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DWT-SVD Based Image Steganography Using Threshold Value Encryption Method

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Abstract: Digital image steganography technique based on hiding the secret data behind of cover image in such a way that it is not detected by the human visual system. This paper presents an image scrambling method that is very useful for grayscale secret images. In this method, the secret image decomposes in three parts based on the pixel's threshold value. The division of the color image into three parts is very easy based on the color channel but in the grayscale image, it is difficult to implement. The proposed image scrambling method is implemented in image steganography using discrete wavelet transform (DWT), singular value decomposition (SVD), and sorting function. There is no visual difference between the stego image and the cover image. The extracted secret image is also similar to the original secret image. The proposed algorithm outcome is compared with the existed image steganography techniques. The comparative results show the strength of the proposed technique.

Keywords: Image steganography; threshold value; sorting; discrete wave transformation; singular value decomposition; color band division; permutation

1 Introduction

Nowadays, the internet's coverage area encompasses the entire globe; the internet allows us to connect people from all over the world. The internet is used not only on Earth, but also in space, where it is mandatory. In this technical and digital environment, the security of information is a high-responsibility job. Information system security is the broad area that introduces the advantages and disadvantages of data digitalization. The challenges of information system security can be concluded in three terms: Confidentiality, Integrity, and Availability, some of which are called CIA [1,2]. The meaning of data confidentiality means not disclosed to unauthorized individuals, integrity means maintaining accuracy and completeness of the data and availability means information must be available when needed. The digital information transmission technique must be an efficient worker for the information system security channels.

Steganography, watermarking, and cryptography are well-known methods for secure information transmission. The roles of these methods are different according to the point of view of utilization [3]. The steganography method uses the technique of hiding information. Watermarking uses two different approaches; one is visible watermarking, and the other is invisible watermarking. Cryptography believes in the direct change in secret data. We are only considering steganography here. Steganography is the art of hiding digital data behind other digital data. The perfect steganography method passes all the channels of steganalysis. The steganalysis process tries to identify the secret information which is hidden behind the front surface. The steganography process is completed by the different types of cover objects like text, audio, images, and videos [4]. By using a different type of cover object, the secret information is transferred from one place to another.

Image steganography is the well-known steganography process. It uses an image to create a cover image behind which the secret data is hidden and securely transmitted over the internet or other transmission medium. The digital image is a collection of pixels. The pixel value is crucial in the filled with image steganography [5]. Image steganography is accomplished by two broad image steganography techniques, known as spatial domain and transform domain. The traditional image steganography method is a spatial domain technique. In the spatial domain, to hide the secret data in the cover image, the pixel value modification directly takes place. The well-known spatial domain image steganography technique is the least significant bit (LSB). The direct operation on the pixel value makes this method not reliable. The transform domain image steganography method works on the amplitude, phase, and frequency of the signal. The transform domain image steganography method is divided into two broad categories: discrete cosines transform (DCT) and discrete wavelets transform (DWT). The transform domain image steganography method was inspired by the fast fourier transformation (FFT). Image steganography based on the wavelet is more secure and robust as compared to the other techniques [6,7].

The fourier transform provides the frequency spectrum of the real signal, but all the frequency channels are not covered by the fourier transform. Due to this, the original time resolution of the real signal is missed. The wavelet comes as a solution for fourier transform drawbacks. The wavelet has a family of mother wavelets, but the fourier transform has only one kind of transformation [8]. The main categories of mother wavelets are continuous wavelet transform (CWT) and discrete wavelet transform (DWT). The CWT sets the scaling and translation as arbitrary, but DWT restricts them.

The information system security strengthens the image steganography technique so that secret images can be hidden behind the cover image properly [9]. The image steganography process starts with the selection of the correct steganography technique, but direct embedding of data is the old method. According to the new approach, the secret image is first scrambled by a different scrambling method then embedded into the cover image. The scrambling method changes the position [10] of the secret image pixels, and makes it invisible to the human visual system. This information system security concept provides the security against attackers available on the network.

2 The Steganography Method

In the proposed image steganography method, the cover image is a 256×256 Lena grayscale image. The secret information is a Pepper grayscale image of size 256×256. To transfer the secret image invisible to the human visual system, the secret image is embedded into the cover image using the concepts of DWT, scrambling the colour channel based on a threshold value, and singular value decomposition (SVD) methods. These method combinations provide improved security, and the extracted secret image quality is not too much affected.

2.1 Discrete Wavelet Transformation

The wavelet fluctuation breaks down the difference of a period series and, subsequently, gives an examination of change. A wavelet transformation can be either continuous or discrete. The DWT is more widely used. The dwt2 order plays out a solitary two-dimensional wavelet disintegration concerning either a specific wavelet or specific wavelet deterioration channels you indicate [11].

Fig. 1 shows the part that plays out an online DWT on the information signal. The approximation output and multidimensional output belong to the low and high-frequency components of the signal, respectively. Before applying DWT to the signal, the signal is sampled by the sampling parameter which is defined by the user. Additionally, the anti-aliasing function and type of wavelet from the DWT family are also selected by the user. The simulation time depends upon the sampling frequency, wavelet type, and the number of levels required [12,13].

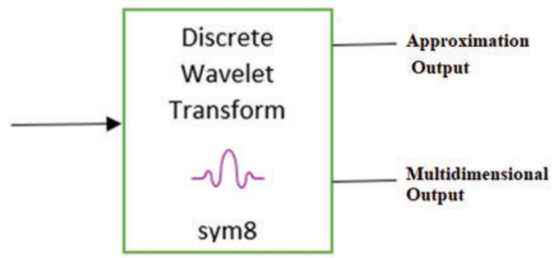

Figure 1: Discrete wavelet transforms input and output parameters

As shown in Fig. 2, the DWT image decomposition method divided the two-dimensional plain image into four equal parts. Each part contains the information about the original image according to the filter applied. By using their filter characteristics, the LL, LH, HL, and HH represent the different varieties of filtering. By using their filter characteristics, the plain two-dimension image breaks into multiple parts [14]. The decomposed part is used to hide the secret data according to the user, requiring the selection of a filter area.

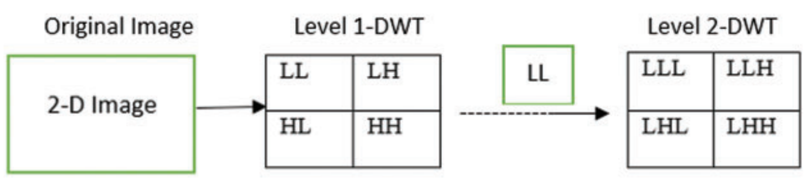

Figure 2: Discrete wavelet transform two-level decomposition

2.2 Scrambling

Detailed information scrambling improves the confidence of data transmission. The pixel changes place according to the applied method. The scrambling method is different from the cryptography method. In the cryptography method, the original value is replaced by the new value, which may exist or not exist in the present data. The scrambling method assures the sender that the hidden data can only be extracted by the authorized receiver [15,16]. The image is a 2-Dimensional data set that contains the pixel value by using the different scrambling methods. The image is created in the form of an unreadable data set by the attacker present in the transmission channel. The images are of two types: one is grayscale and the other is a colour image. In the colour image, three colour channels are available, which are known as red, green, and blue, but in the grayscale image, only one-color channel is available. In a Gray Scale image, the colour channel is divided based on the threshold value. The division of a grayscale image is broadly classified into three parts: Dark Pixels, Middle Pixels, and Bright Pixels.

The division of grayscale images according to the threshold value of pixels is shown in Fig. 3. According to the intensity of the pixels available in the image, the grayscale image was divided into three parts. These three-part pixel values are used to create the scrambled secret image.

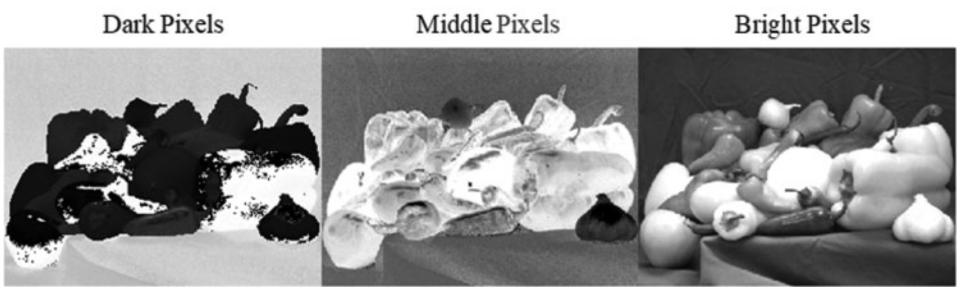

Figure 3: Division of grayscale image in three different parts using the threshold value

The scrambling process flow is represented in Fig. 4. First, the input secret image is converted into a one-dimensional array. The converted one-dimensional array is sorted by the sort function of MATLAB, a sort function used to arrange data in ascending and descending order [17]. The sorting function used in the proposed scrambling algorithm is:

$$[\mathrm{v}, \mathrm{ix}] = sort(A) \tag{1}$$

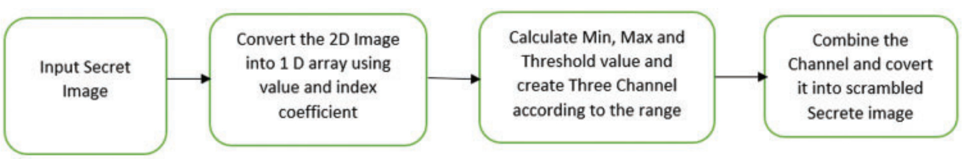

Figure 4: Scrambling process to make secret image scrambled before inbuilt into the cover image

The sorting function is also able to return the array indices. If the array A is an M x N matrix, then each column of ix is a permutation vector of the corresponding column of A. The returned indices preserve the original ordering, which is used as a key at the time of secret image extraction.

Proposed Scrambling Algorithm:

1. Convert the image 2 D array in 1 D array using two coefficient v and ix they are storing the value and index location respectively.
2. Sort step 1 generated 1 D image array.
3. Select initial Minimum, Maximum, and Threshold value, typically the mean 8-bit value of the original image

4. Divide the original image into three portions;
   a) Dark Pixels = (Minimum Value of Image Array + Maximum Value of Image Array)/2 <Threshold Value.
   b) Middle Pixels = (Value >= (Minimum Value of Image Array + Maximum Value of Image Array)/2) & (Value <= Threshold Value));
   c) Bright Pixels = Value > Threshold Value);
5. Combine the scrambled channel data and create a scrambled secret image.

The peppers' secret image pixel maximum intensity value is 233, the minimum value is 1, and the mean value is 120.93, calculated by the max, min, and mean functions. Let's put the value and understand the algorithm properly:

1. On the basis of secret image here the mean value is 120.93 take it as 121 Threshold value.
2. Divide the original image into three portions; (Here grayImage variable contain the secret image)
   a) DarkPixels = grayImage (grayImage < 117);
   b) MiddlePixels = grayImage ((grayImage >= 117) & (grayImage <= 121));
   c) BrightPixels = grayImage (grayImage > 233);
3. Combine DarkPixels, MiddlePixels & BrightPixels Scrambled channel and create scrambled secret image.

The outcome of the scrambling process is shown in Fig. 5. For the embedding process now, this scrambled secret image is used.

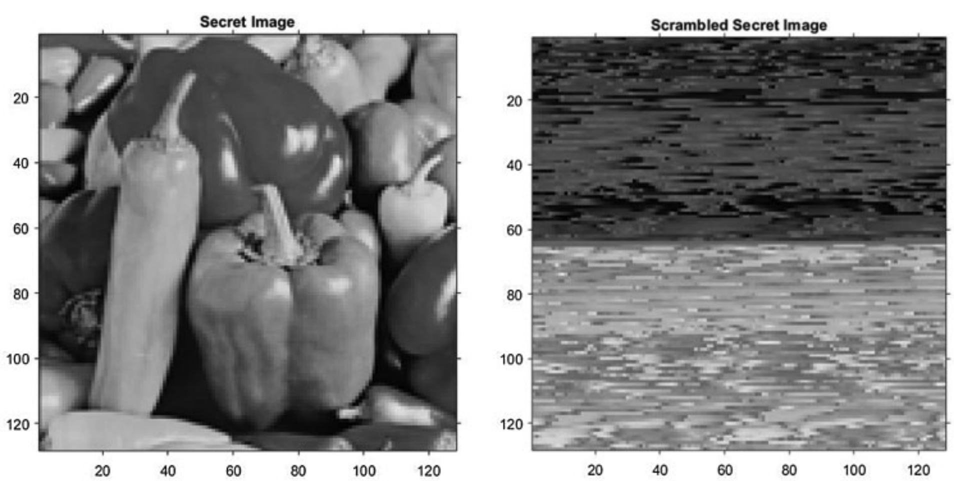

Figure 5: Original and scrambled secret pepper image

2.3 Singular Value Decomposition

To acquire understanding of the singular value decomposition (SVD), treat the columns of an n × d grid as n focuses in d-dimensional space and think about the issue of tracking down the best k-dimensional subspace for the arrangement of focuses [18]. In terms of direct polynomial math, the SVD is a factorization of a genuine and complex matrix. We can consider what we did in that deterioration as separating the first changes into three changes. Assuming we increase the furthest right network by any vector, and duplicate the center lattice by that item, and afterward increase the furthest left grid on the right-hand side by that item, we would see that beginning vector be changed multiple times. That interaction would be comparable to increasing the beginning vector by the first lattice [19,20].

We can likewise say that, in that unique change framework, which we'll call A, we planned a bunch of symmetrical vectors, or vectors at right points to one another (1, 0), and (0, 1) onto a bunch of non-symmetrical vectors (0,–2), and (1,–3) as shown in Fig. 6. We don't need to duplicate every vector by the change lattice each in turn. We can duplicate the arrangement of vectors, as a lattice, by changing the grid, as so.

Original Matrix | Eigenvectors Matrix | Eigenvalues Matrix | Inverse of Eigenvectors Matrix

$$\begin{bmatrix} 0 & 1 \\ -2 & -3 \end{bmatrix} = \begin{bmatrix} -1 & -1 \\ 2 & 1 \end{bmatrix} \begin{bmatrix} -2 & 0 \\ 0 & -1 \end{bmatrix} \begin{bmatrix} 1 & 1 \\ 2 & -1 \end{bmatrix}$$

Figure 6: Original matrix subdivision using the concept of SVD

Similarly, the calculation of SVD of matrix A factorized the two-dimensional matrix into three matrices, $A = UDV^T$, where columns U and V are orthonormal and matrix D is diagonal with the positive real entries [11]. A matrix contains orthonormal columns, which means each orthonormal column represents an $U^TU = I$.

2.4 Secret Image Embedding Algorithm

The following steps explain the embedding process:

1. Apply DWT on the Cover image (C).
2. Apply SVD on the Cover image LL filter Decomposition part.
3. Cover the Secret image (S) two-dimensional array into a one-dimensional array.
4. Apply Sort Function on the one-dimensional converted array, sort function store value, and location of the pixel.
5. Calculate the Max, Min, and Threshold value and apply the channel division according to the range defined in the proposed scrambling algorithm:
   a) Dark Pixels = (Minimum Value of Image Array + Maximum Value of Image Array)/2 <Threshold Value.
   b) Middle Pixels = (Value >= (Minimum Value of Image Array + Maximum Value of Image Array)/2) & (Value <= Threshold Value));
   c) Bright Pixels = Value > Threshold Value);
6. Combine the color channel and covert one-dimensional secret image array into a two-dimensional scrambled image (SS).
7. Apply the SVD on the Scrambled secret image (SS) and insert the secret image (SS_S) into the cover image using alpha blending.
8. Take the inverse of the embedded image (A_G) and generate the stego image (I).

Fig. 7, represents the entire flow of the algorithm used for embedding secret image inside the cover image, and the result comes out in the form of a stego image.

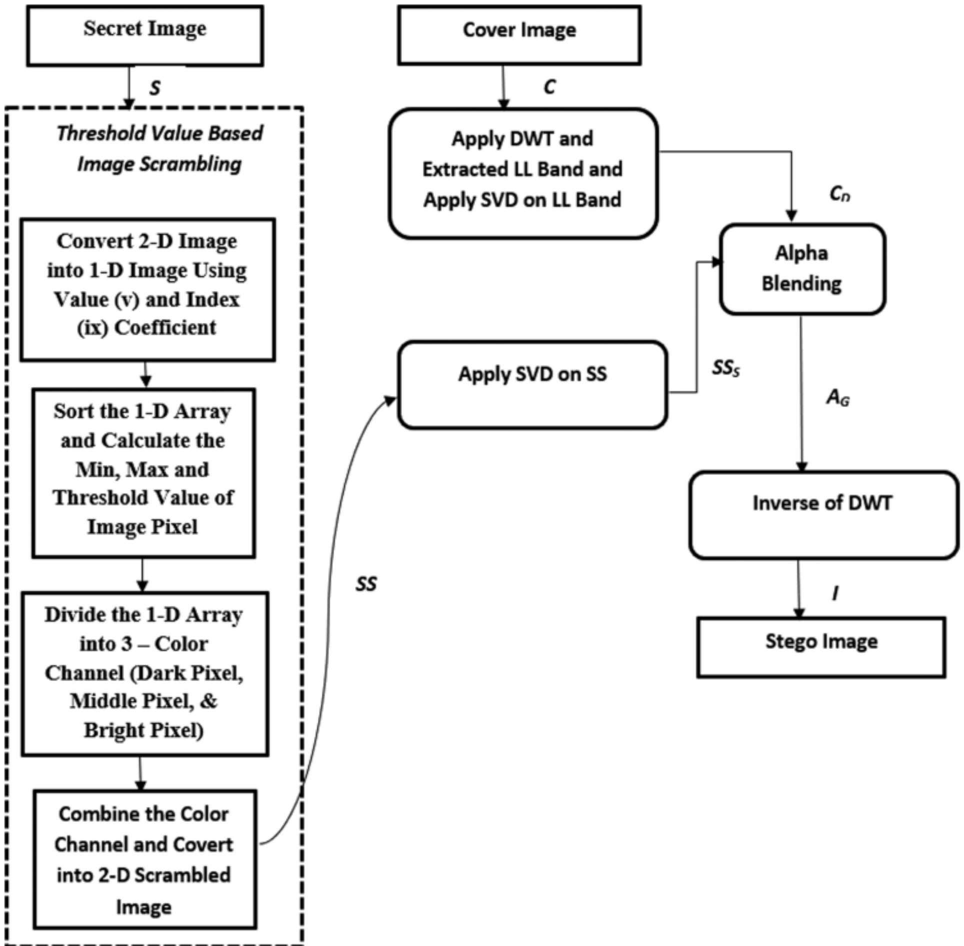

Figure 7: Secret image embedding flowchart

2.5 Secret Image Extraction Algorithm

The extraction algorithm consists of eight steps as follows:

1. Apply DWT and SVD on the Stego image (I).
2. Covert the extracted image (I_D) two-dimensional array into a one-dimensional array.
3. Apply the sorting function which contains the extracted secret image pixel value and location.
4. Rearrange the one-dimensional sorted array according to the location key array generated at the time of secret image embedding process.
5. Convert the one-dimensional array into an extracted two-dimensional secret image.
6. Rotate the extracted secret image 270-degree angle.
7. Apply Flip Function on output image come from step 6.
8. Show the extracted secret image (S).

Fig. 8, represents the entire flow of the algorithm used for extracting secret images from the stego image, and the result comes out in the form of a secret image which is most similar to the original secret image.

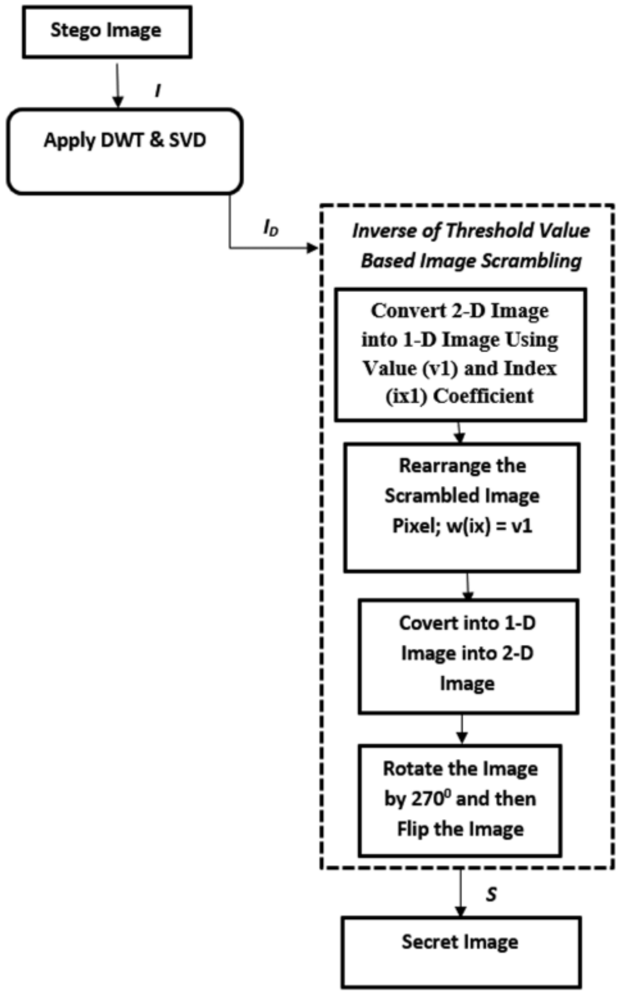

Figure 8: Secret image extraction flowchart

3 Experimental Results

This section includes the outcome of the proposed algorithm. The image steganography outcome comes from the combination of the wavelet transform in the form of the discrete wavelet transform, linear matrix division in the form of singular value decomposition, and the scrambling method. The motive for using this technique is to provide secret image security between transmission channels [21]. Secret image security depends upon secret data invisibility in the transmission channel. The secret image embedding process is complete by using DWT, SVD, scrambling, sorting, array dimension conversation, and inverse DWT of the image.

The secret image is extracted at the end by an authorized user by using DWT, SVD, rotation, location key, and flipping processes. The programming implementation also shows the peak signal to noise ratio (PSNR) and mean square error (MSE) comparative results in terms of the original cover image and stego cover image.

The image steganography quality depends upon the quality of the stego image. According to the previous research done on the grayscale image, the PSNR value of the stego image must be greater than

37 dB. If the value of PSNR is greater than 37 dB, then the approximation of successful transmission of secret data can be considered [22].

As we show in Figs. 9a–9d, the standard well-tested Lena grayscale image was taken for the cover image and the Pepper grayscale image was taken as a secret image. The PSNR and MSE of the stego image are 37.72 dB, and 11.00 respectively, for alpha value 0.05. After that, the results of PSNR were less than 37 dB. The programming result is acceptable to the human visual system.

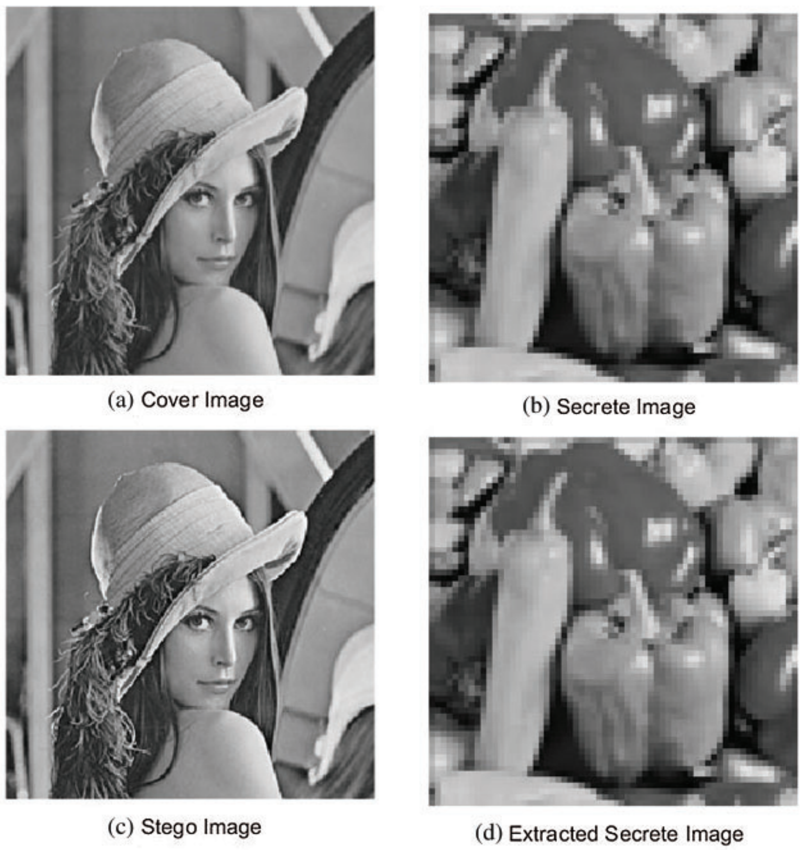

Figure 9: The secret image embedding and extracting outcome

Tab. 1 presents the results of PSNR and MSE values for different alpha values, and we can see that for different alpha they all are reasonable output in visual quality.

Table 1: Comparison of PSNR of Lena image for different values of alpha

Alpha value	PSNR (dB)	MSE
0.01	51.70	0.44
0.02	45.67	1.76
0.03	42.15	3.96
0.04	39.65	7.04
0.05	37.72	11.00

Fig. 10 shows the impact of alpha value on the PSNR and MSE values. Here the term alpha shows the transparency of colour when the secret image is embedded into the cover image. In most of the graphics, the alpha values lie between 0% to 100%. A value of 0% denotes full transparency. It means the secret image is fully visible, but if the value is equal to 100%, it means that the colour channels are completely opaque. So according to the requirement, an intermediate value is selected to blend the secret image with the cover image pixels. The value of alpha is decided based on the stego image PSNR value. The value of stego image PSNR must not be less than 37 dB according to the human visual system analysis. In the proposed work, the alpha value of 0.01 to 0.05 is provided as the accepted outcome.

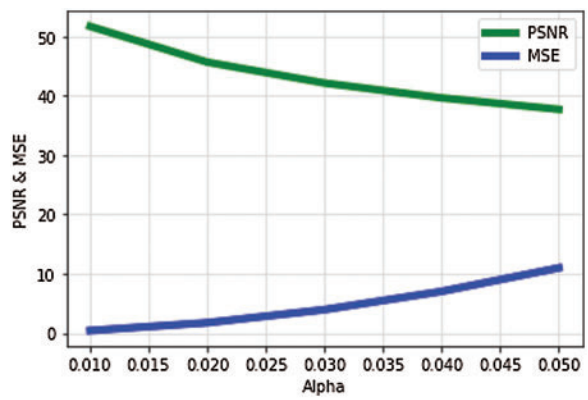

Figure 10: Performance visualization of proposed image steganography method in terms of PSNR and MSE for the different alpha value

The Structural Similarity Index Measure (SSIM) method is used for predicting image quality. The quality measurement by SSIM is done by finding the similarity between two images. The PSNR and MSE methods were used to find the absolute errors, but the SSIM is a prediction-based model which considers image degradation as a perceived change in structural information.

The first, comparative study of the proposed work check is based on the SSIM value generated by the previous work [23]. The test images shown in Figs. 11a–11d, used in the previous work are Cameraman, House, and Boats as a cover image and Peppers image as a secret image, the proposed work tested for given tested images. The result is generated for the comparative structural difference between the stego image and the original cover image. Every cover value is tested for different alpha values and results are recorded in Tab. 2.

(a) (b) (c) (d)

Figure 11: Test images: (a) Cameraman (b) House (c) Boats (d) Pepper10

Table 2: SSIM based performance comparison with different values of scaling factor

Image	SSIM for $\alpha = 0.01$		SSIM for $\alpha = 0.05$		SSIM for $\alpha = 0.1$		SSIM for $\alpha = 0.2$		SSIM for $\alpha = 0.3$	
	[23]	Proposed work	[23]	Proposed work	[23]	Proposed work	[23]	Proposed work	[23]	Proposed Work
Boats	0.8102	1.00	0.9879	1.00	0.9747	1.00	0.9286	0.99	0.8845	0.98
Camera-man	0.8835	1.00	0.9919	1.00	0.9896	1.00	0.9752	0.98	0.9532	0.97
House	0.9123	1.00	0.9938	1.00	0.9980	1.00	0.9942	0.99	0.9816	0.98

According to Tab. 2 and Figs. 12a–12c, the proposed work stego image generated of boats, cameraman and house for $\alpha = 0.01$, 0.05 and 0.1; there is no structural difference between stego image and original cover image. Also, for $\alpha = 0.2$ and 0.3 the structural difference is much less and better than previous image steganography technique.

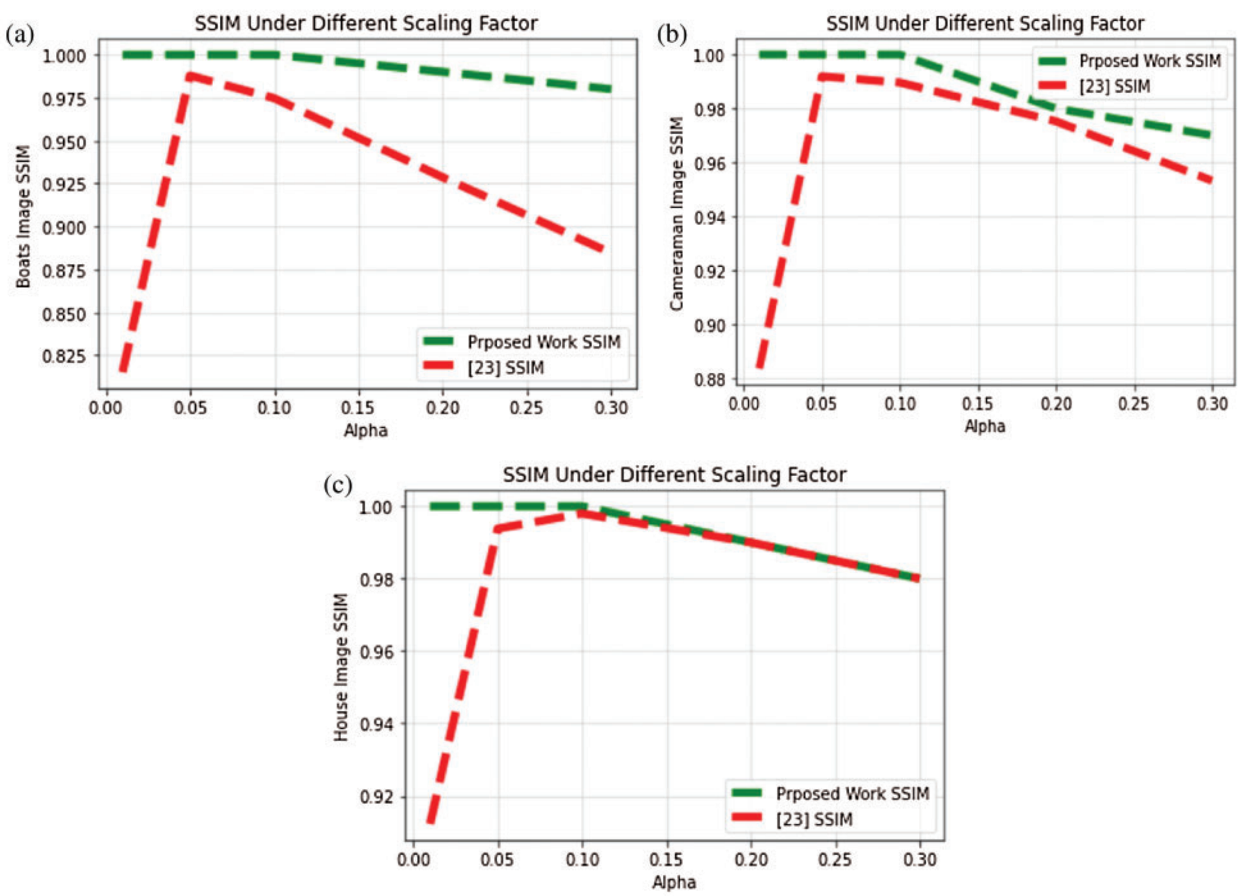

Figure 12: Comparative SSIM visualization of proposed work and [23] for the different cover image and alpha value

The second, comparative study of the proposed work checked for PSNR value generated by the previous work [24]. The tested images shown in Figs. 13a and 13b, used in the previous work, were the City as a cover image, and the Baboon Image as a secret image. The proposed work is tested for given test images. The previous work employs the transform domain family's traditional discrete cosine transform (DCT) .The elliptic curve cryptography (ECC) is used for scrambling and the SegNet deep neural network is used to improve the steganography capacity. The result is generated for the PSNR difference between the stego image and the original cover image. The results generated from the proposed work are included in Tab. 3 and calculated for different alpha values.

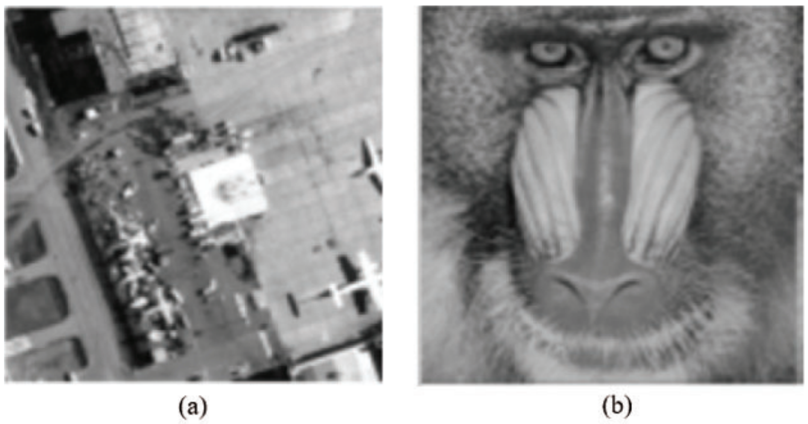

Figure 13: Test images: (a) City (b) Baboon

Table 3: PSNR based performance comparison with different values of scaling factor

Stego image	[24]	Proposed work PSNR					Average PSNR of proposed work
		$\alpha = 0.05$	$\alpha = 0.04$	$\alpha = 0.03$	$\alpha = 0.02$	$\alpha = 0.01$	
City	PSNR = 42.00 dB	PSNR = 40.12 dB	PSNR = 42.06 dB	PSNR = 44.56 dB	PSNR = 48.08 dB	PSNR = 54.10 dB	PSNR = 45.78 dB

According to the result discussion part of previous work [24], the higher PSNR value for the tested stego image is 42.00 dB. In the proposed work, the stego image difference from the original cover image is calculated for various alpha values. The average value of PSNR on different alpha values shows a better result as compared to the previous work [24].

4 Conclusions

In this study, the image steganography algorithm for hiding the secret image behind the grayscale cover image based on DWT, SVD, and division of grayscale image based on the threshold value is suggested. The threshold value-based image division gives the secret image scrambled view. The scrambled secret image provides the robustness necessary for the entire image steganography method [25]. The imperceptibility level of the stego image is analyzed based on PSNR, MSE, and SSIM values [26]. The comparative studies also show the successful completion of the proposed work. According to the result, there is no structural loss in the image quality of the stego image.

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