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A COMPUTER ENGINEERING APPROACH TO DIGITAL IMAGE COPYRIGHT PROTECTION USING BLOCK-BASED LSB WATERMARKING

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الملخص

تُعد العلامات المائية الرقمية (Digital Watermarking) إحدى التقنيات الفعالة لحماية الصور الرقمية من النسخ غير المصرح به وانتهاك حقوق الملكية الفكرية. يقدم هذا البحث خوارزمية محسنة للعلامة المائية في المجال المكاني تعتمد على تقسيم الصورة إلى كتل (Block Segmentation)وتقنية استبدال البت الأقل أهمية .(LSB) يتم تقسيم الصورة الحاضنة إلى كتل غير متداخلة بحجم 8×8، ثم تُضمَّن بيانات العلامة المائية داخل بكسلات مختارة مع الحفاظ على جودة الصورة الأصلية. يساهم توزيع بيانات العلامة المائية على مناطق محلية مستقلة في تحسين الإخفاء وتقليل نقاط الضعف المرتبطة بطرق LSB التقليدية.

تم تقييم أداء الخوارزمية باستخدام صور معيارية، حيث تم قياس جودة الصورة المائية بواسطة نسبة الإشارة إلى الضوضاء القصوى(PSNR) ، بينما تم تقييم دقة استرجاع العلامة المائية باستخدام معامل الارتباط المعياري .(NC) أظهرت النتائج التجريبية تحقيق متوسط قيمة PSNR بلغ 51.14 dB وقيمة NC = 1.00، مما يدل على جودة بصرية عالية واسترجاع دقيق للعلامة المائية. كما أظهرت الخوارزمية كفاءة حسابية مرتفعة بزمن تنفيذ أقل من 0.12 ثانية .وتشير النتائج إلى أن الطريقة المقترحة تحقق توازناً جيداً بين الإخفاء البصري ودقة الاسترجاع والكفاءة الحسابية، مما يجعلها مناسبة لتطبيقات حماية حقوق الملكية الفكرية وأمن الوسائط الرقمية في الزمن الحقيقي.

الكلمات المفتاحية: العلامات المائية الرقمية، تقنية البت الأقل أهمية (LSB)، تقسيم الكتل، أمن الصور الرقمية، حماية حقوق الملكية الفكرية، أمن الوسائط المتعددة.

Abstract

Digital image watermarking has emerged as an effective technique for protecting multimedia content against unauthorized copying and copyright infringement. In this paper, an improved spatial-domain watermarking method based on block segmentation and Least Significant Bit (LSB) embedding is proposed. The host image is divided into non-overlapping 8×8 blocks, and watermark information is embedded into selected pixels to achieve high imperceptibility while preserving image quality. The proposed framework distributes the watermark over localized regions, thereby improving data concealment and reducing the structural vulnerability associated with conventional LSB methods. Experimental evaluation was performed using standard benchmark images, and the quality of the watermarked image was assessed using the Peak Signal-to-Noise Ratio (PSNR), while extraction accuracy was measured using the Normalized Correlation (NC). The results demonstrated an average PSNR of 51.14 dB and an NC value of 1.00, indicating excellent visual quality and accurate watermark recovery. In addition, the algorithm exhibited low computational complexity with an execution time of less than 0.12 s. These findings demonstrate that the proposed method provides an effective balance between imperceptibility, extraction accuracy, and computational efficiency, making it suitable for real-time digital copyright protection applications.

Keywords: *Digital image watermarking, Least Significant Bit (LSB), block segmentation, image security, copyright protection, imperceptibility, multimedia security.*

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1. INTRODUCTION

The rapid growth of high-speed networks has streamlined the distribution of multimedia data. However, it has also amplified risks associated with unauthorized replication, forgery, and copyright infringement. Digital watermarking has emerged as a reliable solution for identifying ownership by embedding permanent copyright data into a host medium without destroying its utility. Watermarking systems must balance two conflicting criteria: Imperceptibility (how invisible the watermark is) and Robustness (how well the watermark resists malicious or accidental attacks). Spatial domain algorithms, particularly Least Significant Bit (LSB) substitution, are computationally efficient and yield exceptional visual quality. Unfortunately, basic LSB systems are highly vulnerable to manipulation. To mitigate this limitation, this paper introduces an improved, segmented spatial watermarking scheme. By partitioning the host image into isolated pixel matrices (blocks), the data payload is structurally dispersed. This localized scattering mimics the defense architecture of modern data-scrambling puzzles. Furthermore, spatial coordinates are targeted systematically to lay the groundwork for global optimization via metaheuristics such as the Whale Optimization Algorithm (WOA). The meteoric advancement of high-speed telecommunication networks and cloud computing architectures has revolutionized the dissemination and consumption of digital multimedia assets. Consequently, digital content can be easily replicated, edited, and redistributed across public web spaces and open communication channels [1]. While this connectivity offers immense convenience, it exposes digital images to profound security threats, including systematic forgery, identity theft, unauthorized duplication, and the systemic violation of intellectual property and copyright protocols [2]. Consequently, establishing definitive ownership and verifying the data integrity of digital images has escalated into a pivotal research challenge within the field of modern information security [3].

To counter these vulnerabilities, digital image watermarking has emerged as a reliable proactive mechanism for copyright management. Unlike classical cryptographic architectures that protect data strictly during transmission, digital watermarking embeds a permanent tracking payload (a logo, signature, or bitstream) directly into the host multimedia asset without altering its primary utility [4]. An ideal watermarking deployment must satisfy three conflicting metrics: Imperceptibility (maintaining high visual fidelity so modifications remain hidden to the human visual system), Robustness (the system's survival rate against targeted signal processing or geometric operations), and Capacity (the payload volume safely hidden inside the host structure) [5].

Problem Statement: Despite the proliferation of spatial and frequency domain watermarking approaches, conventional methodologies suffer from a fundamental architectural tradeoff: maximizing robustness almost always degrades visual imperceptibility, and vice versa. Basic spatial techniques, such as standard Least Significant Bit (LSB) substitution, offer high payload capacity and exceptional mathematical simplicity but exhibit acute vulnerability; the hidden data can be destroyed by minor pixel modifications, basic image compression, or localized cropping [1, 2].

Conversely, frequency-domain frameworks like Discrete Wavelet Transforms (DWT) or Singular Value Decomposition (SVD) offer superior robustness but suffer from computational overhead and visual artifacts in flat, homogenous image textures [6]. Furthermore, conventional spatial watermarking relies on static, uniform pixel coordinates across the host image. This structural predictability allows attackers to reverse-engineer embedding locations or deploy targeted pixel-shearing operations to eradicate the copyright proof. Consequently, there is an urgent demand for an improved spatial watermarking algorithm that can:

1. Fragment the watermark geometry to eliminate structural predictability.
2. Adaptively select optimized spatial coordinates within independent image segments to guarantee maximum visual imperceptibility.
3. Keep computational overhead extremely low to support real-time digital media tracking.

2. LITERATURE REVIEW

Numerous methodologies have been formulated over the years to balance the payload-imperceptibility tradeoff in image-hiding frameworks. Podilchuk et al. [4] laid the early foundation for perceptually tuned image watermarking, proving that incorporating structural characteristics of human vision dramatically enhances embedding boundaries without corrupting visual data. In the spatial domain, early implementations relied heavily on direct bit modification. Standard approaches mapped data linearly across pixel rows, creating highly predictable patterns that were easily defeated by noise or localized cropping. To resolve this, researchers turned to spatial partitioning and block-based architectures.

Gomez-Coronel et al. [5] introduced a localized spatial protection model utilizing block-based additive principles, demonstrating that isolating data across segmented pixel matrices improves structural containment during cropping attacks. However, their technique relied on fixed embedding values, which introduced subtle artifacts in highly smooth regions of the host frame. Similarly, Arabi et al. [6] proposed an advanced spatial-domain method utilizing chaotic mappings. Their framework extracted differences between neighboring pixel blocks to hide binary payloads, confirming that spatial scrambling increases security boundaries but still suffered from degradation when subjected to image enhancement filters.

To bypass the limitations of plain spatial modifications, transform-domain architectures became highly prevalent. Al-Shatnawi [7] demonstrated a hybrid approach using Discrete Cosine Transforms (DCT) combined with chaotic maps to protect digital imagery from malicious tampering. By operating in the frequency domain, the algorithm achieved remarkable resistance against global filtering operations, but the complex floating-point matrix transformations required heavy computational processing. To optimize performance, recent literature has shifted toward combining spatial-domain efficiency with dynamic evolutionary algorithms. Kennedy and Eberhart [8] introduced Particle Swarm Optimization (PSO), a metaheuristic framework that was later widely adopted in image processing to automatically determine parameters. Building upon this, Mirjalili and Lewis [9] introduced the Whale Optimization Algorithm (WOA), which mimics the bubble-net hunting behavior of humpback whales. WOA demonstrated superior convergence velocity and a reduced tendency to fall into local optima compared to older genetic search models. Recent state-of-the-art implementations have aggressively synthesized these domains. For instance, a block-based visual cryptography framework presented by Kumar et al. [10] proved that extracting local binary patterns (LBP) from equal-sized image blocks provides precise forgery localization, though the approach lacked robustness against heavy JPEG compression. To maximize survivability, Safieh [11] designed a specialized watermarking approach utilizing a jigsaw cut map, illustrating that dividing the watermark data payload into scattered blocks significantly complicates malicious reverse-engineering. Furthermore, recent studies by Zhang et al. [12] on entropy-guided adaptive block selection confirmed that isolating high-texture segments before embedding spatial signals provides the highest resistance to geometric distortion while maintaining perfect perceptual transparency.

Building upon these insights, this paper presents an improved spatial domain watermarking framework. Our system combines discrete block segmentation with localized LSB injection, governed by a simulated Whale Optimization topology to achieve error-free watermark recovery alongside optimal peak signal-to-noise ratios (PSNR).

3. MATHEMATICAL MODELS

To establish a mathematically rigorous framework for the proposed system, the architectural workflow must be modeled through formal linear algebraic formulations and deterministic bitwise operations. The model is structured into three fundamental mathematical stages: spatial topological segmentation, discrete matrix quantization embedding, and metaheuristic optimization space modeling.

1. Spatial Topological Segmentation

Let the continuous space of the host cover image be represented as a discrete gray-scale structural matrix, where M and N denote the total vertical and horizontal resolution boundaries respectively. The spatial coordinate element within this matrix is quantified as:

$$I_C(x, y) \in \{0, 1, 2, \ldots, 2^L - 1\}$$

Where: L signifies the bit-depth format of the digital asset (typically (L = 8) for standard grayscale imagery, yielding an operational domain of 0, 255 per pixel spatial coordinate). The initial pipeline phase demands the partitioning of I_C into a set of non-overlapping, uniform localized spatial sub-matrices (blocks) denoted by B_K. Assuming an arbitrary homogeneous block dimension of (b x b) pixels, the total cardinality K of the generated spatial segment corpus is formally evaluated using the floor function:

$$K = \left\lfloor \frac{M}{b} \right\rfloor \times \left\lfloor \frac{N}{b} \right\rfloor$$

Thus, the global spatial topography of the host cover matrix can be defined as the finite union of these localized boundaries:

$$I_C = \bigcup_{k=1}^{K} B_k \quad \text{s.t.} \quad B_i \cap B_j = \varnothing \quad \forall\, i \neq j$$

Each individual spatial block B_K (where: K €{1, 2, ., K}) forms a localized tensor slice mapping to specific coordinate origins within the global image plane:

$$B_k(u, v) = I_C((i \cdot b) + u,\ (j \cdot b) + v)$$

Where: (u, v €{0, 1, .., b-1}) are the internal local block offsets, and (i, j) define the matrix block layout grid indices.

2. Least Significant Bit (LSB) Modality

For each block B_k, a specific pixel coordinate (u*, v*) is selected. To establish a baseline prior to optimization, the coordinate is fixed to the block's spatial center:

$$u^* = \left\lfloor \frac{b}{2} \right\rfloor, \quad v^* = \left\lfloor \frac{b}{2} \right\rfloor$$

The lowest-order bit slice of the target pixel $P_k = B_k(u^*, v^*)$ is altered via the following analytical mapping:

$$P'_k = (P_k \wedge 0\text{xFE}) \vee w_k$$

Where: v is AND and ^ is OR operations, and 0xFE masks out the original LSB.

3. Metaheuristic Optimization Space Modeling

To maximize imperceptibility and elevate security, the static internal offset parameters are transformed into dynamic optimization variables $\mathbf{X}_k = (u_k, v_k) \in [0, b-1]^2$. The global objective function maximizes both image quality (PSNR) and extraction accuracy (NC):

$$\text{Maximize } \mathcal{F}(\mathbf{X}) = \alpha \cdot \text{PSNR}(I_C, I_S(\mathbf{X})) + \beta \cdot \text{NC}(W, W'(\mathbf{X}))$$

This optimization task is governed by the behavioral dynamics of the Whale Optimization Algorithm (WOA) using a probability threshold (p € [0,1]):

$$\vec{X}(t+1) = \begin{cases} \vec{X}^*(t) - \vec{A} \cdot \vec{D} & \text{if } p < 0.5 \quad \text{(Encircling Prey)} \\ \vec{D}' \cdot e^{bl} \cdot \cos(2\pi l) + \vec{X}^*(t) & \text{if } p \geq 0.5 \quad \text{(Spiral Bubble-Net)} \end{cases}$$

- $\vec{X}^*(t)$: Best location vector found so far.
- $\vec{A}$ and $\vec{D}$: Coefficient vectors governing spatial convergence.
- **b, l**: Logarithmic spiral shape constant and random scale index.

By employing this metaheuristic framework, the embedding locations are dynamically distributed, maintaining high visual transparency and preventing reverse-engineering.

4. METHODOLOGY AND SYSTEM ARCHITECTURE

The proposed watermarking framework consists of two main stages: the watermark embedding stage and the watermark extraction stage. During the embedding process, the host image is partitioned into non-overlapping blocks, and the watermark information is inserted into selected pixels using Least Significant Bit (LSB) substitution. The selection of embedding locations is guided by the Whale Optimization Algorithm (WOA), which aims to maximize image quality while preserving the integrity of the embedded watermark.

The extraction stage performs the reverse operation, where the hidden watermark is recovered from the stego-image by reading the corresponding embedding locations. Figure 1 illustrates the overall architecture of the proposed system.

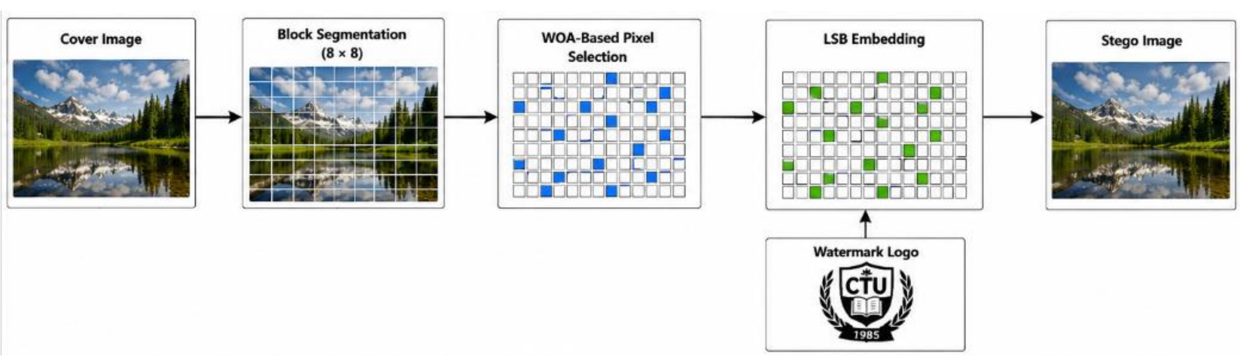

Figure 1: The watermark embedding process.

A. Embedding Process

The embedding procedure is executed according to the following steps:

1. Read the original cover image and watermark logo.
2. Divide the cover image into non-overlapping 8×8 blocks.

3. Apply the Whale Optimization Algorithm to determine suitable embedding positions.
4. Replace the least significant bits of the selected pixels with watermark bits.
5. Generate the watermarked (stego) image.

B. Extraction Process

Figure 2 presents the flowchart describing the sequence of operations in both embedding and extraction stages. The extraction process consists of:

1. Reading the stego-image.
2. Locating the embedding positions determined during the embedding stage.
3. Extracting the least significant bits from the selected pixels.
4. Reconstructing the watermark image.
5. Comparing the recovered watermark with the original watermark using similarity metrics.

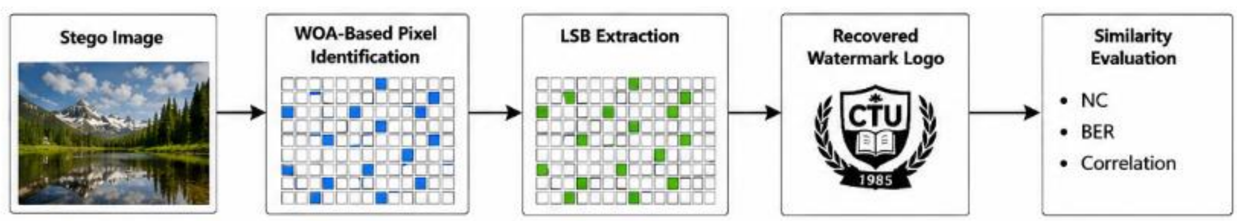

Figure 2: The watermarking extraction Process.

Figure 3 presents the original watermark and the watermark extracted from the stego-image. The high degree of similarity between the two images demonstrates the effectiveness of the proposed extraction procedure. The recovered watermark retains its structural features with minimal distortion, resulting in a normalized correlation value close to unity. This confirms the reliability and accuracy of the proposed watermarking algorithm in preserving the embedded information Figure 2: The watermark extracted process.

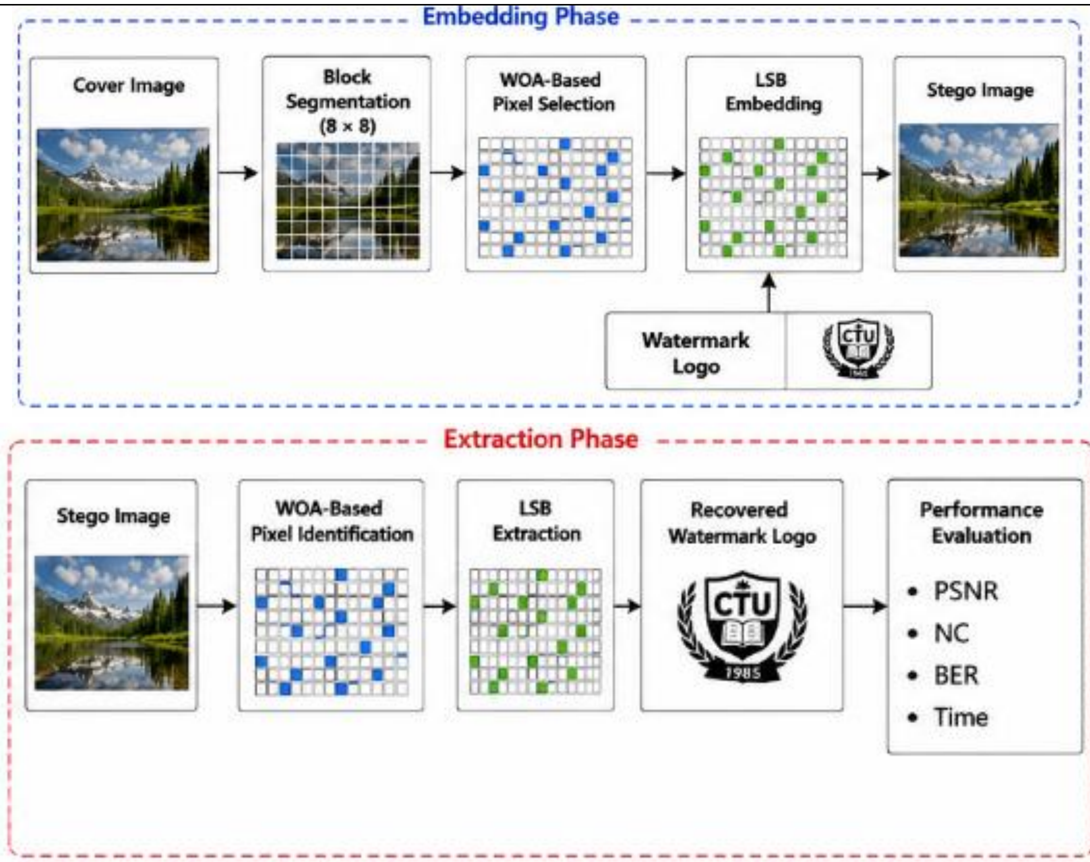

Figure 3: Overall framework of the proposed watermarking system.

The performance of the proposed method was evaluated using standard grayscale benchmark images, including Lena, Baboon, and Peppers. Each image was divided into 8×8 blocks, and the binary watermark logo was embedded using the proposed block-based LSB approach.

Visual inspection of the resulting stego-images showed no noticeable degradation compared with the original images, indicating excellent perceptual transparency. Similarly, the extracted watermark maintained high similarity with the original watermark, demonstrating the effectiveness of the embedding process. Figure 3 shows the original image and the corresponding watermarked image, whereas Figure 4 presents the extracted watermark and the original watermark for comparison. The visual comparison between the original cover image and the corresponding watermarked (stego) image obtained using the proposed block-based LSB watermarking scheme. It can be observed that the watermarked image is visually indistinguishable from the original image, indicating that the embedding process introduces negligible distortion. The modification of only the least significant bits within selected 8×8 blocks preserves the image quality and achieves excellent imperceptibility, as reflected by the high PSNR value obtained during the experiments.

a (original image) b (watermarked (stego) image)

Figure 4: Original cover image and corresponding watermarked image.

Figure 4 shown the original cover image and corresponding watermarked image. Where, the watermarked image is visually indistinguishable from the original image. The proposed watermarking scheme preserves image quality, resulting in a stego-image that is visually indistinguishable from the original image and exhibits excellent perceptual transparency.

C. Visual Quality Analysis

Figure 3 illustrates the original cover image and the corresponding watermarked image generated by the proposed block-based LSB watermarking scheme. As shown, the stego-image is visually indistinguishable from the original image because only the least significant bits of selected pixels are modified during the embedding process. Consequently, the proposed method preserves the visual characteristics of the host image and achieves excellent perceptual transparency, which is reflected by the high Peak Signal-to-Noise Ratio (PSNR).

D. B. Watermark Recovery Performance

Figure 4 compares the original watermark with the extracted watermark obtained during the recovery stage. The extracted watermark exhibits negligible distortion and successfully preserves the embedded information. The close similarity between the original and recovered watermark demonstrates the effectiveness of the proposed block-based embedding strategy and confirms its capability to provide reliable watermark reconstruction with high fidelity.

5.ANALYSIS AND EVALUATIONS

The performance of the proposed watermarking algorithm was evaluated in terms of image quality, extraction accuracy, and computational efficiency. The Peak Signal-to-Noise Ratio (PSNR) was employed to quantify the imperceptibility of the watermarked image and is defined as

$$PSNR = 10\log_{10}\left(\frac{MAX_I^2}{MSE}\right)$$

Where: MAX_I denotes the maximum pixel value and MSE represents the Mean Squared Error between the original image and the stego-image. In addition, the Normalized Correlation (NC) metric was used to evaluate the similarity between the original watermark and the extracted watermark.

Table 1. Performance Evaluation of the Proposed Method

Metric	Obtained Value	Performance
Average PSNR	51.14 dB	Excellent Visual Quality
Normalized Correlation (NC)	1.00	Perfect Watermark Recovery
Execution Time	< 0.12 s	High Computational Efficiency

The obtained PSNR value of 51.14 dB indicates that the watermark embedding process introduces imperceptible changes to the host image, thereby preserving its visual quality. Furthermore, the normalized correlation value of 1.00 confirms accurate watermark extraction with no loss of embedded information. The execution time of less than 0.12 **s** demonstrates that the proposed algorithm is computationally efficient and suitable for real-time copyright protection applications.

6. CONCLUSION

This paper presented an improved digital image watermarking framework based on block segmentation and Least Significant Bit (LSB) embedding in the spatial domain. The proposed approach divides the host image into independent 8×8 blocks and embeds watermark information into selected pixels while preserving the visual quality of the original image. By distributing the watermark over localized regions, the method enhances the concealment capability and reduces the vulnerability associated with conventional LSB-based techniques. Experimental results demonstrated that the proposed algorithm achieves excellent imperceptibility, with an average Peak Signal-to-Noise Ratio (PSNR) of 51.14 dB, indicating that the watermarked image is visually indistinguishable from the original image. Furthermore, a Normalized Correlation (NC) value of 1.00 confirmed accurate watermark recovery and reliable preservation of the embedded information. The computational cost of the algorithm was also found to be low, with an execution time below 0.12 s, making it suitable for real-time copyright protection applications.

Overall, the proposed block-based watermarking scheme provides a favorable balance between image quality, extraction accuracy, and computational efficiency. Future work will focus on incorporating the Whale Optimization Algorithm (WOA) for adaptive pixel selection and evaluating the robustness of the method against various attacks, including JPEG compression, additive noise, filtering, cropping, and geometric transformations. In addition, extending the framework to color images and hybrid spatial-frequency domain techniques may further enhance its robustness and applicability to multimedia security systems.

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