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Comprehensive Study and Implementation of LSB and DWT-based Image Steganography

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Abstract : Data is concealed using a security technique called steganography in a variety of digital media, including music, video, and photographs. Steganography, also referred to as invisible communication, is the use of a variety of methods to conceal the transmission of a message while maintaining its confidentiality. There are many different steganography techniques, and they vary based on the message to be concealed, the type of file being used as the carrier, the compression algorithm, etc. This work aims to conduct a detailed investigation of two efficient steganographic methods, one from the spatial domain and the other from the transform domain. The outcomes of implementing the Least Significant Bit (LSB) approach and the DWT-based information hiding method for various images are compared. Methods are thoroughly examined and tested from all angles. The number of bits required to disguise the data in the LSB technique ranges from 4 to 7. For varied embedding strengths ranging from 0.01 to 0.5, DWT-based methodology is used. To test the efficacy of these techniques, various images including scenery, animals, and text are taken into consideration. Comparative metrics include Mean Square Error (MSE) and Peak Signal-to-Noise Ratio (PSNR). Results indicate that DWT is superior to LSB. The in-depth examination of these steganography methods may give scholars in this area not just understanding and recommendations, but also suggestions for future work.

IndexTerms **- Image Steganography, Least Significant Bit (LSB), Discrete Wavelet Transform (DWT), Mean Square Error (MSE), Peak Signal-to-noise Ratio (PSNR).**

Introduction

The development of the internet has made it simple and convenient to exchange information in the form of digital media. Along with the benefits, this creates a greater requirement to ensure the data's security and privacy. Watermarking, cryptography, and steganography are the three main types of data encoding and hiding techniques. When data, such as audio, images, videos, or text, is watermarked, a signal known as a digital watermark is permanently incorporated into the data [1]. Thus, using a watermark helps verify copyright protection and the data's authenticity. By turning plain text to encrypted text, cryptography aims to make the data unreadable [2]. Both steganography and cryptography are methods of securing data from unauthorized parties, although neither one is perfect and can be broken [3]. As a result, combining two techniques can increase the effectiveness [4]. The primary goal of steganography techniques is to maximize the embedding rate and minimize the detectability of the resulting steganographed images [5].

The paper is organized as follows: The taxonomy of several image steganography techniques depending on parameters is enumerated in Section II. With a quick summary of the typical methodologies, Section III describes classic approaches of statistical methods in image steganography. Implementation information is provided in section IV. The comparison between the Discrete Wavelet Transform (DWT) method and the Least Significant Bit (LSB) approach from the transform domain is shown in Section V. The conclusion is discussed in Section VI.

I. Classification of Image Steganography

Steganography is the process of hiding confidential multimedia data inside bigger multimedia data. Different types of multimedia can be used as cover objects for hiding secret data.

This section discusses how to categorize image steganography. An image steganography categorization flowchart is shown in Fig. 1. The classification is based on the size of the cover picture, the type of embedding process (i.e., various embedding methods), and steganography based on file format and compression method.

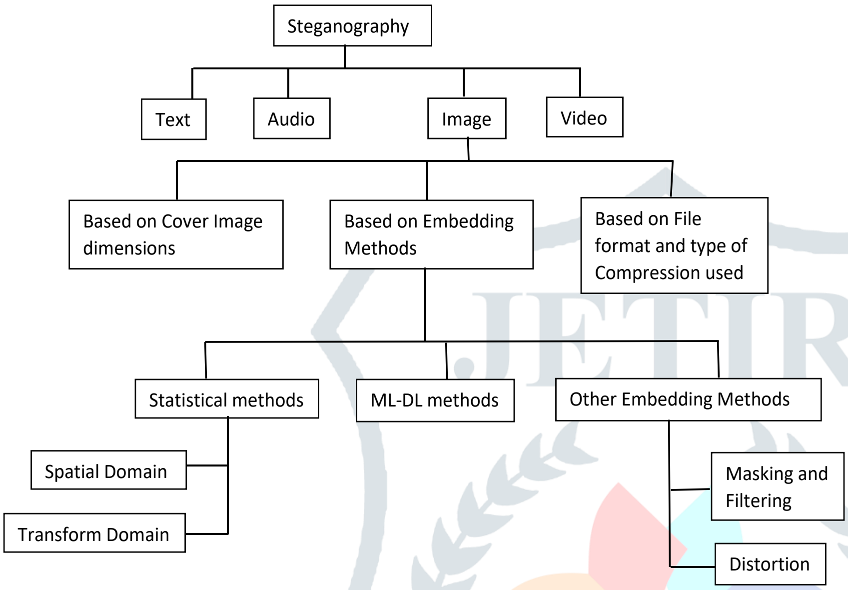


Fig.1. Classification of image steganography techniques

2.1 Based on cover image dimension

Steganography techniques are categorized as 2D image steganography or 3D image steganography depending on the sort of cover image employed, such as a colourful or grayscale image. A 2D image is used as a cover in 2D image steganography, where secret data is hidden inside the pixel values. But with 3D image steganography, a 3D image is utilized as a cover image with points or vertices in the 3D geometry that are changed to contain the secret data [6].

2.2 Based on embedding methods

The methods used to change the cover image file format and the methods used to change the secret data are primarily used to categorize image steganography approaches. These approaches are mainly divided into three categories: classical approaches or statistical approaches, ML and DL-based approaches, and alternative embedding approaches that make use of distortion, masking, and filtering techniques.

Statistical methods involve manipulating the statistical properties of the cover images to embed the secret data. Based on the domain type, these methods are further categorized as spatial or image domain and transform or frequency domain. Spatial domain methods modify the cover image pixel values and secret data is embedded by changing the pixel value intensities directly or indirectly. Transform domain is a more complex way of hiding the secret data.

In recent years the embedding efficiency is enhanced as advanced machine learning methods are used for steganography [7]. In distortion, signal distortion is used to store hidden information. The encoder then makes a series of adjustments to the cover image. The decoder measures the difference between the original and steganographed image during the decoding process. Grayscale pictures can also be embedded using masking and filtering techniques. They overlay the cover image with secret data by adjusting the luminance of specific regions. It embeds the message in significant bits of the cover image [8].

2.1 Based on file format and type of compression used

The Graphics Interchange Format (GIF), Joint Photographic Expert Group (JPEG), Portable Network Graphics (PNG), and Bitmap (BMP) formats are the most widely used picture file types. These file formats serve as the foundation for the majority of steganography methods. Lossy compression and lossless compression are the two types of compression [9]. Each of them has different effects on the secret data embedded.

II. Statistical Methods

Traditional methods used for image steganography employ different statistical techniques. Spatial domain techniques and transform domain techniques are commonly used in traditional image steganography.

3.1 Spatial Domain

3.1.1. Least Significant Bit (LSB):

One of the simplest and thus most widely used techniques in the spatial domain is this one. As is common knowledge, an image's pixels are made up of 3 8-bit red, green, and blue values each. The Least Significant bit refers to the final bit in a pixel. This is due to the fact that any changes made to this bit are too small for human sight to notice. By altering the LSB values of the pixels in the cover image, secret data is directly implanted using LSB-based techniques. or selected. Thus, it is capable of hiding large amounts of secret information without disrupting the visual quality of original image.

Different algorithms have been proposed in the past. One such algorithm is enhanced least significant bit algorithm [11]. Here, the secret data is hidden in only blue color instead of all the three colors of the cover image. This enhances the performance of LSB method as it minimizes the distortion level.

A spiral-based LSB substitution approach based on LSB substitution technique was proposed in [12]. It divides the image into many segments and applies different processing on each segment. This is said to enhance security. It considers three processes corresponding to three sequences - start from corner, start from center, and hybrid. It then applies two directions for the sequencing process - counter clockwise direction and clockwise direction.

There are other statistical methods implemented in spatial domain. Pixel Value Differencing (PVD) uses the difference of two adjacent pixel values to decide the number of secret bits to be embedded in the cover image. Traditional PVD approach was proposed in [13]. Modified approaches like PVD is used along with modulus function in horizontal direction [14]. To increase embedding capacity of the method, a technique was proposed that uses tri-way PVD [15]. The image is divided into 2x2 non-overlapping blocks. Histogram-based embedding scheme shifts the histogram levels of the cover image. It starts with finding the peak (highest) and valley (lowest) points. This technique also supports reversible data hiding which makes it advantageous. An approach that uses histogram shifting was proposed in [16] which tests reversible data hiding using histogram shifting on high-depth medical images. In [17], a cover image is divided into image blocks of size 5x5 which are non-overlapping.

Pixel value modification methods are prominent in image steganography. But in the spatial domain, if these pixels belong to smooth areas of an image, modification of the pixel values results in visual distortion. K.M. Singh et al. proposes an edge-based embedding scheme as edge-based methods are used as they maintain minimum visual distortion [18]. The primary idea behind edge embedding is that it preserves the high quality of the steganographed images while allowing edge sections to carry more secret messages than smooth areas. An edge-detecting filter algorithm called FilterFirst is presented in [19]. Edge sites are chosen and detected for embedding using it. An edge-based embedding method was proposed for color images, which uses the LSB method for embedding [20]. Pixel intensity modulation-based systems were introduced as a modification of the LSB steganography type methods as they provide better quality steganographed images. In [21], a modulation-based technique is proposed that embeds data the steganographed image is produced using a modulation-based technique that embeds data bits in the cover image's surrounding pixels. Another method based on pixel modulation is proposed in [22] called block-based image steganography using smart pixel adjustment and the secret data bits are embedded in host image subblocks.

3.2 Transform Domain

Because of the process's complexity compared to the spatial domain, the system is more secure. Information is also concealed by the transform domain in portions of the image that are less subjected to cropping and compression. They also do not seem to depend on image format. There are various techniques in the transform domain. An enhanced DFT-based technique for steganography known as Discrete Fractional Fourier Transform was proposed where both the spatial and frequency information is present in the transform coefficients and the secret data is also stored in this [23]. DCT assists in dividing an image into the high, middle, and lower frequency bands, each of which has a distinct level of significance (based on the visual quality of the image). During image steganography, secret information can be put in these bands. The cover image is first separated into non-overlapping 8 by 8-pixel chunks. The DCT equation is then applied to each block to produce the DCT coefficients. These DCT coefficients are quantized using a quantization table. Quantized coefficients include the secret data embedded inside them. Different methods can be used to embed this data. One strategy is to group nearby coefficients into groups and hide data bits inside each group [24]. There are different wavelets (such as Harr, Daubechies) and depending on the wavelet's nature DWT (Discrete Wavelet Transform) can be applied to image steganography. DWT involves a series of filters and dividing the images into sub bands. In these sub-bands, one can conceal the secret image. The primary factor that makes DWT superior to DCT or DFT is that in DWT, picture components with high detail are projected onto basis functions with shorter lengths and higher resolution, whereas image components with lesser detail are projected onto basis functions with bigger lengths. As a result, space-frequency localization is optimized.

III. Implementation

4.1. Methodology

Both the methods LSB and DWT have been implemented using MATLAB.

4.1.1. LSB:

In the Least Significant Bit steganography approach the distortion caused in the original image is controlled with the number of bits changed or by changing the more 'significant' bits. In the proposed implementation, the last four bits of each pixel (red, blue, green) of the cover image are replaced by the pixels of the secret image. The cover image and the secret image are initially resized to 256 x 256 dimensions. Two loops are created which run through both these images entirely covering each row and column. Binary values for the RGB pixels are obtained and by using a few transformations decimal values are converted to binary. Next, since there are 8 bits for each pixel, the most significant bits of both the images are taken, that is, 4 leftmost bits of the secret image and 4 leftmost bits of the cover image. These bits are then merged to create a pixel. The merging of bits is done by appending the bits of the secret image to that of the cover image. After this, the binary values are converted to decimal for the position of the pixels. This is how the steganographed image is obtained.

For example: Cover image pixel: 10110010 and Secret image pixel:11010100, the 4 leftmost bits of both the pixels are taken and merged hence computing the resulting value as 10111101.Here the 4 leftmost bits are of the cover image while the other 4 are of the secret image.

The process to reveal such a steganographed image involves knowing the number of bits used to hide the image. In our case initially 4 bits are taken. The number of bits (denoted by 'n') is then manipulated to find the best value.

The two images (cover and secret) are recovered with some loss of quality due to the changed binary values.

4.1.1. DWT:

Discrete Wavelet Transform is definitely better than DCT and DFT and more secure. The suggested system has first-level DWT applied to 2-D pictures. The frequency sub-bands are twice divided either horizontally or vertically in second level DWT. Using high-pass and low-pass filters, DWT essentially divides the signal into high- and low-frequency components. The low-frequency component can be divided once more into high- and low-frequency components [32]. Hence, the division of the main band into 4 sub-bands is as follows:

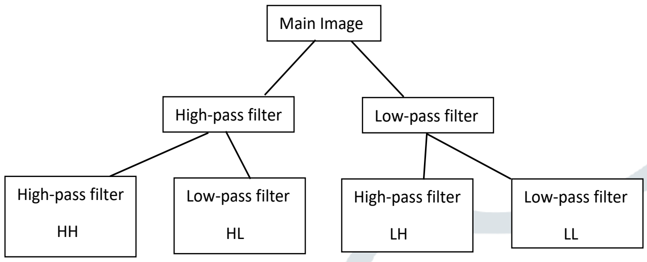


Fig. 2. Decomposition of frequency of an Image

The figure 2 is the decomposition of the main frequency band of image in the horizontal and vertical directions respectively only once (implemented in the proposed system). For each successive level of decomposition, the LL sub-band of the previous level is used as the input. The steganographed image can be embedded into different sub bands on the basis of the system's requirements. LL sub-band has been used in the proposed system as well since this sub-band provides more robustness than the other bands. It has higher energy than the other bands and hence embedding the watermark in this sub-band will not affect the energy value or the coefficient value much, making it less noticeable [33].

The input cover and secret picture is originally scaled during the implementation of DWT. In MATLAB, the function "dwt2" computes the single-level 2-D wavelet decomposition and outputs the approximation coefficient matrix "cA" and the detail coefficient matrices "cH, cV, and cD." (horizontal, vertical, and diagonal, respectively). The type of wavelet used to compute dwt2 (the proposed system utilizes "Haar") is then provided. Four sub-bands are created from the decomposition of the image using the coefficient matrices.

These sub-bands are as follows:

cA = LL = It is low-frequency sub-band, i.e., approximate image of input image. Further decomposition into 3D level dwt happens here itself.

cH = LH = extracts horizontal features of the image

cV = HL = extracts vertical features of the image

cD = HH = extracts diagonal features of the image

The LL sub-band of the cover image is selected and the RGB components of the LL band are generated. These extracted red, green and blue components create three 2-D matrices of the LL sub-band. The USV values of all of these 2D matrices are then determined using SVD (singular value decomposition). An m by n matrix is essentially expressed by singular value decomposition as a product of U*S*V'. With singular values of A on its diagonal, S is a m by n diagonal matrix in this case. The left singular vectors for corresponding singular values are located in the columns of the m-by-m matrix U. The correct singular vectors for corresponding singular values are the columns of the n-by-n matrix V. The complex conjugate of V' is V transposed. One can calculate all of these numbers using the MATLAB function "svd." [34].

Similar procedure is performed on the secret image as well. Further, the S values of the cover image and the secret image are merged to get S value of steganographed image. The embedding strength is taken initially as 0.10 and is tuned to get different levels of distortion in the output images. The secret is extracted finally from the steganographed image using inverse DWT.

4.2. Metrics to be considered

4.2.1. Mean Square Error (MSE):

In order to assess the compression quality of different images, the mean square error is frequently utilized. The cumulative squared error between the steganographic image and the original image is represented by the mean square error in the implemented system [35]. The clarity or the error in the image is directly proportional to the value of MSE. In the given project, MSE is used as a metric to compare the methods performed for image steganography. MSE values can be calculated either for RGB images or they can be converted to grayscale. The MSE is determined by comparing the squared pixel values of the original cover image to the steganographic image. The ideal MSE value for an image would be 0, which would represent an identical match between the cover image and the steganographic image.

Assume that the cover image pixels are K (i, j) and the steganographic image pixels are L for an image with a size of M x N. (i, j) [36].

$$MSE = \frac{1}{M*N}\sum_{i=1}^{M}\sum_{j=1}^{N}([L(i,j) - K(i,j)])^2$$

4.2.2. Peak Signal-to-Noise Ratio (PSNR):

Peak signal-to-noise ratio, which influences the quality of an image's representation, is the ratio of an image's maximum potential power to the power of corrupting noise. A picture's PSNR must be calculated by comparing it to an ideal, clean image with the greatest amount of potential power [37]. A lower discrepancy is indicated by a higher PSNR value. A PSNR value greater than 40 decibels (dB) denotes a high-quality image, while one between 30 and 50 dB is acceptable, and one below 30 dB suggests an image with significant distortion [38].

$$PSNR = 10 * log_{10}\frac{255*255}{MSE}$$

4.3. Comparison of value

The MSE and PSNR values are calculated by comparing the original cover image and the watermarked image for both the methods.

IV. Results

5.1. For LSB:

The number of bits that secret image replaces in cover image is denoted using “n”. This “n” is specified by taking ‘n’ input number in the proposed system. This method has been implemented by trying out multiple values of n from 4 to 7. The higher the value of n, the clearer the secret image will be (which is extracted from the steganographed image). Arriving at the plausible value of n that gives a best trade-off between the quality of extracted secret image and the quality of the watermarked image is the goal of this implementation.

For n=7, the distortion of the steganographed is high as is seen from the MSE values in table 1 and hence this value gets rejected. At n=4, the extracted secret image is extremely difficult to decipher. Hence satisfying the tradeoff, the final value of n can be taken as 5.

5.2. For DWT:

The embedding strength decides how the secret image is hidden in the cover image. As it is decreased, the quality of the extracted images decreases. One needs a value of embedding strength that gives good quality of the extracted secret image such that it is possible to read the message on it and the watermarked image also is not very disproportionate.

According to table 2, The secret images that are extracted seem to be the least distorted (looking at their MSE and PSNR values) when the embedding strength is taken as 0.10. But at this value, the MSE values are way too high for the cover image and watermarked images. Hence this tradeoff can be satisfied when the embedding strength is taken as 0.04. The extracted secret images at 0.04 also are easy to decipher. Hence LSB is done using n=5 and embedding strength= 0.04

The figure 3 and figure 4 shows the MSE and PSNR comparison of two different methods of steganography for 3 image sets. The figures clearly state that DWT gives better values for MSE and PSNR in all image sets. Hence, one can conclude that transform domain methods are much better than spatial domain methods for image steganography.

Table. 1. MSE and PSNR values for LSB Method

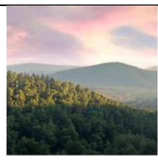
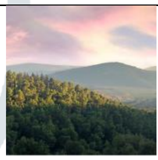
‘n’		Image Set 1	Image Set 2	Image Set 3
	Cover image			
	Secret image			
4	MSE	38.7423	73.8663	45.6207
	PSNR	32.2496	29.4473	31.5615
5	MSE	154.4375	219.2366	185.2660
	PSNR	26.2433	24.7221	25.5519
6	MSE	582.9934	1492.2	720.7398
	PSNR	20.4944	16.3930	19.7155
7	MSE	2.4316e+03	7.4792e+03	2.5566e+03
	PSNR	14.3010	9.3930	14.4633

Table. 2. MSE and PSNR values for DWT based method

Embedding Strength		Image Set 1	Image Set 2	Image Set 3
	Cover image			
	Secret image			
0.10	MSE	229.879	578.749	235.573
	PSNR	24.5526	20.5059	24.427
0.05	MSE	57.4698	144.687	58.8934
	PSNR	30.5732	26.5265	30.4476
0.04	MSE	36.7807	92.5999	37.6917
	PSNR	32.5114	28.4647	32.3858
0.03	MSE	20.6891	52.0874	21.2016
	PSNR	35.0101	30.9635	34.8846
0.01	MSE	2.29879	5.78749	2.35573
	PSNR	44.5526	40.5059	44.427

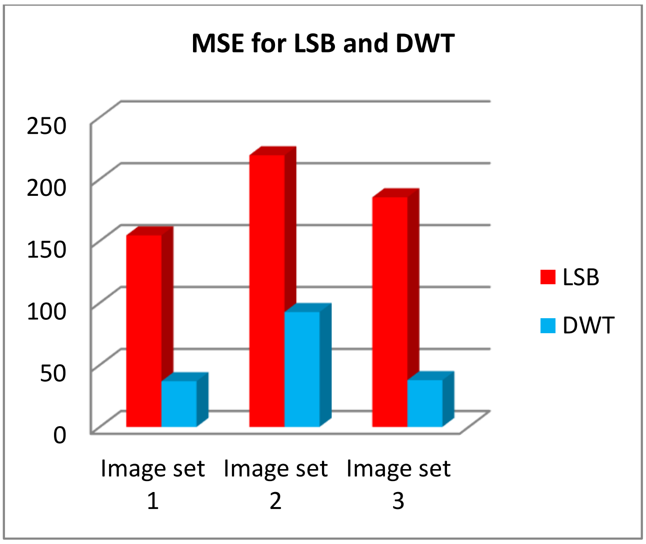


Fig. 3. MSE comparison of two methods

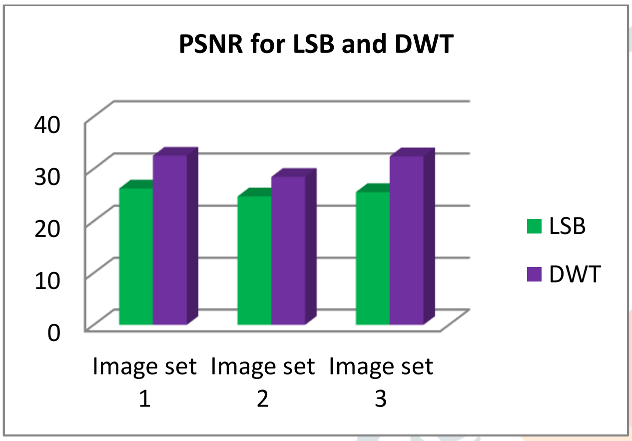


Fig. 4. PSNR comparison of two methods

V. CONCLUSION

In this paper, a methodology to implement image steganography techniques like LSB and DWT was implemented and analyzed. The method was tested by using coloured cover images and secret images. The two techniques were compared based on parameters like MSE and PSNR. A comparative performance analysis of the two methods was conducted by comparing values of the above-mentioned parameters. Here, it is seen that steganographed images that used DWT cause minimum distortion and hide secret images better as they are less prone to attacks. Thus, it can be inferred that transform domain methods (DWT) for images steganography are better than spatial domain methods (LSB). However, there is scope for improvement in image steganography techniques. Hybrid methods that employ data-embedding techniques like spatial domain into frequency bands like transform domain could prove helpful in increasing the embedding capacity and efficiency of image steganography.

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