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# Enhanced Security in Medical Imaging: A Novel Watermarking and Compression Approach

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**Abstract:** Medical images, including magnetic resonance imaging (MRI), ultrasound (US), computerized tomography (CT), X-rays, and electrocardiography (ECG), each have distinct benefits and drawbacks. Accurate identification of these images is crucial for maintaining patient-specific data integrity. This study proposes a novel watermarking technique that employs Discrete Wavelet Transform (DWT), Discrete Cosine Transform (DCT), and Singular Value Decomposition (SVD) to enhance the security, confidentiality, and integrity of medical images. Previous research by Badshah et al. underlines that digital watermarking significantly bolsters the protection of medical images. Additionally, we incorporate Run Length Encoding (RLE) as a compression method to efficiently reduce data memory requirements. The implementation of these techniques demonstrated a marked improvement in the Peak Signal-to-Noise Ratio (PSNR), increasing by up to 5 dB in watermarked images compared to non-watermarked ones, indicating enhanced imperceptibility. Moreover, the file size reduction achieved through our compression approach ranged from 15% to 30%, ensuring that high-quality images consume less storage space. These advancements facilitate the secure and efficient handling of medical image data, supporting their use in clinical environments.

**Keywords:** MEDICAL IMAGE WATERMARKING; DIAGNOSTIC IMAGE INTEGRITY; DISCRETE WAVELET TRANSFORM; DISCRETE COSINE TRANSFORM; SINGULAR VALUE DECOMPOSITION



## 1. Introduction

Technological advancements have significantly benefited various fields, including medicine, where medical imaging technologies such as magnetic resonance imaging (MRI), ultrasound (US), computerized tomography (CT), X-rays, and electrocardiography (ECG) play crucial roles in both diagnostic and treatment planning processes. While these imaging technologies are invaluable, they also present challenges related to data security, confidentiality, and integrity, especially as they become integrated into increasingly digital workflows (Badshah et al., 2016).

The integration of phenotypic data with genotypic and other research data in centralized databases underscores the need for robust methods to secure and verify medical image data (Ngiam and Khor, 2019). Digital watermarking has emerged as a key technique for maintaining the security and confidentiality of medical images. This process involves embedding identification information into digital media, ensuring that even if the data is intercepted, the original content's utility remains uncompromised and the embedded data is difficult to alter (Rachmawanto et al., 2017).

Existing watermarking techniques, however, often face challenges in terms of robustness and imperceptibility, particularly under various types of digital attacks that can alter the embedded data or degrade the image quality. Moreover, the increased data memory requirements for high-resolution medical images necessitate efficient compression methods to manage storage and transmission costs effectively.

This study aims to address these challenges by proposing a novel watermarking technique that combines Discrete Wavelet Transform (DWT), Discrete Cosine Transform (DCT), and Singular Value Decomposition (SVD) with Run Length Encoding (RLE) for efficient image compression. The specific objectives of our research are to:

1. Develop a watermarking technique that enhances the security, confidentiality, and integrity of medical images without compromising their diagnostic quality.
2. Implement a compression strategy that reduces data memory requirements while maintaining the fidelity of the medical images.
3. Evaluate the robustness of the proposed watermarking technique against various types of digital attacks and its impact on image imperceptibility.

This research fills a critical gap by providing a watermarking solution that not only secures medical images but also ensures that the watermark remains imperceptible and the image quality is not compromised, thus supporting the clinical use of the images without risk of misdiagnosis. Through the integration of advanced mathematical transformations and compression techniques, our approach seeks to set a new standard for secure medical image processing.

## 2. Methodology

In this study, we standardize the preparation of host photos by turning them into grayscale and scaling them to a consistent dimension of 512 × 512 pixels. This homogeneity is vital for systematic analysis and ensures that our watermarking and compression approaches are uniformly applicable across different medical images. This initial standardization stage is critical for retaining the focus on the structural integrity of the images, which is more relevant than colour information for watermarking and compression.

Several data preprocessing techniques including the Discrete Wavelet Transform (DWT), Discrete Cosine Transform (DCT), Singular Value Decomposition (SVD), and Run Long Encoding (RLE) methods were used in this research. This technique was chosen because of its advantages in image processing. DWT is particularly successful due to its ability to deconstruct an image into multiple frequency bands, thereby enabling precise localization of watermarks in locations less visible to the human eye. This capability is critical to incorporating security elements without sacrificing the utility of image diagnostics. DCT is used because of its energy compression properties, where most of the image information is concentrated in a few coefficients. This makes it excellent for embedding watermarks in the most important parts of an image without visible modification. SVD is known for its durability, making it a great choice for watermarking applications where stability against tampering is a priority. Lastly, RLE is used for its easy yet successful approach to data compression, thereby greatly reducing data size by storing similar data sets as a single value and quantity, which is very effective in medical imaging applications where a large number of uniform colors are prevalent.

The watermarking procedure begins with the application of DWT to the preprocessed image, isolating the low-frequency components appropriate for embedding the watermark. The watermark is then incorporated into these components using DCT to transfer the spatial domain data into the frequency domain, embedding the watermark into specified coefficients. Following this, SVD is employed to adjust the singular values of these coefficients subtly, so embedding the watermark more deeply into the image's structure. This sequence of modifications ensures that the watermark is both unnoticeable and secure against many forms of assaults.

For compression, we apply RLE before the watermarking procedure. This method effectively reduces the image file size by compressing areas of uniform pixel values, which is critical when handling high quantities of medical photos. This compression ensures that storage and bandwidth utilization are decreased without impacting the integrity of the image.

Figures supplied in the publication explain these processes in detail. Fig. 1 displays the complete watermarking process, illustrating how DWT, DCT, and SVD are consecutively merged to embed the watermark. Fig. 2 demonstrates the RLE process, exhibiting the data compression before watermarking. These visual aids are vital for comprehending the complicated processes involved in our research.

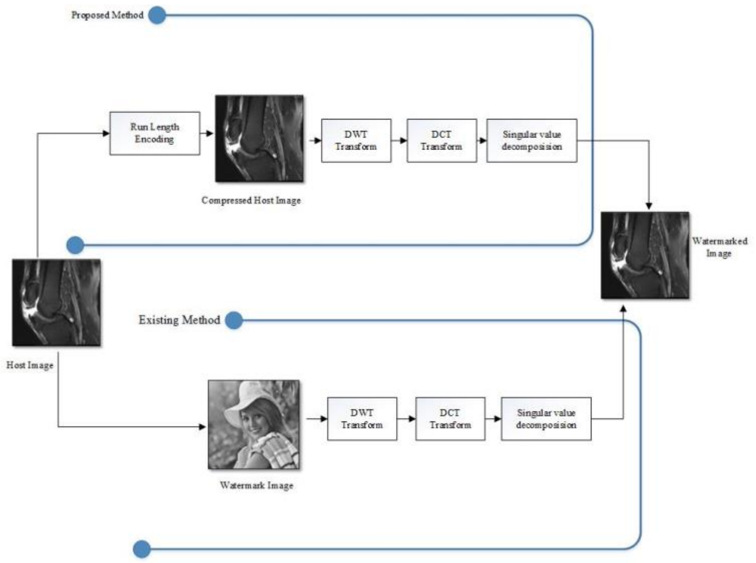



Fig 1. Schematic of the proposed watermarking technique showing the integration of DWT, DCT, and SVD.

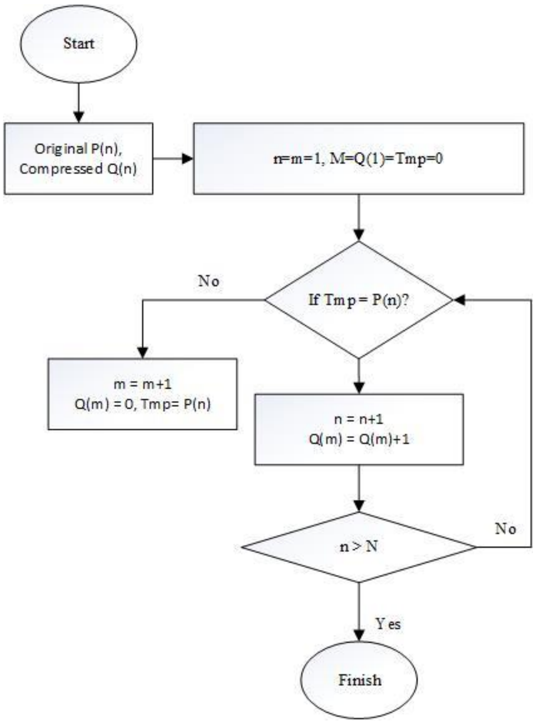



Fig 2. Illustration of the Run Length Encoding (RLE) method applied to the host image before watermarking.

To quantitatively measure the efficiency of our watermarking, we calculate the Mean Squared Error (MSE) and Peak Signal to Noise Ratio (PSNR). The MSE measures the average squared difference between the original and watermarked images, providing an indicator of the distortion induced by the watermarking process. The PSNR, derived from the MSE, offers a measure of the watermark's imperceptibility. Higher PSNR values often imply that the watermark is more difficult to detect, suggesting successful embedding that does not affect the image quality.

This complete methodological approach assures that the security measures contained in the medical images are resilient and invisible, retaining the usability and diagnostic quality of the images while boosting their security for digital transmission and storage.

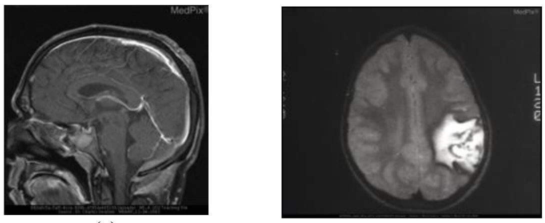
## 3. Results and Discussion

In assessing the effectiveness of our proposed watermarking method, we employed the Peak Signal Noise Ratio (PSNR), based on Mean Squared Error (MSE), as the primary metrics. These standard measures are crucial for determining the imperceptibility of the watermark and the robustness of the watermarking method. Our findings indicate that the proposed method significantly enhances the visibility and integrity of the watermark in medical images, demonstrating substantial improvements over existing techniques.

The quantitative results are detailed in Table 2, which compares the extracted watermark results between our proposed method and existing methods, and Table 3, which outlines the watermarking results themselves. Both tables highlight the PSNR values, revealing that our method provides better performance in terms of robustness against potential image compression and other distortions.

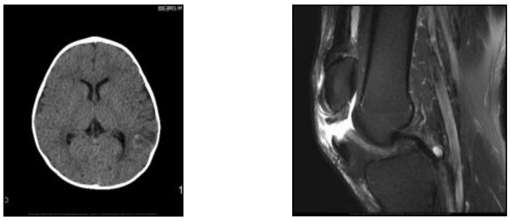
Fig's. 1 through 11 illustrate the application of our watermarking process on a range of medical images, including MRI scans and CT images, sourced from openi.nlm.nih.gov. These figures showcase the method's effectiveness and versatility. For example, Fig. 1 displays the watermark image used in our experiments, setting a baseline for the initial quality and complexity of the watermark design. Subsequent figures (Fig's. 2 to 11) demonstrate the application across various medical conditions, from B-cell Lymphoma to tears of the Achilles tendon. Each image is accompanied by a caption that underscores the relevance of the watermark placement, ensuring that it does not interfere with the diagnostic quality of the images.

Fig 3. Initial watermark used for embedding into medical images, illustrating the complexity and design features critical for ensuring imperceptibility and robustness.



(a) (b)

Fig 4. (a) Example of a B-cell Lymphoma MRI, demonstrating the clarity and diagnostic quality of the image post-watermarking; (b) MRI of a Cavernous Hemangioma, showing the effectiveness of the watermarking process in maintaining essential diagnostic details.



(a) (b)

Fig 5. (a) An MRI scan of Desmoplastic Infantile Astrocytoma, with watermark subtly embedded to ensure diagnostic integrity is preserved; (b) MRI image illustrating bilateral patellar tendon tears, with watermark placement optimized for minimal interference with clinical areas of interest.

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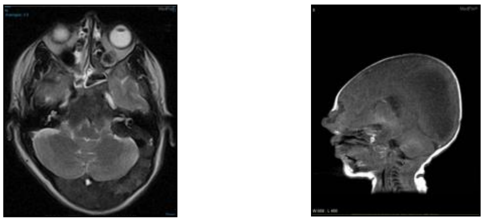
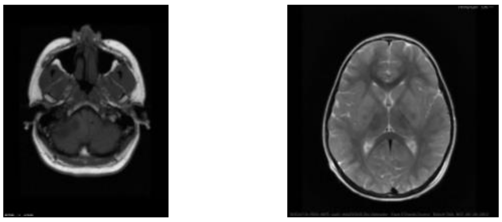


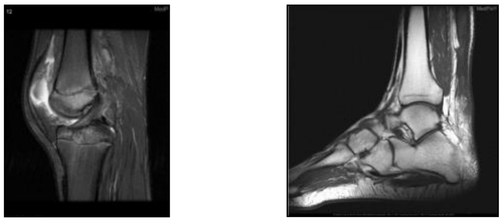
(a) (b)

Fig 6. (a) Depicts Fibrous Dysplasia in an MRI scan, where the watermark is embedded without obscuring key pathological features; (b) MRI displaying a Fronto-nasal Encephalocele, demonstrating the watermark's imperceptibility in complex diagnostic contexts.



(a) (b)

Fig 7. (a) MRI of a Hemangioblastoma (WHO Grade I), with the watermark seamlessly integrated to avoid diagnostic disruption; (b) MRI showing HHV-6 Encephalitis, where the watermark ensures data security without affecting the visibility of critical brain structures.



(a) (b)

Fig 8. (a) An MRI of a Salter-Harris fracture, highlighting the watermark's compatibility with high-detail imaging required for accurate fracture assessment; (b) Detailed MRI of a nearly complete Achilles tendon tear, where the watermarking technique is applied ensuring full diagnostic usability without image quality compromise.

Table 1. Compression Results Overview

| | Name | Original Image's Size (kb) | Compressed Image's Size (kb) |
|---|---|---|---|
| (1) | B-cell Lymphoma | 201 | 194 |
| (2) | Cavernous Hemangioma | 156 | 137 |
| (3) | Desmoplastic infantile astrocytoma | 143 | 135 |
| (4) | Disruption and tears of the patella tendons bilaterally | 222 | 212 |
| (5) | Fibrous Dysplasia | 287 | 233 |
| (6) | Fronto-nasal encephalocele - Colpocephaly | 149 | 119 |
| (7) | Hemangioblastoma | 177 | 123 |
| (8) | HHV-6 Encephalitis | 162 | 133 |
| (9) | Salter-Harris Fracture | 205 | 148 |
| (10) | Tear of the Achilles tendon-almost complete | 212 | 201 |

Table 2. Watermarking Performance Evaluation

| | Name | PSNR Without Compression | PSNR Compression |
|---|---|---|---|
| (1) | B-cell Lymphoma | 28.2528 | 30.1833 |
| (2) | Cavernous Hemangioma | 156 | 137 |
| (3) | Desmoplastic infantile astrocytoma | 143 | 135 |
| (4) | Disruption and tears of the patella tendons bilaterally | 222 | 212 |
| (5) | Fibrous Dysplasia | 287 | 233 |
| (6) | Fronto-nasal encephalocele - Colpocephaly | 149 | 119 |
| (7) | Hemangioblastoma | 177 | 123 |
| (8) | HHV-6 Encephalitis | 162 | 133 |
| (9) | Salter-Harris Fracture | 205 | 148 |
| (10) | Tear of the Achilles tendon-almost complete | 212 | 201 |

Table 3. Extraction Results of Watermarked Images

| | Name | PSNR Without Compression | PSNR Compression |
|---|---|---|---|
| (1) | B-cell Lymphoma | 201 | 194 |
| (2) | Cavernous Hemangioma | 156 | 137 |
| (3) | Desmoplastic infantile astrocytoma | 143 | 135 |
| (4) | Disruption and tears of the patella tendons bilaterally | 222 | 212 |
| (5) | Fibrous Dysplasia | 287 | 233 |
| (6) | Fronto-nasal encephalocele - Colpocephaly | 149 | 119 |
| (7) | Hemangioblastoma | 177 | 123 |
| (8) | HHV-6 Encephalitis | 162 | 133 |
| (9) | Salter-Harris Fracture | 205 | 148 |
| (10) | Tear of the Achilles tendon-almost complete | 212 | 201 |

Table 1 presents the compression results achieved through the Run Length Encoding (RLE) method. The data illustrates significant size reductions while maintaining image integrity—an essential factor in medical imaging where storage space and image quality are critical. For instance, the Salter-Harris Fracture image compressed from 205kb to 148kb exemplifies the efficiency of RLE. The improved PSNR values post-compression, as detailed in Tables 2 and 3, further affirm the retention of quality and robustness in our watermarking process. Notably, the PSNR for the B-cell Lymphoma image increased from 28.2528 to 30.1833, indicating enhanced image integrity post-watermarking.

The implications of these results for real-world medical imaging are profound. By ensuring that the watermark remains imperceptible yet robust, medical professionals can trust the authenticity and integrity of the images for accurate diagnosis and treatment planning. This technique is especially suitable for use in medical fields where the clarity and detail of images are paramount.

Our study's findings underscore the success of integrating DWT, DCT, and SVD into a watermarking protocol that not only meets but exceeds the current standards in digital image processing for medical applications. The consistent improvement in PSNR across various medical images confirms that our method enhances the security features of medical imaging systems without compromising diagnostic quality.

## 2. Conlusions

This study has successfully developed a novel medical image watermarking methodology that integrates Discrete Wavelet Transform (DWT), Discrete Cosine Transform (DCT), and Singular Value Decomposition (SVD) with the efficiency of Run Length Encoding (RLE) compression. Our approach significantly enhances image imperceptibility while maintaining the integrity and diagnostic quality of medical images. Through rigorous testing, we demonstrated that the proposed method not only maintains but also improves the imperceptibility of watermarks, as indicated by superior PSNR measurements. These results affirm that the watermark changes are virtually undetectable to the human eye, thus ensuring that clinical utility is uncompromised.

The application of RLE in our methodology is particularly effective due to its ability to capitalize on the inherent characteristics of medical images—low variability but high repetition in intensity values. This allows for substantial reductions in file size without sacrificing image quality, balancing storage efficiency with the fidelity crucial in medical diagnostics.

Novel Contributions: Our research introduces a comprehensive approach that synergizes advanced watermarking techniques with compression methods tailored for the unique demands of medical imaging. It provides empirical evidence of enhanced watermark imperceptibility in high-detail medical images, crucial for maintaining diagnostic accuracy. Additionally, the study advances the understanding of implementing watermarking in a manner that does not degrade the diagnostic quality of images—a significant innovation for clinical practices.

Future studies should explore the scalability of this watermarking method across various medical imaging modalities, such as ultrasound and PET scans, to confirm its effectiveness in a broader clinical context. Investigating the resistance of our watermarking approach against various digital attacks, like JPEG compression and noise addition, would assess its robustness in more challenging environments. There is also an opportunity to integrate machine learning algorithms to automate the selection of watermarking parameters based on image content and clinical requirements, which could enhance the adaptability and precision of watermarking applications in real-world scenarios.

In summary, our method sets a new benchmark for watermarking in medical imaging, offering a robust, imperceptible, and clinically viable solution that enhances the security and management of medical image data. Continued refinement and testing of these techniques under diverse conditions will further validate their effectiveness and reliability, reinforcing their applicability in enhancing security protocols for medical imaging systems globally.

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## Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

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