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The Digital Watermarking Algorithm for Color Images Based on the Fusion of DWT-DCT-SVD Technology

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ABSTRACT

In this work, a digital watermarking algorithm based on the fusion of Discrete Wavelet Transform (DWT), Discrete Cosine Transform (DCT), and Singular Value Decomposition (SVD) technology for color images is proposed. The algorithm proposed based on DWT to extract the color images to multiple frequency subbands to extract the image features efficiently, and provide the conditions for watermark embedding. Next, the DCT is applied to the extracted subbands to effectively cluster the majority of the image's energy in the lower-frequency portion, which ensures that the watermark is not lost after compressing the image. This method utilizes the SVD technique to improve the strength of the watermark by interweaving it into the singular values of the image's feature matrix, thereby guaranteeing its preservation through numerous attacks and transformations. They ensure that the watermark is imperceptible by attempting to embed the watermark in the low frequency regions, which is relatively stable under different kinds of image processing operations. It was shown by experimental results that the algorithm is very robust to many common image-processing attacks and produces watermarked images of high visual quality. Such a fusion strategy proposes an effective solution for image integrity and copyright protection in digital media.

KEYWORDS

Digital watermarking; DWT; DCT; SVD; Image compression

1 Introduction

Watermarking constitutes an important approach to safeguard the property and correctness of media, particularly color images. Since digital content can be easily shared and distributed, the integrity and security of such is a major concern. Watermarking is used to add extra information (ownership, copyright symbol, etc.) to an image without substantially affecting its visual appearance. Conventional watermarking techniques work well, however, new methods which use advanced signal processing techniques have also evolved to meet the robustness and imperceptibility needs[1]. An example is the application of a combination of DWT, DCT, and SVD in digital watermarking methods for color images. The unique approach of combining them exploits the advantages of each technique in favour of a better performance of the watermarking algorithm. DWT is well suited to break down an image into multiple frequency subbands and is thus widely used for image representation and noise suppression. Moreover, the dual image information of spatial-frequency provided by DWT guarantees that the embedding procedure of watermark does not generate visible artifacts on the cover image. DCT achieves the highest energy compaction of the substantial image information into low frequency coefficients, making it a suitable Task for the watermark insertion method without degrading the quality of the image[2]. Finally, SVD serves as a strong approach to the embedding and extraction of watermark information through the modification of the singular value of an image's feature matrix and is resistant to various attacks such as compression, cropping or noise addition. The combination of these it is proposed the watermarking algorithm that is imperceptible and resistant to common attacks like Gaussian noise or compression based[3]. It has a solution in the form of this technique that must implement proper security measures to reduce breaches in the increasingly digitized world that we currently live in. With the increasing demand for digital watermarking techniques for applications such as copyright protection, authentication and verification, this approach offers a novel and efficient method that minimizes the impact on the original image while maximizing the robustness of the watermark. In this paper, a DWT-DCT-SVD based color image watermarking algorithm is proposed and evaluated for better watermark imperceptibility, robustness and performance of the algorithm.

2 Theoretical Foundations

2.1 Discrete Wavelet Transform (DWT)

In signal processing, the DWT is an essential tool that is widely used in several applications including image processing, compression, or noise reduction. With its strength of frequency feature extraction and noise suppression for signals, it is most beneficial for tasks focusing on images. DWT allows for multi-scale analysis by converting signals into the wavelet domain, which is crucial for isolating and processing different frequency components of an image. The ability to decompose hierarchically is pivotal in capturing sure texture details, thus contributing to both efficiency and efficacy into image processing.

For two-dimensional image treatment, the DWT divides an image into many different frequency subbands, enabling targeted evaluation and manipulation. These subbands do generally consist of the low-frequency subband (LL) that represents the main structural information of the image as well as the horizontal (LH), vertical (HL), and diagonal (HH) high-frequency subbands, which represent finer details and edge information. The LL subband, which maintains the most crucial energy and features, is utilized as a basis of analysis. In this sense, the LL subband can be further processed by more levels of wavelet transformation to obtain a more elaborate image features. The multi-resolution analysis and progressive decomposition allows the extraction of features, noise filtering, and image compression making DWT an integral component of contemporary image processing pipelines.

In addition, the multi-resolution property of DWT guarantees that the important features are kept and processed at the appropriate scales. Such a systematic hierarchy improves the representational power of textures, patterns and edges that play an important role in many applications, for instance watermarking, object recognition, image reconstruction, etc. Additionally, DWT enables selective manipulation by isolating specific frequency bands, thus allowing for denoising and compression techniques that retain important image characteristics while discarding higher frequency components that have little effect on the final representation. This versatility and efficiency of DWT in numerous applications is what drives its wide adoption in many domains like video and image compression (e.g. JPEG2000) and most importantly in the areas of: image and video fusion, content based image retrieval, medical image analysis, information hiding, and image communication system design among others. The underlying approach of DWT is to convolve the image signal with wavelet functions at multiple frequency bands to form relevant image features. Eqs. (1) and (2) defines the DWT for a signa $x(n)$:

$$W_{\varphi}\left[j_0, k\right]=\frac{1}{\sqrt{M}} \sum_n x\left[n\right]\varphi_{j_0,k}\left[n\right] \tag{1}$$

$$W_{\psi}\left[j,k\right]=\frac{1}{\sqrt{M}} \sum_n x\left[n\right]\psi_{j,k}\left[n\right] \tag{2}$$

where, $j \geqslant j_0$, $W_{\varphi}\left[j_0, k\right]$ and $W_{\psi}\left[j,k\right]$ represent the approximation and detail coefficients, respectively.

The inverse transformation for DWT is given by Eq. (3):

$$x\left(n\right)=\frac{1}{\sqrt{M}} \sum_k W_{\varphi}\left[j_0, k\right]\varphi_{j_0,k}\left[n\right]+\frac{1}{\sqrt{M}} \sum_{j=j_0}^{J} \sum_k W_{\psi}\left[j,k\right]\psi_{j,k}\left[n\right] \tag{3}$$

where, M denotes the number of samples, J is the number of decomposition levels,

$n=\left(0, 1, 2,\cdots;M-1,\ j\right)$, $k=(0, 1, 2,\cdots; 2^{J}-1)$; $\varphi_{j_0,k}\left[n\right]$ and $\psi_{j,k}\left[n\right]$ represent the scaling and wavelet functions, respectively. The DWT transformation allows for the efficient extraction of image features across multiple frequency bands, making it a powerful tool for tasks such as watermarking and compression[4].

2.2 Discrete Cosine Transform (DCT)

DCT is a linear transformation widely used in signal processing, which converts a signal from the time domain to the frequency domain. DCT is thus used for signal compression and filtering. With this study, it is revealed that the basic theory of DCT is decompose a signal to a set of orthogonal functions called Discrete Cosine Basis and filtering is applied to the coefficients of the normal variables, i. e. noise is removed to reduce storage data. Digital signal processing - A widely used technique in multiple domains (image processing, audio processing, video processing) to transform a digital signal into a compact version of the original, whilst retaining as much relevant information as possible.

DCT is especially well suited to image processing because DCT causes most of the image energy and important information to be concentrated in the low-frequency components, leaving only high-spindle details in the high frequency components. This fact is what makes DCT a great choice for image compression, as this property enables to effectively compress less important high-frequency details without sacrificing the image quality. Typically, the high-frequency components that have less contribution to the image's visual perception will be eliminated during compression and therefore more likely to be destroyed. Therefore, watermarks are typically bound in the low-frequency domain to maintain their higher robustness after compression or other conversions.

The DCT for an M×N image is defined by Eq. (4):

$$F\left(u,v\right)=\frac{1}{\sqrt{M\times N}} c\left(u\right)c(v) \sum_{x=0}^{M-1}\sum_{y=0}^{N-1} f\left(x,y\right)\cos\frac{\left(2x+1\right)u\pi}{2M}\frac{\left(2y+1\right)v\pi}{2N} \tag{4}$$

where $f\left(x,y\right)$ represents the intensity of the image, and $F\left(u,v\right)$ is the DCT coefficient. The values of x, y, u, and v range from 0 to M−1 and N−1 respectively.

The inverse DCT is computed as Eq. (5):

$$f\left(x,y\right)=\frac{2}{\sqrt{M\times N}}\sum_{u=0}^{M-1}\sum_{v=0}^{N-1}c\left(u\right)c(v)F\left(u,v\right)\cos\frac{\left(2x+1\right)u\pi}{2M}\frac{\left(2y+1\right)v\pi}{2N} \tag{5}$$

This focus on low-frequency parts of the signal is significant for applications such as image watermarking and compression[5]. Watermarking is a well-known technique on digital images, which enhances the robustness of that it continues to remain visible even after some transformations of the image, by embedding watermark data in the lower frequency components.

2.3 Singular Value Decomposition (SVD)

Singular value decomposition (SVD) is an essential matrix factorization methods in linear algebra, generalizing eigenvalue decomposition to all real matrices. Its applications are vast and include signal processing, statistics and many more. For an A×BA \times B matrix PP, SVD decomposes it as follows to obtain Eq. (6):

$$P=USV^{T} \tag{6}$$

where, U is an $A\times A$ unitary matrix, S is a semi-positive definite diagonal matrix of size $A\times B$, and V^T is the conjugate transpose of V, which is a $B\times B$ unitary matrix. The diagonal elements of S are the singular values of matrix P.

The singular values S_1, S_2, S_3, \dots, S_N satisfy Eq. (7):

$$S1\geqslant S2\geqslant S3\geqslant\cdots\geqslant SN\geqslant 0 \tag{7}$$

The order uniquely defines SS for matrix P; the single values summarize the effective energy or variance distribution of the matrix. The matrix PP can be reconstructed through the inverse process using these components, represented by Eq. (8):

$$P=U\cdot S\cdot V^{T} \tag{8}$$

An advantage of such a decomposition is its efficient use in manipulations and analyses of P, such as noise reduction, compression, and detection of relevant substructures or features in data.

3 Proposed DWT-DCT-SVD-Based Watermarking Algorithm

3.1 Watermark Embedding and Extraction Process

Illustration of embedding and extraction for the proposed watermarking algorithm. Figure 1. The first step includes processing raw watermark data through a process of transformations and operations to refine the data for secure and resilient integration into a cover image. The cover image, which is usually a color image, is decomposed into its R, G, and B components during the embedding phase. These be used as color space conversion to compute Y, U and V channels in a way more suitable for perceptual characteristics. A DWT is applied to every color channel to extract the frequency domain features. After that, the blocks of the transformed image will perform DCT to decompose the frequency in detail, which obviously has high energy in a certain area. Then at last the SVD is performed on the blocks to obtain the characteristic matrices of the cover image.

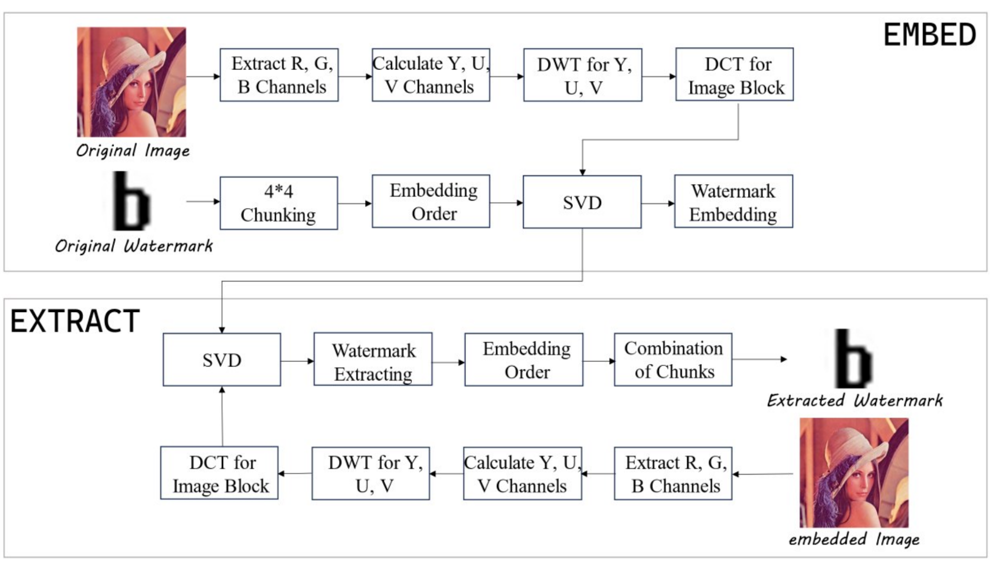

Figure 1 The embedding and extraction process for the proposed watermarking algorithm

Simultaneously, the watermark image is divided into blocks of a desired size. It has a unique index for tracking and management of a block. Then, a pseudo-random number generator is applied to generate the embedding sequence. Where the single values of the cover image are modified based on the watermark image binary. The adjustment works by embedding the watermark into the frequency domain characteristics of the cover image, making this type of watermark resilient against many standard attacks, including noise and compression. In the reconstruction, these steps are inverted: reversed DCT and DWT will be applied on the watermarked frequency domain data, combining it with the source spatial domain data to recover the final watermarked image.

3.2 Watermark Extraction Process

The extraction process follows the same procedure as the embedding phase to maintain consistency and accuracy when retrieving the embedded watermark. Similar decomposition as the cover image is performed on the watermarked image, where R, G, and B channels are transformed into *Y*, *U*, and *V* components. For each channel to obtain the feature matrices corresponding to the watermarked image, DWT, DCT, and SVD are applied[6]. This comparison is done between these embedded matrices and the original matrices of the cover image and through inverse operations the embedded watermark information can be extracted. The watermark's binary values are obtained by inverting the changes applied during embedding. More robust against any noise because it utilizes the frequency domain characteristics. The watermark will be embedded in these regions to minimize the probability of distortion due to image manipulation, as low and mid frequency domain is less vulnerable to usual image processing operations. In addition, utilizing pseudo-random sequences for embedding also protects against potential attacks aimed at removing the watermark from the data. By integrating DWT, DCT, and SVD, it takes advantage of the strengths of each method and guarantees high imperceptibility and robustness. This is especially useful for secure multimedia applications, as the extracted watermark can be checked for fidelity and integrity against the original.

4 Experimental Results

4.1 Watermark Embedding

The watermark embedding procedure was applied on various carrier images to verify the robustness and performance of the proposed approach. Figure 2 shows the carrier image used in the embedding experiment. The watermarked image following embedding is shown in Figure 3. The result of embedding, shown in Figure 4 shows the watermark embedded in the image by the algorithm, and clearly, no great visual distortion is observed in the image. For watermark embedding, DWT-DCT-SVD framework is employed for DWT-DCT-SVD based watermark embedding algorithm. The properties of these transforms were utilized to strike the balance between imperceptibility and robustness of the watermark inside the embedded data[7]. The outcome showed high visual quality of the watermarked image, which resulted in the watermark remaining invisible to the naked eye, and preserving the quality of the original carrier image.

Figure 2 The carrier image used for the embedding experiment

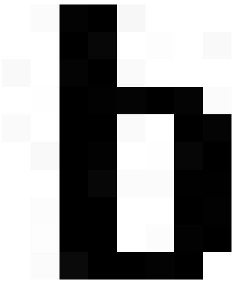

Figure 3 The watermarked image after embedding.

Figure 4 The embedding results.

4.2 Watermark Extraction

In the case of no attacks, the watermark extraction process recovered the same watermark which was embedded. Fig. 5 demonstrates the extracted watermark with no noise, giving a NC value of 1. The perfect correlation is an evidence that the watermark embedded was perfectly retrieved, showing how well the algorithm can reconstruct the embedded information without loss. The observed NC value approaches 1, which confirms the effectiveness of the inverse processes DWT, DCT, and SVD, accurately retrieving the watermarked image. This finding highlights the algorithm's potential for applications where high fidelity in watermark retrieval under ideal conditions is critical, establishing firm networked image authentication as a dependable solution.

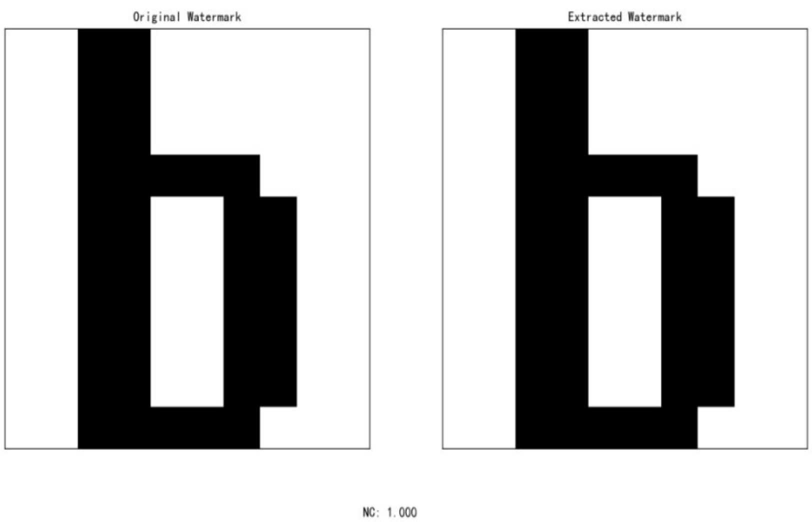

Figure 5 The extracted watermark in a noise-free condition

4.3 Resilience to Gaussian Noise Attacks

In order to assess the reliability of the proposed algorithm against adverse conditions, the watermarked image was attacked with Gaussian noise of standard deviation 0.05. The attacked image is given in Figure 6. We have finally added additional noise and the algorithm was able to extract the watermark with an NC value of 1 This result proved the robustness of the algorithm under Gaussian noise, such that the extracted watermark was visually the same as the originally embedded watermark. This high robustness of the method comes from the multi-level transformation and embedding which spreads watermark information across the frequency domain and thus enhances the watermark against noise interference. This characteristic not only demonstrates the robustness of the proposed method against noise but also illustrates its validity in real-world scenarios where images may be subject to frontal and blank noise during transmission or retrievable storage.

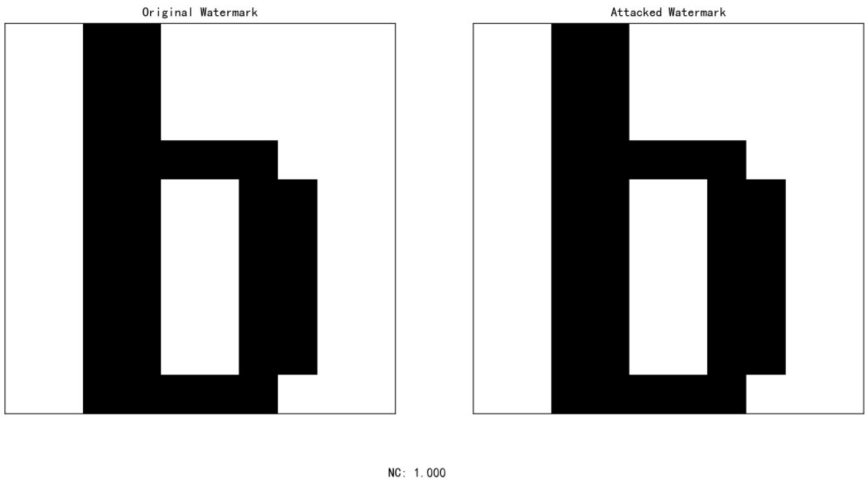

Figure 6 The attacked image subjected to Gaussian noise.

5 Conclusion

A watermarking algorithm based upon the combination of DWT, DCT, and SVD approaches is proposed here which shows an out of the blue precision and equity and robustness for both embedding and extraction. The experimental results confirm that the algorithm achieves effective embedding of the watermark into carrier images with negligible visual distortion and the watermarked images are imperceptible to human perception. By employing multi-level transformations, the algorithm is able to exploit the advantages of all three approaches adopted—DWT can precisely localize features in both spatial and frequency domains, DCT helps in concentrating image energy in the lowest frequency bands while the SVD representation is most robust to reveal features related to the middle and low frequencies of the image—thus leading to a watermarking approach that is both highly secure and computationally efficient. Ideal algorithmic performance was confirmed as yielding perfect NC (1), demonstrating that the embedded information (watermark) can be perfectly extracted at the same time without loss.

The algorithm showed excellent robustness to other attacks, such as Gaussian noise. In extreme circumstances like the addition of modified Gaussian noise of a standard deviation of 0.05, the algorithm has successfully recovered the watermark with around the same degree of NC=1 with the original image found at high quality. These applicable features are mainly because the algorithm distributes the watermark information over a wide range in the frequency domain and thus protects it from localized noise interference. These results confirm the accuracy of the algorithm for real-life applications where images may be subject to noise or other distortions during storage and transmission. Thus, on the whole, the proposed method guarantees the imperceptibility as well as the integrity of watermarked image and is a robust and secure solution for digital watermarking and thus is an excellent choice for copyright protection and authentication of multimedia content.

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