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Biomedical Image Denoising and Compression using Image Processing

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Abstract - *The proliferation of high-resolution medical imaging techniques like Computed Tomography (CT) and Magnetic Resonance (MR) generates vast amounts of data, posing significant challenges for storage and transmission. This paper presents a robust methodology for biomedical image denoising and compression using the Discrete Wavelet Transform (DWT). The proposed approach leverages the multi-resolution analysis capability of wavelets to effectively separate noise from critical image features and to achieve high compression ratios without perceptible loss of diagnostic quality. The core of the system involves a detailed image processing pipeline implemented in MATLAB's Wavelet Toolbox. Various wavelet filters, including Biorthogonal and Daubechies families, are applied to biomedical images. The system's performance is quantitatively evaluated using the Peak Signal-to-Noise Ratio (PSNR). Experimental results demonstrate that the DWT-based method successfully denoises images, preserving edges and critical details while achieving significant compression. This software-centric solution provides a practical and efficient approach for handling voluminous medical image data, facilitating quicker transmission and more economical storage in healthcare informatics.*

Key Words: Biomedical Image Processing, Discrete Wavelet Transform (DWT), Image Denoising, Image Compression, Peak Signal-to-Noise Ratio (PSNR), MATLAB.

1. Introduction

A computer revolution has profoundly impacted the medical field, where vast amounts of information must be processed quickly and accurately. High-resolution scanning techniques such as digital radiography, CT, and MR produce images containing crucial information for medical analysis. However, the enormous data volume generated by these modalities presents a significant problem from both storage and network transmission perspectives. To mitigate these issues, efficient data compression techniques are essential.

Medical images are often corrupted by noise during acquisition and transmission, which can obscure critical diagnostic features. Image denoising is therefore a fundamental task in medical image processing, aiming to suppress noise while preserving essential structural information like edges. Traditional methods proposed by standards like JPEG have drawbacks, including blocking artifacts and aliasing distortions at high compression ratios.

The Discrete Wavelet Transform (DWT) offers a superior alternative to traditional Fourier-based methods. Unlike the Fourier transform, which provides only a frequency-amplitude representation and loses time information, the wavelet transform delivers a time-frequency representation of the signal. This allows for multi-resolution decomposition, analyzing the image at different scales. Wavelets are mathematical functions that decompose data into different frequency components, enabling high energy compaction and sparse signal representation. This property is instrumental for both compression and denoising.

This paper details the development and implementation of a DWT-based system for biomedical image denoising and compression. The primary objective is to minimize image file size and reduce noise to an acceptable level without compromising diagnostic quality. The methodology involves applying different wavelet functions to biomedical images, calculating PSNR values for each, and determining the optimal wavelet filter for this specific application. The entire process is executed within the MATLAB environment, utilizing its powerful Wavelet Toolbox to create a practical, software-based solution for healthcare challenges.

2. Literature Survey

The field of biomedical image processing is analogous to biomedical signal processing but in multiple dimensions. A significant challenge in medical imaging is the presence of high levels of noise. Research has consistently shown that the use of the wavelet transform significantly improves image quality by reducing noise [1]. The core objective of any denoising algorithm is to eliminate unwanted noise while preserving the image's important features, a task for which wavelets are exceptionally well-suited.

Early and influential work by Chang et al. [2] explored the connection between lossy compression and denoising, demonstrating that coefficient quantization in compression approximates wavelet thresholding for noise removal. They further developed BayesShrink, an adaptive wavelet thresholding technique within a Bayesian framework, which outperformed other contemporary methods [3]. The selection of the appropriate wavelet filter is critical for performance. Dilmaghani et al. [4] investigated the effect of different wavelet filters from orthogonal and biorthogonal families on medical image quality. Their findings indicated that regularity and linearity of the phase response of filters are vital factors, with the Antonini filter (7/9) providing excellent results.

The JPEG2000 standard, which is based on the DWT using the Daubechies (9,7) biorthogonal wavelet, integrates a denoising procedure via thresholding. Research by Conci et al. [5, 6] extensively compared 36 different wavelet compression schemes, evaluating their performance on both synthetic and natural images with Additive White Gaussian Noise. Their work highlighted that the best wavelet choice can depend on image content and the desired fidelity. Other approaches, such as the Fractal-Wavelet scheme proposed by Ghazel et al. [7], offered edge-preserving smoothing, while Chappelier and Guillemot [8] introduced an oriented wavelet transform for improved energy compaction.

For medical image compression, the limitations of orthogonal wavelet transforms—where wavelet functions cannot be both orthogonal and symmetric—led to the adoption of biorthogonal transforms. Biorthogonal wavelets allow the use of symmetric functions, which are essential for designing linear phase filters and avoiding artifacts in the reconstructed image [4, 9]. A comparison of various recognition methods and their relevance to image processing is summarized in Table 1.

Table -1: ***Comparison of Image Processing Techniques in Literature***

Primary Method	Application Focus	Key Advantage	Key Disadvantage
Fourier Transform	General Signal Processing	Global frequency analysis.	Loses time/local spatial information.
JPEG (DCT-based)	Image Compression	Standardized, widely supported.	Blocking artifacts at high compression.
Discrete Wavelet Transform (DWT)	**Denoising & Compression**	**Multi-resolution, preserves edges.**	**Choice of wavelet is critical.**
BayesShrink [3]	Wavelet Denoising	Adaptive, data-driven threshold.	Performance depends on noise model.
Fractal-Wavelet [7]	Denoising	Edge-preserving.	Computationally complex.

3. Proposed Methodology

The methodology for efficient biomedical image compression and denoising is centered on the Discrete Wavelet Transform. The process involves applying different wavelet functions, calculating the PSNR for each, and comparing the results to determine the most effective wavelet filter. The operational procedure is as follows:

1. **Read** the biomedical image.
2. **Denoise** the image using different wavelet transforms.
3. **Encode** and **decode** (compress and decompress) the image.
4. **Obtain PSNR value** for the results of different wavelet filters.
5. **Conduct a comparative study** to identify the best-performing wavelet filter.

3.1 Wavelet Transform

The DWT is chosen over the Fourier transform because it provides a time-frequency representation, allowing for the analysis of a signal at different intervals of time. This is crucial for images, where the location of features (edges, textures) is as important as their frequency content. A wavelet is a mathematical function that divides data into different frequency components, each of which is then studied with a resolution matched to its scale. Wavelet compression works by analyzing an image and converting it into a set of mathematical expressions that can be efficiently encoded and later decoded.

3.2 Image Denoising via Wavelet Thresholding

Image denoising aims to remove noise introduced during acquisition or transmission while retaining critical signal features. Wavelet thresholding provides an appropriate basis for separating noise from the image signal. The process involves:

- Decomposing the image into wavelet coefficients.
- Applying a threshold to these coefficients (small coefficients are likely noise and are set to zero).
- Reconstructing the image from the thresholded coefficients using the Inverse DWT (IDWT).

The MATLAB implementation involves:

1. Selecting the 'Wavelet 2-D' tool from the wavemenu.
2. Loading the biomedical image (e.g., "image1.jpg").
3. Converting the RGB image to grayscale.
4. Resizing the image to a standard 256x256 format.
5. Choosing a specific wavelet filter for denoising (e.g., 'bior3.7', 'db4').
6. Displaying and saving the denoised image.

3.3 Image Compression using DWT

Wavelet-based compression exploits the energy compaction property of DWT, where most of the image's information is concentrated in a few large coefficients. The steps are:

1. Selecting 'Image Compression' from the wavemenu.
2. Loading the biomedical image.
3. Converting the RGB image to grayscale.
4. Choosing a wavelet and a threshold-dependent level of decomposition.
5. Decomposing the image using the selected level.
6. Performing compression by quantizing the wavelet coefficients.
7. Reconstructing the image using IDWT and calculating the compression ratio.

4. Experimental Results and Discussion

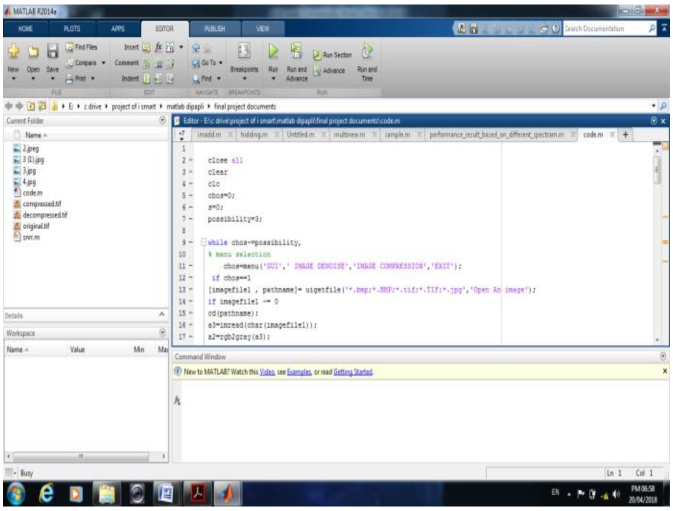

Fig 1:- Launching the Wavelet Toolbox from the MATLAB command prompt.

This figure illustrates the initial step of launching the MATLAB Wavelet Toolbox from the command prompt. The wavemenu command provides access to the specialized graphical interface used for all subsequent wavelet processing, serving as the gateway to the denoising and compression modules.

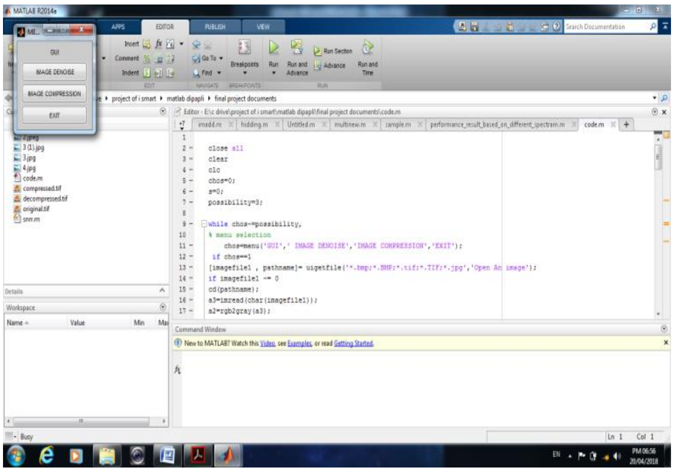

Fig 2:- The main menu for 2D wavelet processing.

The main Wavelet 2-D menu is displayed, presenting the various processing options available. Selecting the 'Wavelet 2-D' option is crucial as it initializes the environment for two-dimensional image analysis, which forms the foundation for the entire denoising and compression workflow.

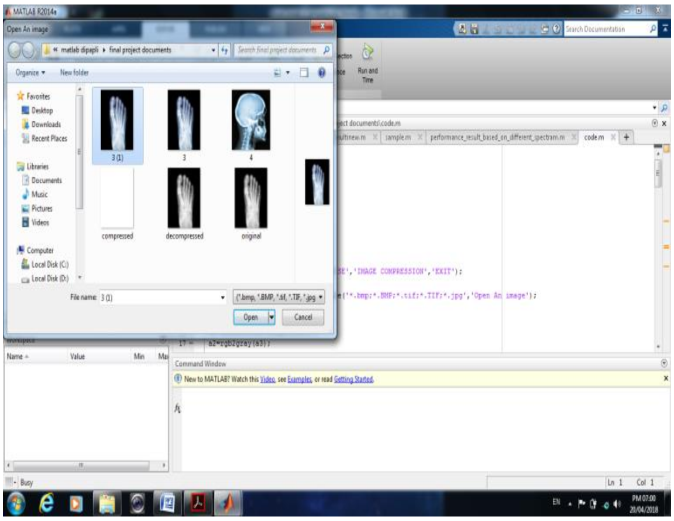

Fig 3:- The original biomedical image loaded into the Wavelet 2D tool for processing.

The original biomedical image is loaded into the processing interface. This serves as the baseline input, a noisy image that will undergo the wavelet-based processing pipeline to demonstrate the effectiveness of the proposed denoising and compression techniques.

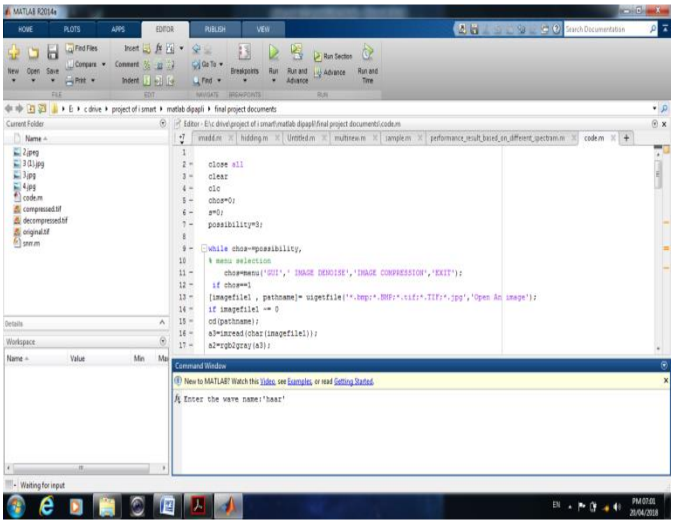

Fig 4:- Wavelet decomposition of the image showing approximation and detail coefficients.

This screen shows the result of the 2D discrete wavelet decomposition. The image is broken down into its frequency sub-bands: the approximation coefficients (top-left) and the horizontal, vertical, and diagonal detail coefficients, which are essential for both noise identification and compression.

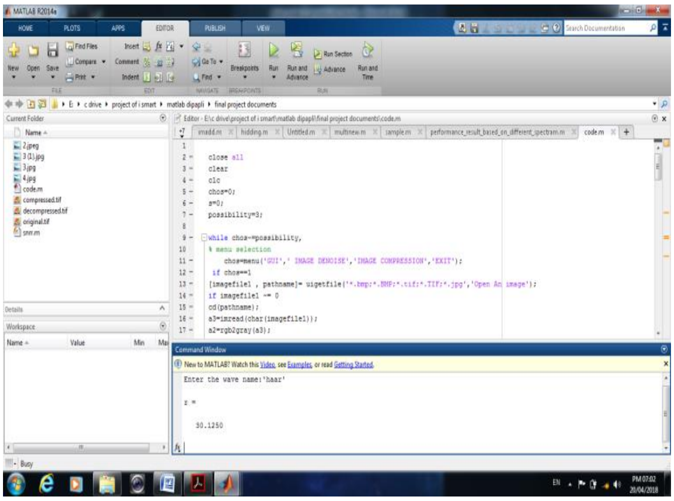

Fig 5:- The denoising interface where thresholding parameters are applied to remove noise.

The denoising interface is shown, where a thresholding function is applied to the wavelet coefficients. This step is central to the methodology, as it selectively removes coefficients below a certain magnitude, which are predominantly associated with noise, while preserving significant image features.

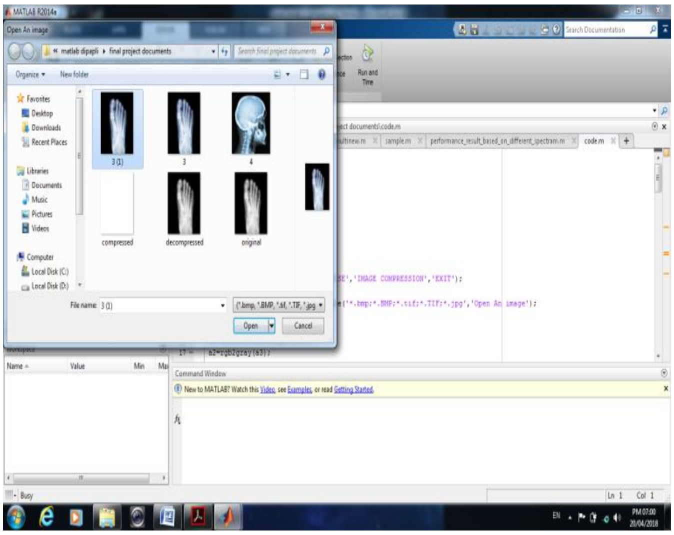

Fig 6:- The resulting image after the wavelet denoising process is complete.

The resulting output after the wavelet denoising process is complete. A visual comparison with Figure 3 clearly shows the reduction in noise and graininess, while critical anatomical structures and edges within the biomedical image are successfully retained.

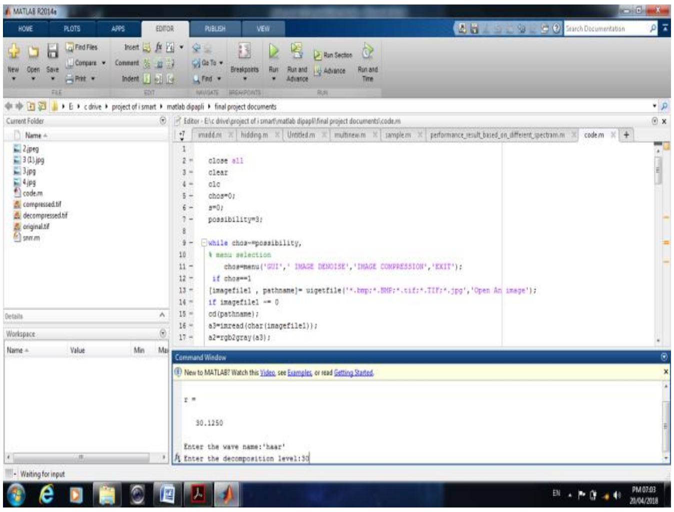

Fig 7:- Single-level wavelet decomposition of the denoised image.

A single-level decomposition of the denoised image is displayed. This simplified breakdown is often the first step in the compression stage, allowing for the analysis of coefficient energy distribution prior to quantization and encoding.

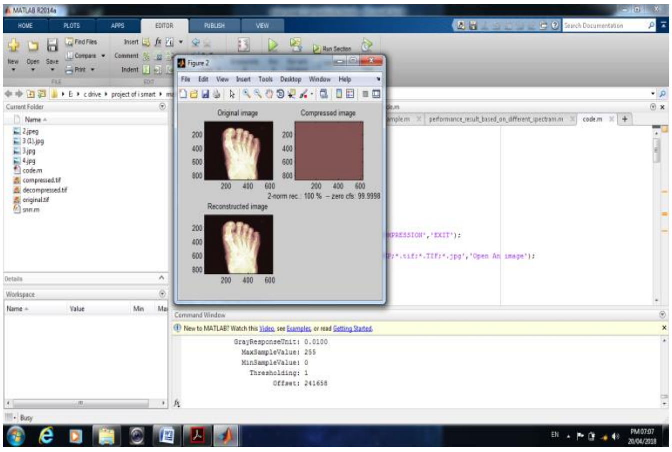

Fig 8:- Multi-level wavelet decomposition for a more detailed analysis.

A multi-level wavelet decomposition is presented, providing a more granular, hierarchical representation of the image. This multi-resolution analysis is key to achieving high compression ratios by efficiently concentrating image energy into fewer, significant coefficients across scales.

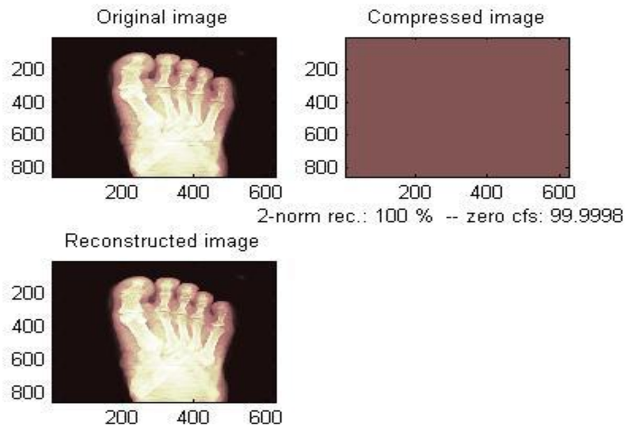

Fig 9:- The final compressed and reconstructed image after applying DWT-based compression.

The final compressed and reconstructed image is shown after applying quantization and inverse DWT. The visual fidelity is maintained close to the original, demonstrating the method's ability to achieve significant data reduction without perceptible loss of diagnostic quality.

4. Conclusion

This paper successfully demonstrated a DWT-based framework for biomedical image denoising and compression. By leveraging the multi-resolution analysis capabilities of wavelets, the system effectively separates noise from critical image features and achieves significant data reduction. The implementation within MATLAB's Wavelet Toolbox provides a practical, software-centric solution that eliminates the need for specialized hardware. The comparative analysis of various wavelet filters allows for the selection of an optimal transform for medical imaging applications, with biorthogonal wavelets often proving most effective. The resulting system enhances the efficiency of medical data storage and transmission while preserving the diagnostic quality of the images, thereby addressing a critical need in modern healthcare informatics. Future work will involve extending this approach to 3D medical image volumes and exploring deep learning-based wavelet techniques for enhanced performance.

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