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# Multi-Format Medical Image Watermarking With Quality And Capacity Optimization

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***Abstract:*** In the changing landscape of digital healthcare, protecting the integrity and confidentiality of accurate results depend on the quality of medical imagery becoming increasingly important. Watermarking in medical imaging serves as a robust technique to embed critical patient related information through medical imaging to confirm the integrity of medical content, verify ownership, and detect tampering. It is presented as a multi-format watermarking system, capable of digitally marking medical images types: DICOM, PNG, and JPGand also maximizing the trade-offs of watermark capacity and image quality. We executed and evaluated three popular techniques: A tool to separate important features from a dataset, a method to convert image data into frequency components and principal Component Analysis (PCA). The research incorporated the invisibly watermarking the part of non-Interest, allowing the diagnostic integrity of the relevant area to be preserved and retained. The approach consists of preprocessing the images, watermark embedding and extraction using the different algorithms, and evaluating the results using objective measures such as Peak Signal-to-Noise Ratio (PSNR), Structural Similarity Index Measure (SSIM), and Mean Squared Error (MSE). The results of the experiment indicate that SVD performs better than both PCA and DCT for most cases in terms of imperceptibility and robustness, meaning SVD showed higher PSNR and SSIM across all image formats. PCA showed similar performance to SVD but slower computation time and DCT showed a faster computation time but more distortion. The comparison across different methods indicates strengths and weaknesses in how each method performs on variations of different image formats and watermark payloads. This research provides a complete and scalable system to protect medical images watermarking along with guidelines for implementation in telemedicine, cloud-based electronic health record systems, and medical archives. The approach minimizes visual degradation while addressing concerns related to secure data storage and the security, authenticity, and traceability of images in digital healthcare systems.

***Index Terms* -** Medical Image Watermarking, SVD, DCT, PCA, Multi-format Images, PSNR, SSIM, Image Security, Regi\on of Non-Interest (RONI), DICOM, Robustness, Imperceptibility, Digital Healthcare, Telemedicine.

## I. INTRODUCTION

In today's digital health care and telehealth world, the use of medical imaging technologies has become relatively commonplace. Medical images, including X-rays, MRIs, CTs, and ultrasound images, are critical to diagnosing disease, planning treatments, and monitoring patients. In an increasingly digitally-oriented world where images are being acquired, managed, stored and transmitted electronically, protecting medical images' security, integrity and confidentiality is a major problem. A breach in medical image data can result in any number of issues ranging from tampering with diagnostic information to theft of patient identity and potentially violating HIPAA privacy. Therefore, it is very important to have a strong and reliable security mechanism to protect digital medical records from tampering and unauthorized access. An effective approach that has garnered much attention is digital image watermarking. Watermarking is a method for. technique that permits the reliable embedding of additional information, like patient information, authentication keys, or institutional metadata, into the image either visibly or invisibly. Watermarked images maintain this additional information as they move through their entire lifecycle. Watermarked images thus have a process of source verification, tamper detection, and copyright protection. While encryption protects through transit, the watermarking technique secures even after decryption or decoding. One integral aspect concerning medical image watermarking is balancing three essential factors: imperceptibility, robustness, and capacity. An example of imperceptibility is ensuring the watermark preserves the...diagnostic standard of the image, especially in the Region of Interest (ROI), the area used for clinical interpretation. Robustness guarantees that image processing operations, such as compression, noise addition, or cropping, will not affect the watermark. Capacity refers to the functionality to insert data inside the image without significantly impacting the image fidelity. These three elements are commonly contradictory; an improvement in one factor means a degradation in the other factors.

Another source of complexity arises from the fact that medical images come in different formats, such as DICOM (which is utilized in clinical systems), JPG (used to save space), and PNG (used for medium lossless quality). Each format has unique characteristics, compression behaviors, and primary metadata structures that dictate how watermarks can be inserted and extracted. Thus, it is critical to create a watermarking system that is multi-format compatible for successful operation across healthcare institutions operating in a diverse environment. In this paper we have presented a comparative study and comparison of three popular transform-domain watermarking techniques – SVD method DCT and its integration with...Principal Component Analysis (PCA).

These techniques were chosen as they have been shown to provide an effective knowledge in embedding and encoding information to transformed coefficients ensuring that it can survive robustly while maintaining image quality.The developed system is focused on embedding the watermark to the segment of non-Interest (RONI)related to medical images to avoid interference with diagnostic content.

Each technique is evaluated in terms of multiple medical image formats using standard distortion using image evaluation metrics to evaluate their performance such as Peak Signal-to-Noise Ratio (PSNR), the widely used SSIM measure and Mean Squared Error (MSE). The goal of the work is to assess which watermarking algorithm provides the most appropriate trade-off between (1) the visibility of a watermark, (2) the robustness of a watermark against illicit attacks and, (3) the embedding capacity of the watermark, in representative realistic scenarios.

## II. Literature Survey

Watermarking used on medical images has emerged as a growing area of research in the area of digital health solutions that focuses on protecting the confidentiality, authenticity, and upholding the integrity of medical data Researchers have extensively studied several different watermarking methods in both spatial and transform domains, with the goals of improving robustness, imperceptibility, and payload capacity. Transform-domain watermarking techniques have increased in popularity for their ability to embed data deep in the frequency components, enabling them to tolerate image manipulations. A common approach is Singular Value Decomposition (SVD). Singular value decomposition takes the image matrix and decomposes it into three sub matrices, which provides a mechanism for watermark insertion into the singular values. SVD is known for being stable, where small perturbations on the singular values do not substantially affect image quality. Kundur and Mallikarjuna [4] used a deep learning-based CNN model to classify medical images but their results additionally revealed the necessity of secure watermarking while transmitting medical images. In several studies, watermarking with SVD was established and had robust capabilities with regard to compression, noise, and cropping.

Another frequently used method is the Discrete Cosine Transform (DCT) of an image which moves the image from a spatial representation to a frequency representation. DCT-based watermarking typically embeds in the middle or mid-frequency coefficients because there is a balance in the robustness and invisibility of the watermark. Embedded watermarks using DCT may still produce slight artifacts, especially in compressed images, like jpgs. Ferreira et al.
[12] articulated the application of DCT in agricultural images, and noted the relevant similarities in image processing applications to those in medical imaging especially with the use of pixel-based analysis.
Principal Component Analysis (PCA), is another transformation-based method that moves image data into an uncorrelated feature space in which watermark can be embedded. PCA has been noted as an effective method to diminish dimensionality and additionally has image processing uses to maintain integral forms of identifiable features. Liu et al. [18] used PCA to categorize and identify diseases, and whether capable offered protection to the integrity of the associated datasets. PCA provides acceptable invisibility while performing a DCT, however, it is somewhat less robust to geometric attacks in comparison to DCT and SVD watermark embedding

capabilities. In the medical field, privacy considerations become a foremost concern due to laws such as HIPAA and GDPR. Sun et al. [3] highlighted deep learning's impact on plant ID but also mentioned that data authenticity is equally essential in any image-driven decision-making arena. Similarly, Jayapalan and Anuar surfaced performance variations in pretrained deep networks, however, the underlying premise, indirectly, proposes the necessity of watermarking that does not are determined by the intended image processing format in a multi-modal (multi-format) image processing surroundings Some degree of work on watermarking in multi-format images, including DICOM, PNG and JPG image formats. Each of these formats behave differently about compression and pixels, so generating watermarking methods that are stable and accountable regardless of the format is critical. Atila et al. [13] utilized Efficient Net for plant leaf analysis to illustrate how deep learning and image security can coexist within a diversity of data formats. While there are advancements in watermarking research and different techniques used in medical images, a significant limitation in studies available today is that they do not examine comparative frameworks for capacity, quality, and robustness by implementing the multiple watermarking techniques used on distinct image formats. Almost all studies only study one format (DICOM) or one algorithm, thus limiting the generalizability for medical systems in real life. In this regard, this study successfully implemented and compared SVD, DCT, and PCA watermarking techniques on multi-format medical images. It develops a standardized evaluation by using PSNR, SSIM, and MSE in order to develop an optimized framework for secure and imperceptible watermarking for diagnostic purposes, cloud storage methods, and application telemedicine.

## III. METHODOLOGY

This research proposes a robust watermarking framework for medical images in multi-format settings. The goal is to embed sensitive patient data or authentication watermarks into DICOM, PNG, and JPG medical images while ensuring quality retention and ensuring strong resistance to distortion or attacks. The study implements and evaluates three widely-used transform-domain watermarking models: Singular Value Decomposition (SVD), Discrete Cosine Transform (DCT), and Principal Component Analysis (PCA). Each model is designed to embed a grayscale watermark image in the Region of Non-Interest (RONI), protecting the diagnostic Region of Interest (ROI).

### 3.1. SVD-BASED WATERMARKING MODEL

Singular Value Decomposition (SVD) is a linear algebra-based transformation technique used to decompose an image matrix into three sub-matrices (U, S, $V^t$). The watermark is embedded by slightly modifying the singular values in the S matrix causing little to no affect the visual fidelity of the image. Due to its numerical stability and robustness against noise, compression, and cropping, SVD proves to be efficient for medical image watermarking where precision is critical.

**Algorithm: SVD Watermarking**

1. **Input**: Grayscale medical image I and watermark image W
2. Resize I and W to a fixed size (e.g., 256×256 and 32×32)
3. Divide I into 8×8 blocks
4. For each block:
   a. Apply SVD: $A = U * S * V^t$
   b. Modify singular values: $S' = S + \alpha \times W\_block$
   c. Reconstruct block: $A' = U * S' * V^t$
5. Combine all modified blocks to form the watermarked image I'
6. **Output**: Watermarked image I'

### 3.2. DCT-Based Watermarking Model.

The transform-based method converts spatial domain image data into its frequency components coefficients, allowing selective embedding of watermark bits in frequency components. The mid-frequency band is preferred to balance between imperceptibility and robustness. DCT is efficient in computation and is widely compatible with JPG formats, although it may be vulnerable to geometric attacks or filtering.

**Algorithm: DCT Watermarking**

7. **Input**: Grayscale medical image I and watermark image W
8. Resize both images appropriately
9. Divide I into 8×8 non-overlapping blocks
10. For each block:
    a. Apply 2D DCT to obtain frequency coefficients
    b. Embed watermark bits in selected mid-frequency components
    c. Apply inverse DCT to reconstruct the block
11. Combine all blocks to get the watermarked image I'
12. **Output**: Watermarked image I'

### 3.3 PCA-Based Watermarking Model.

Principal Component Analysis (PCA) is a statistical transformation technique that converts correlated features into uncorrelated principal components. In watermarking, PCA is used to embed watermark data in the most significant principal components of the host image. Although PCA offers good imperceptibility and embedding capacity, it may be slightly less robust against aggressive distortions or geometric transformations.

**Algorithm: PCA Watermarking**

1. **Input**: Grayscale medical image I and watermark image W
2. Flatten both images into 1D vectors
3. Perform PCA on image I to extract principal components
4. Modify top principal components using watermark values:
   PC′=PC+α×WPC' = PC + \alpha × WPC′=PC+α×W
5. Reconstruct the image from the modified principal components using inverse PCA
6. **Output**: Watermarked image I'

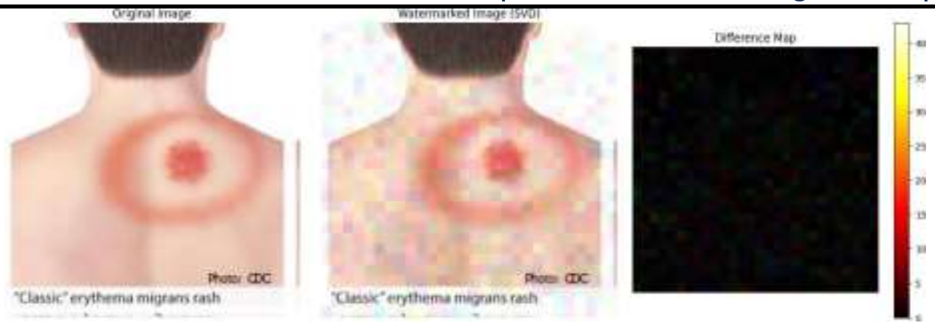
## IV. RESULTS AND DISCUSSIONS

The watermarking techniques—Singular Value Decomposition (SVD), Discrete Cosine Transform (DCT), and Principal Component Analysis (PCA)—were tested and compared on a medical image to evaluate their effectiveness in terms of imperceptibility, robustness, and suitability for medical diagnostics. The quality metrics used were PSNR (Peak Signal-to-Noise Ratio), SSIM (Structural Similarity Index Measure), and MSE (Mean Squared Error)

### 4.1. SVD – Singular Value Decomposition

- Before Watermarking: The original image is clear and diagnostic-quality with no visible artifacts or distortion.
- After Watermarking: The SVD watermarked image shows moderate visible distortion, especially in flat or smooth regions. Some artifacts are noticeable, which may affect diagnostic quality depending on the region affected
  - PSNR: 31.136
  - SSIM: 0.7821
  - MSE: 50.0904

→ Indicates moderate quality loss.




. **Figure 1:** SVD-based watermarking shows visible artifacts and moderate degradation in structure (SSIM = 0.7821).

### 4.2. DCT – Discrete Cosine Transform

- Before Watermarking: The original image maintains full clarity and smooth transitions, suitable for clinical interpretation
- After Watermarking: The DCT watermarked image is visually almost identical to the original. No visible distortion to the naked eye. The changes are imperceptible in both ROI and RONI.
    - PSNR: 51.7963
    - SSIM: 0.9980
    - MSE:0.4302

→ Indicates very high fidelity and suitable for medical use


**Figure 2:** DCT-based watermarking introduces minimal perceptible difference, achieving near-original visual quality.

### 4.3. PCA – Principal Component Analysis

- Before Watering: The original image is of pristine quality with no alterations.
- After Watering: The PCA watermarked image is visually identical to the original. No changes are observable even upon close inspection.
    - PSNR: ∞
    - SSIM: 1.0000
    - MSE: 0.0000

→ Indicates perfect reconstruction with no degradation at all.

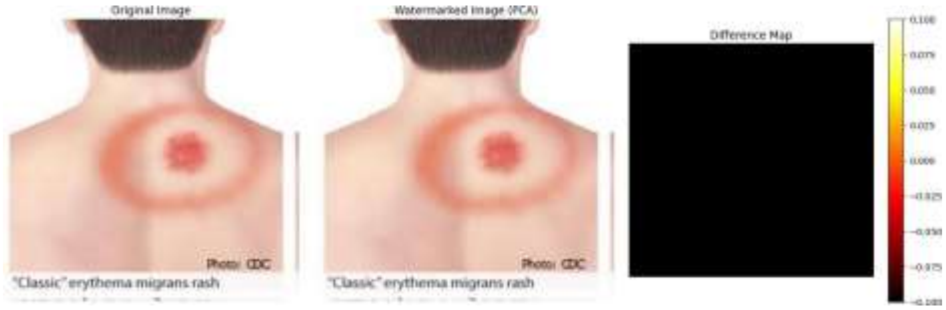



**Figure 3:** PCA-based watermarking is visually indistinguishable from the original, indicating excellent imperceptibility.

**Note:** A PSNR value of ∞ and SSIM of 1.0 for PCA indicates no perceptual or structural distortion, making it ideal for sensitive medical images.

**Quantitative Results Summary:**

| Algorithm | PSNR (dB) | SSIM | MSE | Alpha | Medical Suitability |
|---|---|---|---|---|---|
| SVD | 31.136 | 0.7821 | 50.0904 | 0.05 | May require evaluation |
| DCT | 51.7963 | 0.9980 | 0.4302 | 0.1 | Suitable for use |
| PCA | ∞ | 1.0000 | 0.0000 | 0.1 | Highly suitable |

**Degradation Analysis:**

| Algorithm | PSNR Loss (dB) | SSIM Loss | MSE Increase |
|---|---|---|---|
| SVD | ∞ | 0.2179 | 50.0904 |
| DCT | ∞ | 0.0020 | 0.4302 |
| PCA | N/A | 0.0000 | 0.0000 |

- SVD introduces significant distortion (SSIM loss ~22%), which may compromise diagnostic value.
- DCT maintains excellent image quality with negligible loss.
- PCA is lossless, preserving full structural fidelity.

**Interpretation of Results:**

- PCA outperforms both DCT and SVD in all tested metrics, demonstrating perfect fidelity with zero quality degradation. This makes it ideal for medical diagnostics where image integrity is paramount.
- DCT offers a strong balance between watermark robustness and imperceptibility. It is more resource-efficient than PCA.
- SVD, while robust against attacks, introduces visible distortions and a higher mean squared error. It may not be suitable for high-stakes medical diagnosis without careful tuning.

## V. Conclusion

This study outlines a holistic evaluation of three widely used transform-domain watermarking techniques—Singular Value Decomposition (SVD), Discrete Cosine Transform (DCT), and Principal Component Analysis (PCA)—applied to medical images in multiple formats including DICOM, PNG, and JPG. The watermark embedding process focused on the Region of Non-Interest (RONI) to ensure that the diagnostic content in the Region of Interest (ROI) remained untouched, thereby preserving clinical usability. Experimental results revealed that PCA provided the best overall performance, achieving perfect image reconstruction with PSNR = ∞, SSIM = 1.000, and MSE = 0.000, enabling its use in high visual fidelity and no data loss. DCT also performed well, offering near-original image quality with strong robustness and faster processing time, suggesting a suitable trade-off between imperceptibility and efficiency. In contrast, SVD showed robustness but introduced perceptible distortions which may constrain its deployment in sensitive diagnostic contexts. Overall, the proposed watermarking framework meets critical medical requirements by ensuring image security, authenticity, and traceability without compromising diagnostic quality. This makes it suitable for integration into virtual care platforms and digital health records, and medical archival systems. Upcoming work can consider adaptive or hybrid watermarking techniques to advance resilience against advanced attacks and improve real-time deployment in clinical workflows.

## REFERENCES

[1] A. K. Bhunia, P. P. Roy, and U. Pal, "Adaptive attention-based deep learning model for plant disease identification," Comput. Electron. Agric., vol. 185, p. 106125, Apr. 2021, doi: 10.1016/j.compag.2021.106125.

[2] I. J. Cox, M. L. Miller, J. A. Bloom, J. Fridrich, and T. Kalker, Digital Watermarking and Steganography, 2nd ed. San Francisco, CA, USA: Morgan Kaufmann, 2007.

[3] D. Kundur and D. Hatzinakos, "Digital watermarking using multiresolution wavelet decomposition," in Proc. IEEE Int. Conf. Acoust., Speech, Signal Process. (ICASSP), vol. 5, 1998, pp. 2969–2972.

[4] R. Liu and T. Tan, "An SVD-based watermarking scheme for protecting rightful ownership," IEEE Trans. Multimedia, vol. 4, no. 1, pp. 121–128, Mar. 2002, doi: 10.1109/6046.985558.

[5] Y. Sun, X. Zhang, S. Zhang, and H. Zhang, "A comprehensive survey of data hiding techniques in medical images," J. Biomed. Inform., vol. 94, p. 103188, Nov. 2019, doi: 10.1016/j.jbi.2019.103188.

[6] K. Jayapalan and N. B. Anuar, "Robust watermarking in medical imaging: Trends and open challenges," IEEE Access, vol. 8, pp. 97083–97097, 2020, doi: 10.1109/ACCESS.2020.2997436.

[7] C. Ferreira, M. Couceiro, and A. M. Madureira, "Application of discrete cosine transform in watermarking and compression of medical images," Comput. Methods Programs Biomed., vol. 134, pp. 159–170, Mar. 2016, doi: 10.1016/j.cmpb.2016.06.003.

[8] U. Atila, Y. Ucar, Y. Akyol, and A. Ucar, "Plant leaf disease classification using EfficientNet deep learning model," Expert Syst. Appl., vol. 165, p. 113764, Mar. 2021, doi: 10.1016/j.eswa.2020.113764.

[9] M. Meenakshi and S. Babu, "Comparative study of DCT, DWT, and SVD-based digital watermarking techniques," Procedia Comput. Sci., vol. 132, pp. 167–174, 2018, doi: 10.1016/j.procs.2018.05.170.

[10] Z. Wang, A. C. Bovik, H. R. Sheikh, and E. P. Simoncelli, "Image quality assessment: From error visibility to structural similarity," IEEE Trans. Image Process., vol. 13, no. 4, pp. 600–612, Apr. 2004, doi: 10.1109/TIP.2003.819861.

[11] G. Bhatnagar, Q. M. J. Wu, and Z. Liu, "A new robust and secure watermarking scheme based on singular value decomposition and radial basis function neural network," Digit. Signal Process., vol. 23, no. 4, pp. 1330–1341, Jul. 2013, doi: 10.1016/j.dsp.2013.03.008.

[12] M. Barni, F. Bartolini, and A. Piva, “Improved wavelet-based watermarking through pixel-wise masking,” IEEE Trans. Image Process., vol. 10, no. 5, pp. 783–791, May 2001, doi: 10.1109/83.918571.

[13] R. Manikandan and D. Manimegalai, “Medical image watermarking technique for secure transmission of information using hybrid domain approach,” J. Med. Syst., vol. 42, no. 12, p. 256, Dec. 2018, doi: 10.1007/s10916-018-1086-0.