

Extensive dual tree complex wavelet transform-based image steganography using SVD and CNN subspace

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Abstract

The secret data is hidden behind a cover image using digital image steganography technology that prevents the human visual system (HVS) from identifying it. The proposed image steganography method involves scrambling the secret image and then embedding it within the cover image using the dual-tree complex wavelet transform (DTCWT) and singular value decomposition (SVD) technique. The stego image is generated by applying the inverse of DTCWT on the processed embedded image. The PSNR values for the stego and extracted secret images are 45.51 to 30.08 dB and 45.93 dB, respectively, with an SSIM greater than 0.99 in all cases. In the final step of the proposed method, a convolutional neural network (CNN) is utilized to enhance the quality of the extracted secret image. The effectiveness of the proposed method is confirmed by the comparative results.

Subject Classification: *Primary 94A08, Secondary 68U10.*

Keywords: *Wavelet, Dual tree, Neural network, Steganography.*

1. Introduction

Steganography and steganalysis are two crucial techniques in the field of information security [1, 2, 15]. The primary objective of steganography is to hide a payload within a cover item while maintaining the authenticity of both the cover item and the payload. On the other hand, steganalysis is

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the adversary of steganography, aiming to uncover both the cover items and their hidden payloads [8].

The discrete wavelet transform (DWT) has been utilized quite frequently in image security research for the purpose of feature extraction. The dual-tree complex wavelet transforms, also known as DTCWT, were first suggested by Kingsbury in the year 1998 [6, 17], is essentially shift invariant and permits directed wavelets in dimensions 2 and higher with just 2x redundancy in dimensions 1 and 2 [3]. Two genuine DWTs are used by the DTCWT. One DWT provides the transform's real portion, while the other DWT provides the transform's imaginary portion [12, 20].

The singular value decomposition (SVD) [10, 14, 23], is the finest matrix decomposition in terms of least squares because it condenses the most signal energy into the fewest number of coefficients. This makes it ideal for solving least squares problems or least square error (LSE) [7]. A reliable and efficient technique for breaking the system down into a number of linearly independent components, each of which contributes its own energy. SVD is also used in image compression [4, 24], image compression is also explained in [12]. SVD is capable of adjusting to changes in an image's local statistics [18].

Deep learning (DL) is used by technological companies like Google to classify images. In this study, we use the convolutional neural network (CNN) application to improve the retrieved image's quality [16, 22]. In DL based image steganography, a CNN is utilized since it is suitable for extracting features from images [5]. In CNN, the operation of residuals information extraction can be accomplished by convolution [25].

The remaining sections of this document are structured as described further down in this paragraph. The DTCWT is highlighted in the description of wavelet transform techniques that can be found in section 2. Section 3, which covers the SVD decomposition in a more general sense, is followed by Section 4, which discusses the scrambling technique. Before the conclusion of the study is delivered in Section 6, Section 5 contains a discussion of the findings and an interpretation of those findings using CNN.

2. The Wavelet Transform Methods

A function that only includes positive frequencies in its spectrum is known as a complex (or analytical) wavelet. A complex wavelet generates a transform with a less oscillatory modulus than a real wavelet since it only reacts to the nonnegative frequencies of a given input. This trait makes it much easier to find and follow the signal's instantaneous frequencies.

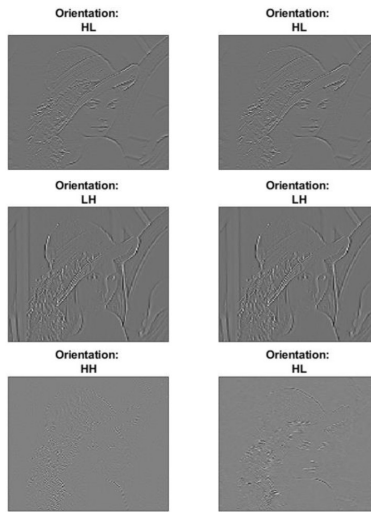


Figure 1

Lenna Six Wavelet Sub-Bands Representation After Applying DTCWT

Using two different DWT decompositions, the DTCWT calculates the complex transform of a signal (tree a and tree b) [19, 20]. Figure 1, give detail information after applying the 2-level DTCWT on Lenna image. The wavelet transformation used an different type of filter banks. Filtering is also used to denoise the noisy image. Different types of image denoising methods are explained in [13].

3. Image Decomposition

The 2-D image is broken down into the form of $M = U\Sigma V^T$ [14, 24] using the SVD, where A represents the size of the image's pixel matrix ($r \times c$), U is a $r \times r$ matrix with orthonormal columns, is a $r \times c$ matrix with singular values on the main diagonal, and V is a $c \times c$ matrix with orthonormal columns. Matrix V 's transpose, which is obtained by switching its rows and columns, is denoted by V^T [11]. By utilizing this computation, we can retain the important singular values required to maintain the image's quality while discarding the less important ones. The square root of the eigenvalues of the matrix $M^T M$, where M is a $c \times c$ matrix, are the singular values of the resulting $r \times c$ matrix M . These singular values are identified and separated from the matrix M , giving rise to the name of the SVD. The arrangement of the singular values is typically in decreasing order of magnitude.

4. Scrambling

Once data is securely transmitted to the recipient end, information hiding is an art that has been properly achieved. The process of scrambling adds a layer of security to the sensitive data. The scrambling method used in the proposed DTCWT-SVD and CNN based image steganography is a modified version of image scrambling method which is used in our earlier published paper [9]. In [9], image scrambling method performed with DWT. Earlier steps of current image scrambling method used in this paper, perform the row wise image matrix pixel information interchanging and get image (say I_r) then perform the image scrambling according to the algorithm suggested in table 1. It converts a 2D image matrix into a 1D array and arranges the elements in a sub-band according to the specifications. Algorithm 1 describes the image-scrambling procedure (Table 1).

Table 1
Image Scrambling Algorithm Used In Proposed Steganography.

Algorithm 1: Image scrambling	
Input:	Plain Image (secret image)
Output:	Scrambled Image (S_c)
BEGIN Group two adjacent rows at a time and perform Neighbors Row wise image matrix pixel information interchanging, Apply it on complete image and get image I . $Length(I) = row(I) \times column(I)$ $A = I(1:Length(I))$ // Matrix to 1 D array Conversion $[v, ix] = sort(A, descending)$ Low = Find the minimum value of A []. Mean = Find the mean value of A []. for each pixel A [] do if $Pixel < (Low + Mean)/2$ then $Sub\ band\ 1[] < -Pixel$ else if $Pixel < ((A \geq (Low + Mean)/2) \& (A \leq Mean))$ then $Sub\ band\ 2[] < -Pixel$ else $Sub\ band\ 3[] < -Pixel$	

Contd...

Perform array combing operation on Sub band 1, 2 and 3 and store in scramble image array S_c .
 Reshape array scramble image array S_c from 1D to 2D array according plain image (I) dimenstions.
 END

5. Results and Interpretation

The proposed image steganography technique is divided into two main phases: the image embedding process and the image extraction process. The techniques described above are used in between these operations to keep them secure. At the very end of the image extraction process, the CNN model is applied to the extracted image in order to improve the image's overall visual quality.

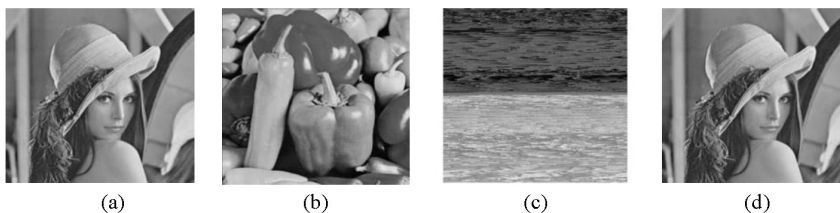
Table 2
Proposed Image Steganographic Embedding Process

Algorithm 2:	Proposed steganography system to embed the scrambled secret image
Input:	Cover Image (C_i) and Secret Image (S_i)
Output:	Stego Image (S_s)
	BEGIN
	Apply DTCWT on cover image (C_i):
	$[a, b] = dualtree2(C_i, Level', 2)$
	Scramble the secret image (S_i) using image scrambling method shown in table 1.
	Apply SVD on Tree 'a' and scrambled secret image than perform embedding operation and get embedded image (E)
	Apply the inverse of DTCWT to generate stego image (S_s):
	$S_s = idualtree2(E, b);$
	END

The Algorithm 2 (Table 2) applied on cover and secret image to get the stego image. The outcome of each step is shown in Figure 2.

The Stego Image (S_s), travel from the transmission medium, receiver used that image to extract the secret image (S_i).

In order to acquire an extracted secret image from a stego image, the Algorithm 3 (Table 3) is applied to the stego image. The results of each stage of this procedure are illustrated in Figure 3. The extracted Secret

**Figure 2**

The Given Images Are Represented (a) Cover Image (C_i) (b) Secret Image (S_i) (c) Scrambled Image (S_c); and (d) Stego Image (S_s)

image, denoted by the notation S_{E_i} can be obtained by applying the image extraction procedure to the stego image, denoted by S_s . The peak signal to noise ratio (PSNR)[21] and the structure similarity index (SSIM) [10] are utilised in order to quantify the degree of similarity that exists between the original cover image (C_i) and the stego image (S_s), as well as the level of similarity that exists between the original secret image (S_i) and the extracted secret image (S_{E_i}), respectively.

Table 3
Proposed Image Extraction Process

Algorithm 3: Proposed steganography system to extract the secret image	
Input:	Stego Image (S_s)
Output:	Extracted Secrete Image (S_{E_i})
BEGIN	
Apply DTCWT on stego image (S_s) :	
$[a1, b1] = \text{dualtree2}(S_s, \text{'Level'}, 2)$	
Apply SVD on Tree 'a1' to get extracted scrambled image (E_i)	
Convert 2D to 1D and rearrange the pixel according to the original position	
$[v1, ix1] = \text{sort}(E_i, \text{descending})$	
$w(ix) = v1;$	
Reshape the 1D array into 2D array and get secret image	
Next perform the Neighbors row wise image matrix pixel information- interchanging on secret image and get (S_{E_i}) image.	
Apply CNN on secret image (S_{E_i}) to generate enhanced secret image (S_{CNN})	
END	

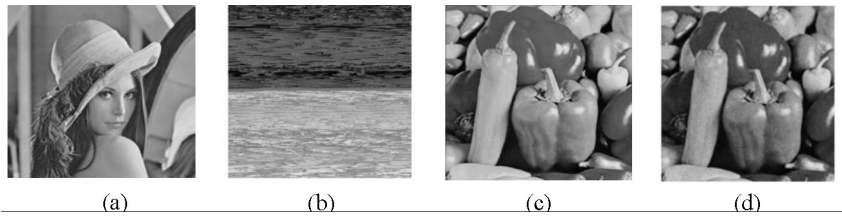


Figure 3

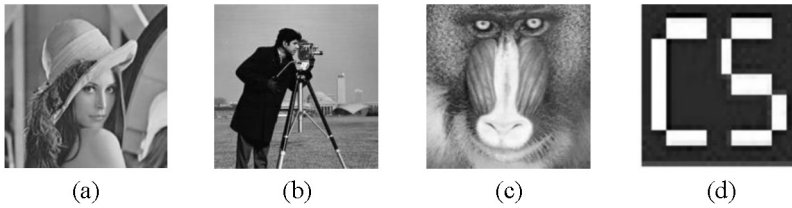
The Given Images Are Represented (a) Stego Image (S_s) (b) Extracted Scrambled Image (E_i) (c) Extracted Secret Image (S_E); and (d) Post Process Image (S_{CNN})

Postprocessing techniques are applied to enhance the visual appearance of the extracted secret image, which has been processed by a CNN model trained for this purpose. Figure 3(d) shows the resulting image after the postprocessing step. The performance and comparison of the postprocessed images are evaluated and presented in Table 4 and Table 5.

Table 4, represents the correlation between outcome of embedding and extraction process images. Here the value of alpha is used to decide estimates of steganographic messages within images.

Table 4
Outcome of PSNR and SSIM for Different Alpha Values

Alpha Value	PSNR Between (C_i) and (S_s) in dB	PSNR Between (S_i) and (S_E) in dB	SSIM Between (C_i) and (S_s)	SSIM Between (S_i) and (S_E)
0.01	45.5152	45.9351	0.9998	0.9977
0.02	39.5684	45.9354	0.9994	0.9977
0.03	36.1560	45.9411	0.9989	0.9977
0.04	33.5886	45.9447	0.9983	0.9977
0.05	31.6825	45.9495	0.9975	0.9977
0.06	30.0867	45.9515	0.9966	0.9977

**Figure 4**

The dataset used for comparative study with [10] (a) Cover Image Lena (b) Cover Image Cameraman (c) Cover Image Baboon; and (d) Secret Image Sign

Table 5

SSIM Based Performance Comparison with Different Values of Scaling Factor

Scaling Factor (Alpha)	Lena Image SSIM (C_r, S_s)		Cameraman Image SSIM (C_r, S_s)		Baboon Image SSIM (C_r, S_s)	
	[10]	Proposed Work	[10]	Proposed Work	[10]	Proposed Work
0.01	0.9987	0.9997	0.9978	0.9993	0.9988	0.9999
0.02	0.9987	0.9994	0.9978	0.9988	0.9988	0.9996
0.03	0.9986	0.9989	0.9978	0.9975	0.9988	0.9991
0.04	0.9986	0.9982	0.9977	0.9962	0.9987	0.9983
0.05	0.9986	0.9975	0.9977	0.9943	0.9986	0.9972
0.06	0.9985	0.9966	0.9976	0.9923	0.9986	0.9956

Many researchers work on DTCWT, DWT, and different wavelets to perform image steganography. Here in Table 5, comparative studies between proposed work and other researchers' work on watermarking are summarized. The dataset used to perform comparative study show in Figure 4. Steganography and watermarking are two approaches that are roughly comparable, but their applications are quite distinct from one another. Here we compared, our results with the existing watermarking technique [10].

According to the result shown in Table 5, the SSIM results of [10] and proposed work are approximately similar. The stego image quality is quite acceptable according to the experimental results.

6. Conclusions

Emerging image steganography systems are being developed to ensure secure communication of confidential information. Various

methods are employed to enhance the security and quality of the stego image. In this study, a highly secure image steganography algorithm is introduced to ensure the quality of the stego image. The proposed method utilizes multiple techniques, including DTCWT and SVD, to hide a scrambled secret image within the cover image. The algorithm was designed to increase the security of the secret image prior to embedding. The proposed method has been evaluated with PSNR and SSIM values, resulting in a 45.51 to 30.08 dB PSNR and a 0.99 SSIM for different alpha values. The extracted secret image achieved a PSNR of 45.93 dB and SSIM of 0.99. A trained CNN model was used to improve the quality of the extracted secret image, and comparative studies confirmed the success of the proposed method. The results demonstrate that the quality of the stego image was not degraded structurally.

Data Availability

The dataset utilized in this study can be accessed for free through the following dataset link.

Kaggle Data Set: - <https://www.kaggle.com/datasets/jyotikhandelwal/dtcwt-svd>

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