Performance Enhancement of Digital Image Watermarking Based on Particle Swarm Optimization

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Abstract - Digital image watermarking is a critical technique for protecting multimedia data from unauthorized copying, tampering, and distribution. This review explores a hybrid approach that combines Discrete Wavelet Transform (DWT), Singular Value Decomposition (SVD), and Particle Swarm Optimization (PSO) to enhance the performance of watermarking schemes. The method addresses key challenges such as false positives and diagonal line problems in SVD-based watermarking by embedding principal components of the watermark into the host image's sub-bands using an optimized scaling factor derived from PSO. The proposed scheme ensures high robustness against attacks while maintaining imperceptibility and fidelity. Experimental evaluations demonstrate superior results in terms of Peak Signal-to-Noise Ratio (PSNR), Structural Similarity Index (SSIM), and Normalized Correlation (NC). This work highlights the relevance of optimization techniques in improving copyright protection for digital images.

Keywords: Digital Image Watermarking, Discrete Wavelet Transform (DWT), Singular Value Decomposition (SVD), Particle Swarm Optimization (PSO), Robustness, Imperceptibility, Copyright Protection.

1.INTRODUCTION

In the digital era, illegal copying, modifying, tampering, and copyright infringement of multimedia content have become significant concerns. Digital watermarking emerges as a robust solution to protect multimedia data by embedding imperceptible signals into host content for ownership verification. This technique hides data (watermark) within a cover signal without noticeably altering its quality, ensuring it survives common distortions like compression, noise, or malicious attacks.

Traditional watermarking methods, such as those based on Discrete Cosine Transform (DCT) or Discrete Wavelet Transform (DWT), provide basic protection but often suffer from limitations in robustness and imperceptibility. Singular Value Decomposition (SVD) enhances stability by modifying singular values, which represent intrinsic image properties. However, SVD-based schemes are prone to false positives and diagonal line issues in reconstructed watermarks.

To overcome these, hybrid approaches integrating DWT, DCT, and SVD with optimization algorithms like PSO have been proposed. PSO optimizes the scaling factor for watermark embedding, balancing robustness and fidelity. This review synthesizes existing literature, proposes a methodology based on the hybrid scheme, and discusses future enhancements, drawing from the project synopsis focused on performance improvement through PSO in DWT-SVD watermarking.

2. Literature Review

The field of digital image watermarking has extensively explored hybrid transform domains to achieve an optimal balance between the imperceptibility of the watermark and its robustness against various attacks. A prominent trend in this research involves the fusion of the Multi-Resolution Analysis (MRA) of the Discrete Wavelet Transform (DWT), the energy compaction properties of the Discrete Cosine Transform (DCT), and the stability offered by Singular Value Decomposition (SVD). The seminal work by **Bhattacharyya and Sharma (2008)** [1] laid a crucial foundation by introducing a DWT-SVD based scheme that strategically embedded watermark information in the principal components of the DCT-transformed DWT sub-bands. A key innovation of their work was the application of the Particle Swarm Optimization (PSO) algorithm to automatically determine the optimal scaling factor, thereby eliminating the need for manual, trial-and-error tuning and significantly enhancing the scheme's performance. This hybrid DWT-DCT-SVD framework, optimized by PSO, was further solidified by **Rao et al. (2012)** [4], who demonstrated its efficacy in achieving a superior trade-off between imperceptibility and robustness.
Building upon this core framework, subsequent research has pursued enhancements in robustness, particularly against challenging geometric attacks. **Fazli and Moeini (2016)** [2] integrated a novel geometric attack correction technique into their DWT-DCT-SVD method, which was further bolstered by a PSO-like optimization, showcasing significantly improved resilience to rotations and scaling. The comparative analysis of transform domains was advanced by **Awasthi and Srivastava (2022)** [3], who systematically evaluated LWT-DCT-SVD against DWT-

DCT-SVD. Their study highlighted that while both transforms are effective, their performance can be substantially elevated using optimization algorithms, not only PSO but also the parameter-free Jaya algorithm, offering a valuable comparison of metaheuristic optimizers in this context.

The scope of optimization has also been expanded to include blind watermarking schemes, which do not require the original image for detection. **Kang et al. (2020)** [5] employed a multi-dimensional PSO to optimize a robust blind watermarking system operating in a hybrid domain, further strengthening security through the use of chaotic maps for encryption. Similarly, **Guo et al. (2017)** [6] demonstrated that alternative bio-inspired optimizers, such as the Firefly Algorithm (FA), are equally potent for blind watermarking in a hybrid DWT and QR decomposition domain, achieving performance comparable to PSO-based methods.

Parallel research efforts have focused on modifying the core transforms to introduce inherent robustness. **Makbol et al. (2016)** [7] addressed the shift-variance limitation of standard DWT by proposing a block-based, translation-invariant DWT combined with SVD, creating a more robust watermarking base algorithm that is inherently suitable for integration with optimizers like PSO. Similarly, **Roy and Pal (2018)** [9] utilized Redundant DWT (RDWT) for its shift-invariance properties and combined it with SVD and Arnold scrambling to develop a robust, location-specific watermarking scheme for color images. On a different front, **Ariatmanto and Ernawan (2022)** [10] focused on the adaptive selection of significant DCT coefficients for embedding, a strategy that, when combined with optimization techniques, provides a principled method for determining scaling factors to enhance robustness. While some studies, such as that by **Mehta et al. (2015)** [8], have achieved success within a pure DCT domain using Genetic Algorithms (GA), their approaches underscore the broader theme of metaheuristic optimization, which is directly transferable and highly beneficial to the more complex DWT-DCT-SVD hybrids.

In summary, the literature clearly establishes the DWT-DCT-SVD framework as a highly effective and versatile foundation for robust image watermarking. The integration of metaheuristic optimization algorithms, particularly PSO and its variants, has been a critical driver in automating and enhancing the performance of these schemes. Future research directions indicated by this survey include the exploration of newer transform domains, the comparison of a wider range of optimizers, and the development of adaptive techniques for intelligently selecting embedding parameters and coefficients.

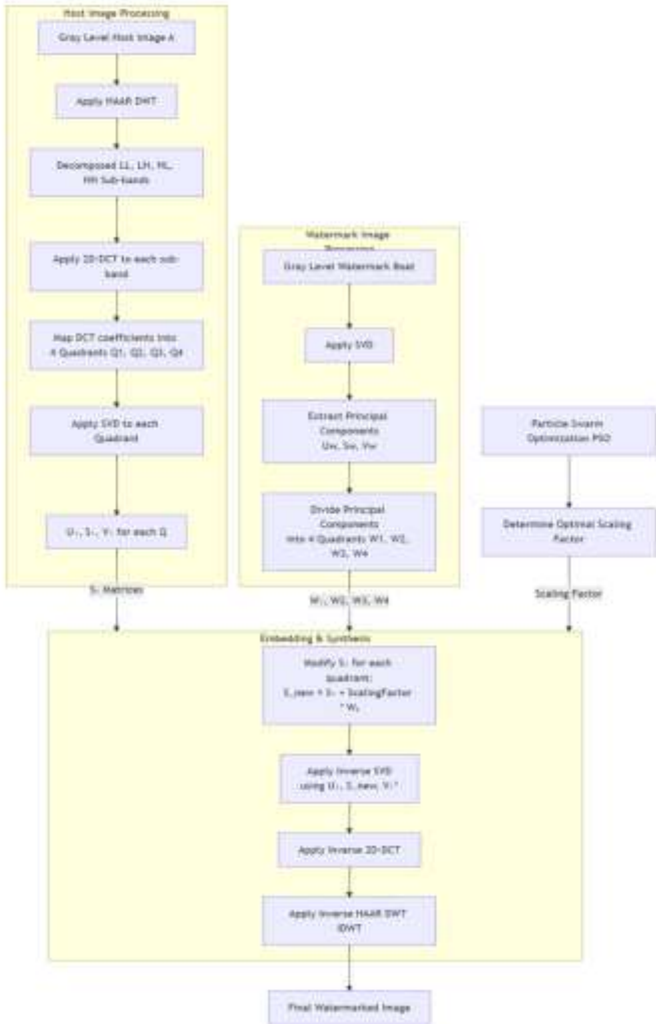

Fig. Block Diagram

Encryption Flow

DWT-SVD Watermarking: Designed to **encrypt** (embed) the watermark image into the host image. It uses a Discrete Wavelet Transform (DWT) to decompose the host image into sub-bands, applies Singular Value Decomposition (SVD) to the LL sub-band, and modifies the singular values by adding a scaled version of the watermark's singular values. The result is a watermarked image where the watermark is imperceptibly embedded. This aligns with the encryption flow chart, where the process starts with applying Haar DWT, modifying coefficients with SVD, and reconstructing the watermarked image.

Hybrid DWT-DCT-SVD Watermarking: This code is also intended for **encryption** (embedding), but it extends the process by incorporating a Discrete Cosine Transform (DCT) on the HL sub-band, dividing it into quadrants, and applying SVD to each quadrant. It modifies the singular values with parts of the watermark's principal components, optimized by a scaling factor (though PSO is not fully implemented here). This produces another version of the watermarked image, following a more complex hybrid approach as outlined in the proposed work.

Decryption

the decryption (extraction) process to retrieve the original watermark image from a watermarked image, following a hybrid approach that combines Discrete Wavelet Transform (DWT), Discrete Cosine Transform (DCT), and Singular Value Decomposition (SVD). This process is designed as a non-blind extraction method, requiring the original host image for accurate retrieval, and it aligns with the decryption flow

Methodology

The methodology follows a hybrid DWT-DCT-SVD approach optimized by PSO for scaling factor evaluation.

Proposed Work

A hybrid watermarking scheme for digital images based on singular value decomposition (SVD) and particle swarm optimization (PSO) is proposed. The two key aspects of watermarking schemes are copyright protected and robustness. In this work, the principal components of the watermark in the DCT domain of DWT sub-band of host image are embedded, for providing copyright protection as well as reliability.

Singular Value Decomposition (SVD)

SVD decomposes an image A (M x N) as A = U S V^T, where U and V are orthogonal matrices, and S is diagonal with singular values.

Encryption

1. Apply one-level Haar DWT to decompose the host image A into four sub-bands: LL, HL, LH, HH.

2. Consider DWT sub-band and perform 2D DCT using zig-zag sequence, map the DCT coefficients of DWT sub-band into four quadrants: B1, B2, B3 and B4.

3. Apply SVD to all four quadrants, Bk = U^k S^k V^k^T, where k=1,2,3 and 4.

4. Apply the SVD on the watermark image and calculate the principal components of the watermark: P = U^w S^w V^w^T.

5. Divide the principal components P into four quadrants: P1, P2, P3 and P4.

6. Modify the singular values of the DCT coefficients of the cover image with the principal components of watermark image, i.e., Swk = Sk + φ Pk, k = 1, 2, 3 and 4, where φ is the scaling factor matrix calculated from the PSO and '.' indicates array operation.

7. Perform, B^w_U = S^w_U V^T, where k=1,2,3and4.

8. Map the coefficients of Bkw back to their original positions and apply IDCT to produce the modified HL band, AwHL.

9. Perform the inverse DWT by using modified and non-modified coefficients to get the watermarked image, Aw.

Decryption

1. Apply one-level Haar DWT to decompose the watermarked (possibly attacked) image Aw* into four subbands: LL*, LH*, HL* and HH*.

2. Apply DCT on DWT sub-band and using zig-zag scan arrange the DCT coefficients of HL* into four quadrants B1*, B2*, B3* and B4*.

3. Subtract each quadrant with the original transformed quadrants: Ck = Bk* - Bk, where k=1, 2, 3, and 4.

4. Compute the distorted principal component parts, EPck = (Uk* Ck Vk^T) / φ, where '.' indicates array operation.

5. Construct the distorted principal component from their parts.

6. Obtain the extracted watermark: EW = Epc Vw.

Particle Swarm Optimization for Scaling Factor Evaluation

PSO optimizes the scaling factor φ to balance robustness and fidelity. Particles represent potential scaling values, updated via velocity equations for global best solutions.

Conclusion & Future Scope

In conclusion, the hybrid DWT-DCT-SVD watermarking scheme optimized by PSO provides enhanced performance in terms of robustness against attacks and imperceptibility, addressing limitations like false positives in traditional SVD methods. By embedding principal components with adaptive scaling, the approach ensures reliable copyright protection for digital images.

Future scope includes integrating advanced optimizers like Genetic Algorithms or Firefly Algorithm, extending to video watermarking, incorporating deep learning for blind extraction, and evaluating against emerging attacks like AI-based tampering.

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