Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 7, No.2, July : 2024

A BLIND WATERMARKING ALGORITHM USING WALSH HADAMARD TRANSFORM

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ABSTRACT
This paper presents a novel method for embedding digital watermarks into double color images, focusing specifically on harnessing the power of the Walsh-Hadamard Transformation (WHT). This innovative technique involves strategically selecting positions for embedding to enhance concealment efficacy. The proposed approach capitalizes on the energy aggregation characteristic of WHT and the strong correlation among matrix coefficients in the frequency domain post-transformation. Initially, the color host image undergoes segmentation into its constituent Red (R), Green (G), and Blue (B) channels, which are subsequently partitioned into smaller blocks of size 4x4. Through meticulous analysis, the algorithm identifies WHT coefficients that are least susceptible to visual distortions when dealing with color images, thereby optimizing embedding locations to achieve maximum concealment. The embedding process entails adjusting coefficients within specified matrix blocks to incorporate the digital watermark seamlessly. Extensive simulation results substantiate the superiority of this methodology over existing techniques in terms of concealment efficacy, embedding capacity, and resilience against attacks.

Keywords:
Walsh Hadamard Transform, Arnold Transform, Imperceptibility

I. Introduction
The widespread availability of the internet in contemporary times has simplified the process of transforming multimedia content, including audio, video, images, and text. However, this accessibility has led to a surge in copyright violations, piracy, infringement, and tampering of digital content. The ease of access and distribution of copyrighted material without proper authorization or compensation to the content owner has become a complex issue affecting various industries such as entertainment, publishing, and software.

Problem Definition: The primary objective of this paper is to address the issue of decreased imperceptibility that occurs when embedding a watermark into a cover image, resulting in a disturbed watermarked image. Imperceptibility refers to the degree to which the watermarking process alters the visual quality of the original image, with lower imperceptibility indicating a more noticeable change. To achieve higher imperceptibility, several specific project goals have been identified:

Higher Imperceptibility: This goal involves minimizing the perceptible alterations introduced to the cover image during the watermarking process. The aim is to embed the watermark in such a way that it is as visually inconspicuous as possible, ensuring that the watermarked image closely resembles the original cover image to the human eye.

Lower Mean Square Error (MSE): Mean Square Error is a metric used to quantify the average squared differences between the pixel values of the original and watermarked images. By minimizing the MSE, the objective is to reduce the overall discrepancy between the two images, indicating a closer resemblance between the watermarked image and the original.

Higher Peak Signal-to-Noise Ratio (PSNR) Ratio: PSNR is a measure of the quality of the reconstructed signal relative to the original signal, expressed in decibels (dB). A higher PSNR indicates a lower level of distortion introduced during the watermarking process. Thus, the goal is to achieve a higher PSNR ratio, which signifies a closer match between the watermarked image and the original, resulting in improved image fidelity.

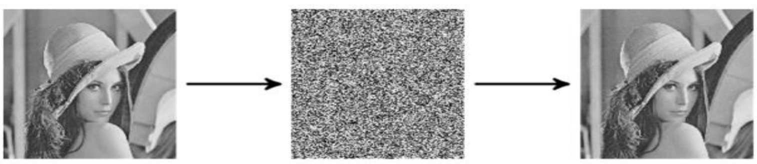
Watermarking is defined as Watermarking involves the embedding of additional information, known as a watermark, into digital content such as images, audio, video, or documents. This watermark can be either visible or invisible and serves various purposes including copyright protection, authentication, and tamper detection. The Fig1 shows how a cover image is embedded with watermark image to get watermarked image which is the target image.

II. Literature

[1]This article discusses a method for secure communication of medical images using fragile data hiding techniques that employ Discrete Wavelet Transform and A_5 Lattice Vector Quantization.[2] This paper presents a watermarking scheme designed for encrypted images, utilizing scrambling and Kronecker Compressed Sensing to ensure robustness of the watermark against various attacks.[3] This article describes an image information hiding technique that involves adaptation and radix methods, published in the Optik International Journal of Light and Electron Optics in 2015. [4] Published in IEEE Transactions on Image Processing in 2017, this paper introduces a novel features classification forest approach that enhances robustness in blind watermarking techniques.[5] This article presents a watermarking algorithm designed for color images, employing techniques in the combined domain, published in Multimedia Tools and Applications in 2020.[6] Published in Visual Computing in 2020, this paper proposes a blind image watermarking scheme that integrates techniques from both spatial and frequency domains for enhanced performance.[7] This article presents an improved color image watermarking technique focused on rapid implementation and robustness in the spatial domain, published in IEEE Access in 2019.[8] This paper introduces an enhanced color image watermarking algorithm utilizing QR decomposition, published in Multimedia Tools and Applications in 2017.[9] This article describes a high-efficiency blind watermarking algorithm designed for double color images, incorporating Walsh Hadamard transform techniques, published in Visual Computing in 2022.

2.1. Proposed Methodolgy

This proposed algorithm delineated into two primary stages: watermark embedding and watermark extraction, as depicted in Fig 2. During execution, the left multiplication of an image block matrix by the Hadamard matrix localizes the matrix energy primarily in the first row, where strong correlations among transformed elements emerge. Leveraging this inherent characteristic of WHT, the algorithm embeds and extracts a pair of watermark information bits by precisely adjusting the size relationship between the first and second elements, as well as the third and fourth elements, within the first row of the block matrix post-transformation. This embedding approach significantly enhances robustness against various attacks while ensuring minimal impact on the image's visual fidelity. Subsequent sections delineate the step-by-step processes of watermark embedding and extraction within the proposed algorithm.



(a) (b) (c)

Fig1. (a) Original Image (b) Watermark Image (c) Watermarked Image.

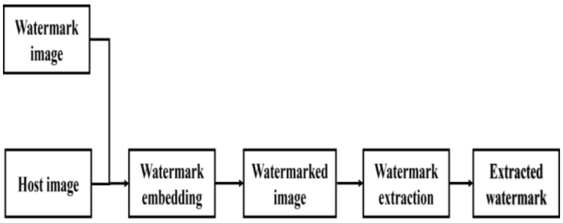


Fig. 2 The flow chart of overall algorithm

2.2 Watermark Embedding

The embedding process involves utilizing a color host image, denoted as *H*, to incorporate a color watermark image, represented by *W*. This method delineates the detailed steps of watermark embedding. Considering H as the initial color host image with a side length of *M*, and *W as* the original color watermark image with a side length of *N*, the procedure entails a systematic integration of the watermark into the host image, resulting in a merged visual composition.

Step 1 Color watermark image preprocessing.

For the purpose of improving the security and robustness of proposed algorithm, firstly, the color watermark image *W* is processed by dimensionality reduction as W_i(i=1, 2, 3) according to the order of red, green, and blue color channels. And then, carry out the Arnold scrambling transformation. Finally, each pixel represented by a decimal format in the scrambled watermark image channels is transformed to an 8-bit binary number, and for each channel, those series of 8-bit binary information obtained are successively connected so as to organize a $8N^2$-length bit sequence of watermark S_{Wi}(i=1, 2, 3).

Step 2 Colour host image preprocessing

First, divide the original colour host image *H* into three colour channels H_i(i =1, 2, 3) according to red, green, and blue. And then, each host channel image H_i is partitioned into non-overlapping 4×4 blocks.

Step 3 Selecting the embedding blocks

The sub-blocks obtained are filtrated by the localization list generated by the MD5-based Hash pseudo-random algorithm based on the key K_{bi} to select a more appropriate image blocks for watermark embedding, so as to ensure the robustness of the watermark against cropping attack.

Step 4 obtaining the frequency domain coefficient through WHT

Consider *A* as an image block selected by the method mentioned above, and then WHT is carried out according to Eq (1) to obtain the frequency domain coefficient after transformation.

$$H_R=\frac{1}{N}\times H_A \times A \qquad (1)$$

where *N* is the size of the image block, and $H_N$is the Hadamard matrix of order *N*×*N* and consists of the values 1 and-1. In this paper, *N*=4.

Step 5 Embedding the watermark.

Two bits of watermark information $w1$ and $w2$ are taken out from the channeled binary watermark sequenceS_{Wi}, and then, use the size relation of the first-row coefficients of the transformed block matrix to embed the 2-bit watermark information into the transformed matrix according to Equations (2), (3), (4), and (5).

Case 1 If w_j = 1 and ($H_{R1,j}$ - $H_{R2,j}$) ≤ *e*, modify the values of $H_{R1,j}$and H_{Rj2}(*j* = 1 to 2) as follows:

$$H_{A1j}^{*} = avg_j + \frac{T}{2} (j\ =\ 1\ to\ 2) \qquad (2)$$

$$H_{A2j}^{*} = avg_j - \frac{T}{2} \quad (j\ =\ 1\ to\ 2) \qquad (3)$$

Case 2 If w_j= *0*and(H_{R2j} - $H_{R1,j}$) ≤ *e,* modify the values of H_{R1j} and H_{R2j} (*j* = 1 to 2) as follows:

$$H^*_{A1j} = avg_j - \frac{T}{2} \quad (j = 1\ to\ 2) \quad (4)$$

$$H^*_{A2j} = avg_j + \frac{T}{2} \quad (j = 1\ to\ 2) \quad (5)$$

Step 6 Inverse WHT transform.
According to the inverse WHT of Eq. (6), the image block A* containing watermark is obtained.

$$A^* = H_N \times H^*_A \qquad (6)$$

where H^*_A is the frequency domain matrix containing watermark.
Step 7 Repeating the step above and reorganizing the watermarked image
Repeat the above steps from Steps 2 to 6 until all of the binary watermark information is embedded, so as to obtain the channeled host image with watermarkH^*_i. Finally, each channeled host image containing watermark $H^*_i$is combined to obtain the watermarked image H*.

2.3 Watermark extraction

The detailed process of watermark extraction proposed is as follows.
Step 1 Watermarked image preprocessing.
Firstly, the watermarked image H*is divided into three channels H^*_i(i=1, 2, 3) according to the order of primary colors red, green, and blue. Meanwhile, each channel is partitioned into 4×4 non-overlapping sub-blocks.
Step 2 Obtaining the frequency domain coefficient with watermark.
The frequency domain coefficient of the block containing watermark is obtained by WHT. Consider an image block A*is selected, and Eq. (7) is used to carry out WHT.

$$H^*_A = \frac{1}{N} \times H_N \times A^* \qquad (7)$$

where H^*_Arepresents the matrix obtained after WHT of image block A*, N is the size of image block, and H_N is the Hadamard matrix of order N×N.
Step 3: Extracting the watermark.
Using Equations (8) and (9), watermarks $w^*_1$and w^*_2contained in image block H^*_A are extracted.

$$w^*_1 = \begin{cases} 0, if\ H^*_{A1,1} \le H^*_{A21} \\ 1, \quad else \end{cases} \qquad (8)$$

$$w^*_2 = \begin{cases} 0, if\ H^*_{A31} \le H^*_{A41} \\ 1, \quad else \end{cases} \qquad (9)$$

where w^*_irepresents the i-bit watermark extracted from H^*_A,and $H^*_{Am,n}$represents the element in row m and column of H^*_A.
Step 4 Repeating the steps above and regrouping the watermark sequence.
Repeat Steps 2 to 4 to extract the binary watermark sequence $S^*_{wi}$of each channel, and then convert every 8-bitbinary information into a group of pixel values converted into decimal system, where i =1, 2 and 3 represent red, green, and blue channels, respectively.
Step 5 Inverse Arnold transformation.
Carry out inverse Arnold transformation on the encrypted watermark sequence of each color channel, and the watermark for each channel W^*_i(i=1, 2, 3,) is obtained.
Step 7 Reconstructing the watermark image.
Recombine channeled watermark$W^*_i$to form the final extracted watermark W*.

III. Conclusion

The proposed algorithm's practicality is assessed through an examination of its invisibility and robustness. This evaluation entails analyzing the algorithm's ability to operate covertly, withstand potential disruptions, accommodate sufficient data embedding, execute efficiently in real-time scenarios, and maintain data security.
In the simulation experiment, a set of fifteen color images, each sized at 512 × 512 pixels and sourced from the public standard database CVG-UGR, are designated as the host images (refer to Fig.3, denoted as (a)-(f)). Additionally, a single color image, measuring 64 × 64 pixels and obtained from the common standard database SC-SIPI, is selected as the watermark image (illustrated in Fig. 4 (a)). The watermarked images of fig 3 (a)-(f) are shown in fig 5 (a)-(f) respectively. The scrambled watermark and extracted watermark are shown in fig 4 (b) and (c) respectively.
This paper aims to assess the performance of a digital watermarking algorithm in terms of invisibility, embedding capacity, and real-time performance. The algorithm's effectiveness is evaluated by comparing experimental data with other existing watermarking technique i.e., Siyu Chen's approach. Invisibility, crucial for assessing the visual quality of watermarked images, is a key criterion. Peak Signal-to-Noise Ratio (PSNR) serves as a vital objective measure in this regard. PSNR quantifies the similarity between the original host image and the watermarked image, with each image channel's PSNR value defined by Eq. (10).

$$PSNR_j = 10\lg \frac{M \times \mathrm{N} \times \max\{[\mathrm{H(x,y,j)}]^2\}}{\sum_{x=1}^{M}\sum_{y=1}^{N}[H(x,y,j) = H*(x,y,j)]\text{^}2} \qquad (10)$$

where j = 1, 2, 3 represents three channels of the color image, M is the row size, and N is the column size of the image matrix, H(x, y, j) and $H*$ (x, y, j), respectively, represent the pixel on the coordinate (x, y) of the j th channel of the original host image and the watermarked image.
The PSNR value of the color image is obtained by accumulating that of the three channels of the color image as Eq. (11).

$$PSNR = \sum_{j=1}^{3} PSNR_j \qquad (11)$$

The assessment of image similarity and the efficacy of watermarking algorithms often rely on the Structural Similarity Index Measurement (SSIM). SSIM provides a criterion for evaluating the likeness between two images while considering factors such as brightness, contrast, and structural composition. This index delineates structural information within images, independent of variations in brightness and contrast, thereby capturing the inherent structure of objects in the scene. SSIM quantifies distortion as a blend of brightness, contrast, and structural dissimilarities. Specifically, it utilizes the mean value to gauge brightness, the standard deviation to assess contrast, and covariance to quantify the degree of structural similarity between images.
They are expressed as Equations (12), (13), and (14) in several.

$$l(H,H^*) = \frac{(2\mu_H\mu_{H^*}+C_1)}{(\mu_H^2+\mu_{H^*}^2+C_1)} \qquad (12)$$

$$c(H,H^*) = \frac{(2\sigma_H\sigma_{H^*}+C_2)}{(\sigma_H^2+\sigma_{H^*}^2+C_2)} \qquad (13)$$

$$s(H,H^*) = \frac{(2\sigma_{HH^*}+C_3)}{(\sigma_H\sigma_{H^*}+C_3)} \qquad (14)$$

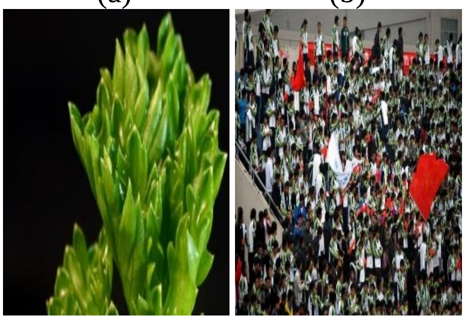
where μ_H is the mean value of the original host image H, while μ_{H^*} is the mean value of the watermarked image H^*; σ_H and σ_H^2 are the standard deviation and variance of the original host image H, respectively, while σ_{H^*} and $\sigma_{H^*}^2$ are the standard deviation and variance of the watermarked image H^* in several; $\sigma_H\sigma_{H*}$ represents the covariance of the original host image H and the watermarked image H^* .$l(H,H^*)$is the luminance comparison function and could be obtained by calculating μ_H and

μ_{H^*} of original image *H* and watermarked image *H** . *c (H, H*)* is the contrast comparison function. And *s(H, H*)* is the structural similarity comparison function.
C1, C2 and *C3* are all constant to avoid having a 0 value in the denominator.
Then, SSIM consists of the above three parts and can be calculated by Eq. (15)
SSIM $(H, H^*) = l(H, H^*)c(H, H^*)s(H, H^*)$ (15)
In addition, robustness also plays an important part in evaluating the performance of watermarking algorithms, in which, Normalized Cross-coefficient (NC) is one of the standards to test the robustness of watermarking algorithm. It describes the similarity between the original watermark image and the extracted watermark image, and its calculation method can be defined as Eq. (16).

$$NC = \frac{\sum_{j=1}^{3}\sum_{x=1}^{M}\sum_{y=1}^{N}[W(x,y,j) \times W^*(x,y,j)]}{\sqrt{\sum_{j=1}^{3}\sum_{x=1}^{M}\sum_{y=1}^{N}[W(x,y,j)]^2}\sqrt{\sum_{j=1}^{3}\sum_{x=1}^{M}\sum_{y=1}^{N}[W^*(x,y,j)]^2}} \quad (16)$$

where j=1, 2, 3, represents R, G, and B channels of the color image. *M* and *N* represent the row and column sizes of the color watermark image in several. *W*(*x, y, j*) and *W*(x, y, j)*, respectively, denote the *(x, y)* pixel value of the j-th channel of the original watermark image and the extracted watermark image. The NC value is between 0 and 1, and the closer it is to 1, the better the robustness of the watermarking is.
Choosing an appropriate quantization step size is an imperative link in the design of watermarking algorithm. In order to determine the quantization step size to embed watermark, we observed the PSNR value, SSIM value, and NC value when the watermarked image is not attacked of the watermarking algorithm through several embedding and extraction experiments.

(a) (b)



(c) ***(d)***

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 7, No.2, July : 2024

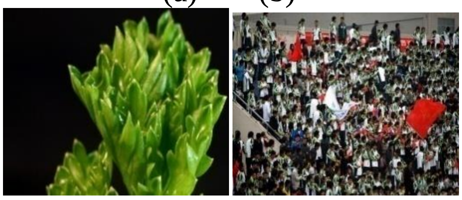
(e) (f)

Fig 3: (a)-(f) Cover images

(a) (b) (c)

Fig 4 (a) Watermark Image (b) scrambled Image (c) Watermarked image

(a) (b)



(c) ***(d)***

(e) (f)

Fig 5 (a) –(f) Watermarked images of Cover images of fig 3.1 (a)-(f)

Table 3.1 provides a detailed comparison of the Peak Signal-to-Noise Ratio (PSNR), Structural Similarity Index (SSIM), and Normalized Cross-Correlation (NC) metrics between the existing algorithm, attributed to Siyu Chen, and the newly proposed algorithm. This table serves to elucidate the refinement differences observed in these key performance indicators following the integration of the proposed algorithm when compared against the established method. By presenting a comprehensive analysis, it offers insights into the specific alterations in these metrics resulting from the adoption of the proposed algorithm as opposed to the currently employed one. On an average, PSNR of our proposed algorithm is 1.3156 dB higher than existed algorithm's PSNR and Average SSIM of proposed algorithm is 0.0050 higher than the SSIM of existed algorithm.

Table 3.1: Resulted values of both existed and proposed algorithm

Cover image in Fig 3.1	**Siyu Chen's approach (Existed algorithm)**			**Proposed method**		
	PSNR (dB)	**SSIM**	**NC**	**PSNR (dB)**	**SSIM**	**NC**
(a)	**35.2452**	**0.9740**	**1**	**35.5996**	**0.9776**	**1**
(b)	**32.2464**	**0.9742**	**1**	**33.0877**	**0.9789**	**1**
(c)	**35.4074**	**0.6291**	**1**	**36.4997**	**0.6405**	**1**
(d)	**26.7323**	**0.9227**	**1**	**29.0826**	**0.9288**	**1**
(e)	**34.5022**	**0.5802**	**1**	**35.7817**	**0.5856**	**1**
(f)	**32.4219**	**0.6812**	**1**	**34.3976**	**0.6820**	**1**

Conclusion

This paper introduces a pioneering watermarking methodology tailored for digital images, presenting a novel blind watermarking algorithm specifically designed for double colour images utilizing the Walsh Hadamard transform (WHT). By harnessing the energy gathering function of WHT and leveraging the significant correlation observed among matrix coefficients in the frequency domain post-transformation, the proposed algorithm effectively embeds digital watermarks. The process begins with segmenting the color host image into its respective Red (R), Green (G), and Blue (B) channels, followed by partitioning each channel into 4×4 blocks. Through meticulous analysis of the frequency domain coefficients of WHT blocks, a notable correlation emerges, particularly among the coefficients within the first row. Exploiting this correlation, the digital watermark seamlessly integrates into the matrix block by precisely adjusting the mentioned coefficients, and watermark information is subsequently extracted through the discrepancy between the two coefficients. Extensive simulation results validate the efficacy of the proposed algorithm, showcasing superior performance in terms of invisibility and robustness. Overall, this research presents a promising approach for secure and efficient blind watermarking in double color images, contributing significantly to the advancement of digital image watermarking techniques.

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