering, wavelet transforms, and Non-Local Means, often struggle to balance noise removal with the preservation of important structural features, leading to blurred edges or artifacts that may hinder accurate diagnosis.

To overcome these challenges, deep learning-based approaches, particularly Convolutional Neural Networks (CNNs), have gained prominence in medical image processing. In this work, a CNN-based model inspired by the SpinalNet architecture is proposed for effective noise reduction in low-light spinal images. The model employs a gradual input mechanism, residual learning, and perceptual loss functions to ensure efficient noise suppression while preserving critical anatomical structures. This approach aims to produce high-quality, diagnostically reliable images, thereby improving clinical decision-making and enabling safer and faster imaging procedures.



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II. RELATED WORK

Medical image denoising has been an active area of research due to its critical role in improving diagnostic accuracy. Traditional methods such as Gaussian filtering, median filtering, wavelet transforms, and Non-Local Means (NLM) have been widely used for noise reduction in MRI and CT images. While these techniques are effective in reducing noise to some extent, they often suffer from significant drawbacks, including loss of fine structural details, edge blurring, and high computational complexity. Additionally, these conventional approaches are not well-suited to handle complex noise distributions such as Rician and Poisson noise commonly present in medical imaging.

With the emergence of deep learning, Convolutional Neural Networks (CNNs) have significantly improved the performance of image denoising tasks. Models such as DnCNN, autoencoders, and U-Net-based architectures have demonstrated superior capability in learning complex mappings from noisy to clean images while preserving important anatomical features. Advanced techniques incorporating residual learning, perceptual loss, and multi-scale feature extraction have further enhanced denoising performance. However, despite these improvements, challenges remain in effectively preserving fine spinal structures and adapting to varying noise levels, which motivates the need for specialized architectures like the proposed SpinalNet-based approach.

III. METHODOLOGY

The proposed system introduces a specialized Convolutional Neural Network (CNN) based on the SpinalNet architecture for effective denoising of low-light spinal images. Unlike conventional deep learning models, the SpinalNet architecture employs a gradual input mechanism in which each layer receives not only the output from the previous layer but also a portion of the original input image. This design creates a continuous information flow, often referred to as a “gradient highway,” which helps preserve spatial details and prevents the loss of important anatomical features during deep network propagation. As a result, the model is particularly well-suited for maintaining the structural integrity of spinal components such as vertebrae, discs, and nerve roots.

To further enhance performance, the proposed model incorporates a residual learning framework, where the network is trained to predict the noise component rather than directly reconstructing the clean image. This approach simplifies the learning process and improves convergence, especially in low signal-to-noise ratio conditions. Additionally, a perceptual loss function is integrated alongside traditional pixel-wise loss to ensure that the restored images retain both visual quality and structural consistency. The system is designed as an end-to-end pipeline capable of handling medical image formats such as DICOM and NIfTI, performing simultaneous denoising and contrast enhancement. Overall, the proposed approach aims to generate high-quality, diagnostically reliable spinal images while reducing scan time and improving clinical efficiency.

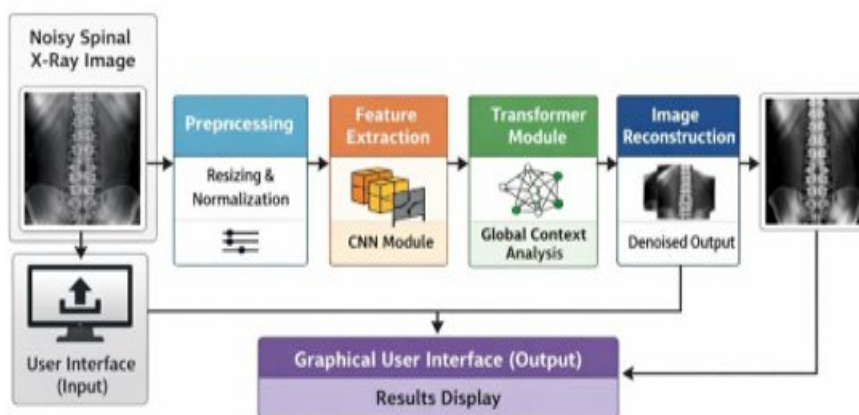


FIG 1: BLOCK DIAGRAM OF NOISE REDUCTION IN LOW LIGHT SPINAL IMAGE USING CNN



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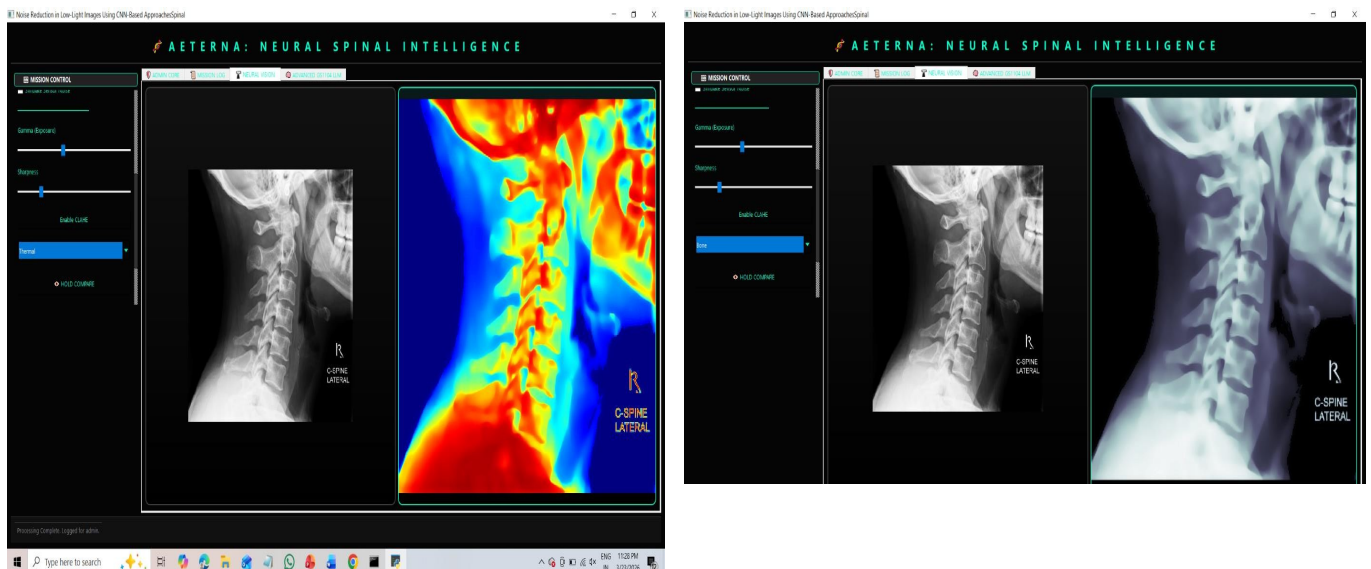
The overall system architecture of the proposed image denoising system is designed to efficiently process low-light spinal X-ray images and generate high-quality, denoised outputs. The system follows a structured pipeline that includes multiple stages such as input acquisition, preprocessing, feature extraction, noise removal, and image reconstruction. Initially, the system takes a noisy spinal X-ray image as input through a user interface. In the preprocessing stage, the image is resized, normalized, and prepared for further processing. This ensures consistency in input data and improves model performance. The preprocessed image is then passed to the feature extraction stage, where important image features are identified using Convolutional Neural Networks (CNNs).

After feature extraction, the data is processed through Transformer-based modules, which utilize self-attention mechanisms to capture global relationships and dependencies within the image. This helps in effectively distinguishing noise from important structural details. The combination of CNN and Transformer components forms a hybrid model that enhances both local and global feature understanding.

Finally, in the reconstruction stage, the processed features are combined to generate a high-resolution, denoised output image. The system also includes a graphical user interface (GUI) that allows users to upload images and view results easily. Overall, the architecture ensures efficient processing, improved image quality, and reliable performance, making it suitable for medical imaging applications.

IV. EXPERIMENTAL RESULTS

The proposed SpinalNet-based CNN model was evaluated on low-light spinal MRI/CT images using standard metrics such as PSNR and SSIM. The model, trained with a combination of MSE and perceptual loss, demonstrated superior performance compared to traditional and baseline methods, achieving PSNR > 30 dB and SSIM > 0.90. The results indicate effective noise removal while preserving important anatomical structures like vertebrae and discs, with consistent performance across different noise levels and spinal regions, making the system suitable for clinical applications.



(a) Thermal

(b) Bone

FIG 2: NOISE AND DENOISED IMAGES

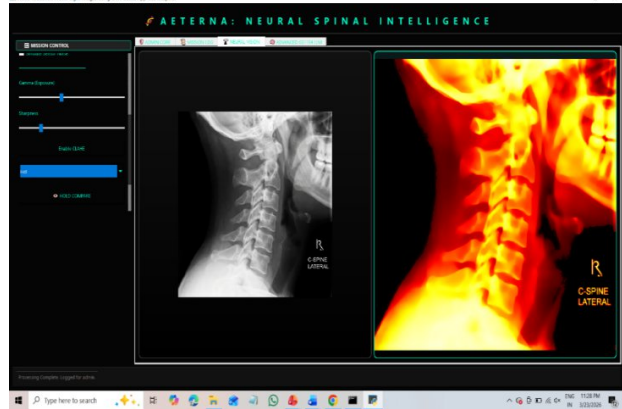


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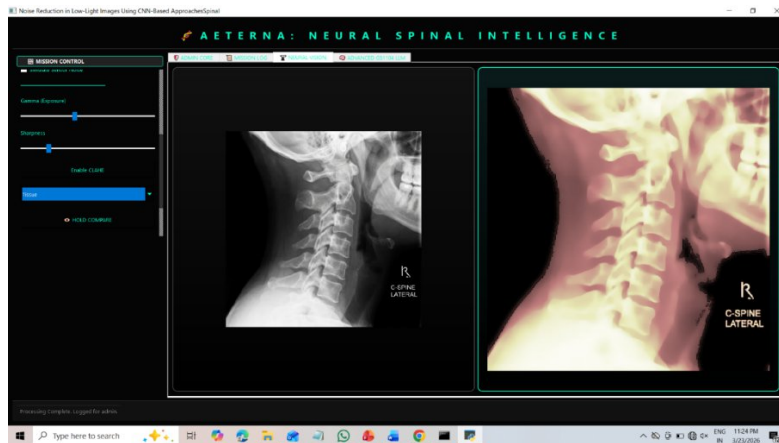
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(c) Grayscale



(d) Hot



(e) Tissue

V. CONCLUSION

In this work, a SpinalNet-based Convolutional Neural Network (CNN) was proposed for effective noise reduction in low-light spinal images. The model utilizes a gradual input mechanism, residual learning, and perceptual loss to achieve efficient denoising while preserving important anatomical structures. Compared to traditional methods, the proposed approach effectively handles complex noise distributions and minimizes loss of structural details, leading to improved image quality and diagnostic reliability.

Experimental results demonstrate that the proposed system achieves superior performance in terms of PSNR and SSIM, along with enhanced visual clarity of spinal images. The model shows robustness across different noise levels and spinal regions, making it suitable for practical clinical applications. Overall, the approach provides a reliable solution for improving low-light medical imaging, with future scope for extension to 3D data and real-time implementations.

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