A Robust Approach to Image Steganography for Secure Communication Using Dual-Tree Complex Wavelet Transformation (DTCWT) and Bit Plane Slicing

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Abstract: Steganography is a covert communication technique that conceals secret information within seemingly innocuous cover media. Combining transformation methods with data embedding techniques has gained significant attention in digital images. This paper presents an innovative approach to image steganography by harnessing the power of Dual Tree Complex Wavelet Transformation (DTCWT) in conjunction Bit Plane Slicing (BPS) technique. In the proposed model, the Cover Image (CI) undergoes DTCWT decomposition, splitting it into frequency sub bands. The magnitude features of the DTCWT applied Payload Image (PI) is embedded in CI, improving the balance between imperceptibility and payload capacity. Experimental results demonstrate the fusion of DTCWT and BPS outperforms conventional steganographic methods in terms of both security and perceptual quality. The combination of DTCWT and BPS techniques serves as an innovative approach that addresses the ever-evolving challenges in the field of data security and achieved the PSNR of 84.60dB and MSE of 0.015 respectively.

Keywords: Bit Plane Slicing (BPS), Dual-Tree Complex Wavelet Transformation (DTCWT), Image Steganography, Peak Signal-to-Noise Ratio (PSNR), Mean Squared Error (MSE)

1. INTRODUCTION:

The art of concealing confidential information from display while preserving the integrity of digital images is referred to as image steganography. The art and science of hiding secret information within images while maintaining the image's visual quality. It is crucial in secure data communication, digital watermarking, and copyright protection. To meet this demand, a technique for hiding sensitive information within seemingly innocent images is essential. In the digital communication and information-sharing age, the need for secure and covert data transmission has become increasingly important. Image steganography, a method of concealing secret information within seemingly innocuous images, is pivotal in addressing this need. An innovative approach of image steganography that combines the power of the Dual-Tree Complex Wavelet Transformation (DTCWT) with the classic BPS technique. Steganography leverages the ability to embed data within cover media in a way that remains imperceptible to the human eye, while DTCWT, a multi-resolution complex wavelet transformation, offers advanced spatial and frequency domain analysis. DTCWT is a multi-resolution, complex wavelet transform that provides excellent spatial and frequency domain analysis. The DTCWT offers several advantages, such as shift-invariance, directional selectivity, and reduced aliasing. These characteristics make it an ideal candidate for enhancing the imperceptibility and robustness of hidden data in steganographic applications.

The integration of these two techniques promises a heightened level of security and imperceptibility in hidden data, allowing for secure communication in applications where data privacy is paramount. This approach also emphasizes the incorporation of quality assessment metrics such as PSNR and MSE to ensure that visual fidelity is preserved during data embedding, thus making it a promising solution for secure and efficient image steganography. Higher PSNR values indicate better image quality, while lower MSE values signify minimal distortion. The terminologies are discussed below;

a) **Cover Image (CI):** A CI is the original image in which we intend to hide a payload.
b) **Payload Image (PI):** PI is the image or data that we want to hide within the CI.
c) **Stego Image (SI):** The SI is the result of embedding the PI into the CI. It appears similar to the CI but contains hidden data from the PI.
d) **Mean Squared Error (MSE):** MSE is a quantitative measure used to evaluate the difference between two images, such as the CI and the SI. A lower MSE indicates that the SI is closer to the CI, signifying better visual fidelity.

e) **Peak Signal-to-Noise Ratio (PSNR):** PSNR is a metric used to assess the quality of SI compared to the CI. Higher PSNR values indicate a higher-quality SI. PSNR is expressed in decibels (dB).

1.1 CONTRIBUTION:

The paper proposes a hybrid steganographic technique by combining the DTCWT and BPS techniques. Five-level DTCWT is applied to the input image to obtain real and imaginary sub bands to generate DTCWT coefficients and the BPS technique to generate a SI. This fusion of two distinct methods aims to leverage the strengths of each approach, creating a more robust and effective means of concealing information within images and brings about enhanced security in the steganographic process.

1.2 ORGANIZATION:

The paper is organised as follows. Section II is literature survey. Section III is the proposed model. Section IV explains the algorithm and results analysis and Section V is the conclusion.

2. LITERATURE SURVEY:

K.S. Seetha Lakshmi [1] proposed visual cryptography and neural networks. The data is encrypted using AES algorithm. Neural network and LSB is used to embed. S Bukhari, M S Arif [2] proposed the information protection in wireless channel. The embedding of the data is achieved using LSB; the image is divided into blocks whose size is 8 x 8. R Das and I Das [3] presented an enhanced safe data transfer scheme in smart Internet of Things (IoT) devices such as home server & cloud server.

A Gambhir and S Khara [4] proposed the data encryption using RSA algorithm. Using LSB the encrypted data is hidden within audio file. R Indrayani, H A Nugroho [5] proposed the Mp3 file as a cover file. The secret information is encrypted using AES algorithm and MD5 hash function. N Patel and S Meena [6] use space domain steganography. An image is embedded into another using a key as a seed pseudo random number.

K Joshi and R Yadav [7] proposed the encryption of secret message using vernam cipher and data is embedded using LSB. V Shanna and Madhusudan [8] proposed the S-DES algorithm to encrypt the secret message to produce an array. XOR operation is used to embed the data.

M Mukhedkar, P Powar and P Gaikwad [9] used blowfish algorithm to encrypt the image. Then the encrypted image is embedded using LSB. Jing-Ming Guo and Thanh Nam Le [10], measured the quality factor of JPEG images by maintaining quantization tables and performed some permutations along with this scheme to transmit a hidden file.

Kamal deep Joshi and Rajkumar Yadav [11] proposed the combined cryptography with steganography by first encrypting a message and then embedding it using LSB technique with shifting. Seetha Lakshmi et al. [12] implemented neural networks to identify best locations in the host image to embed the secret data.

Nikhil Patel and Shweta Meena [13] superimposed the dynamic cryptography with steganalysis. The LSB of the picture element is modified with the MSB and pixel selection is done using pseudo random numbers. May H [14], proposed the combined image steganography with cryptography. Both encryption and decryption are done using RC4 stream cipher and a hash function along with RGB pixel shuffling are used for steganalysis.

A.A.A. El-Latif, B. Abd El Atty [15] proposed two quantum image hiding strategies. A steganography quantum approach is proposed to hide an image in another image file. Secondly, a quantum watermarking approach is used to hide a water-marked gray image to a carrier image. Z. Qu, Z. Cheng et al [16] proposed a quantum steganography approach using matrix coding for color images.

N. Subramanian et al [17] provides a detailed examination of image steganography methodologies, focusing on traditional methods, CNN-based techniques, and GAN-based approaches. It highlights the significant impact of deep learning methods, such as Convolutional Neural Networks (CNNs) and Generative Adversarial Networks (GANs), on the evolution of steganography. Inas Jawad Kadhim, et al [18], proposed the types of image steganography and the recent contributions, general operation, requirements, different aspects, different types and their performance evaluations.

C Rama Mohana et al [19] proposed the DTCWT that employs two significantly sampled filter banks and provides great directional selectivity because it produces 6 sub-bands in each (±15∘, ±45∘, ±75∘), both real and imaginary, whereas DWT only gives restricted directions in (0∘, 45∘, 90∘), which increases transformational correctness and maintains more in-depth features. jyotsna yadava, khushwant sehra [20] presents a watermarking scheme using the DTCWT – PCA – SVD hybrid structure using a scrambled image as watermark.

Sunil Kumar B S et al [21] presents an adaptive DTCWT using the Motion Block Estimation (MBE), Large Diamond Search Path (LDSP) and a Small Diamond Search Path (SDSP) from diamond search.

3. PROPOSED MODEL:

The proposed model that makes use of Bit Plane Slicing (BPS) and Dual Tree Complex Wavelet Transformation (DTCWT) is shown in Figure1 below. The cover and payload images are read and pre-processed. In pre-processing the images are converted to grayscale if it is RGB and then resized. The Payload Image (PI) is separated into frequency sub bands using DTCWT decomposition in the suggested method. BPS is applied on CI and PI respectively. The average of MSB planes are further processed using DTCWT and magnitude features are chosen to embed in the CI to get stego image. By embedding the magnitude features of the DTCWT applied Payload Image (PI) in CI, the trade-off between imperceptibility [58] [59] [60] and payload capacity is improved. BPS, pixel value adjustment and DTCWT are described below.

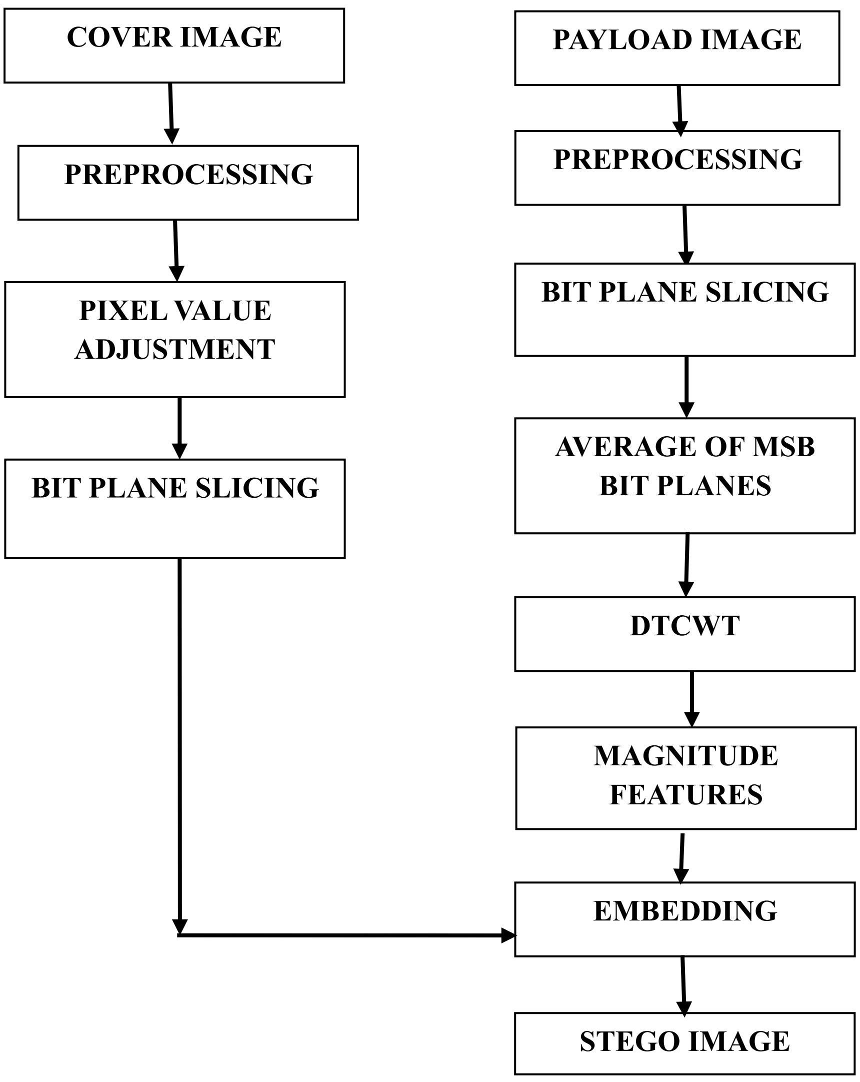
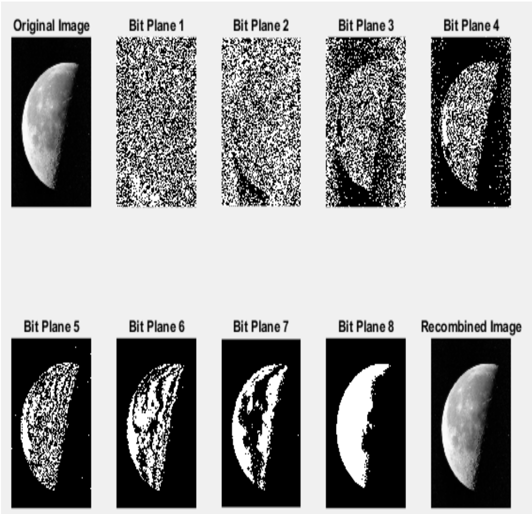


Figure1: Proposed model of image steganography

3.1 BIT-PLANE SLICING (BPS):

In grayscale image, each pixel has values ranging from 0 to 255. Each pixel value can be represented as an 8-bit binary number. Bit-plane slicing involves treating each bit of the binary representation as an individual image, revealing the contribution of that bit to the overall intensity of the image. For example, in an 8-bit image, the most significant bit (MSB) represents the highest intensity level, and the least significant bit (LSB) the lowest intensity level [22][23][24]. By extracting and visualizing each bit-plane separately, the distribution of intensity levels and the significance of each bit in forming the image can be observed. Figure 2 represents the contribution of each bit plane.



3.2 Pixel Value Adjustment (PVA):

PVA is an essential step in image steganography, particularly when embedding data into the CI. The primary goal of this process [25][26][27] is to ensure that the steganographic image appears natural and visually indistinguishable from the CI while concealing hidden data [28][29][30]. If the pixel value is equal to 255 then it is modified to 255-15, otherwise kept as it is.

3.3 Dual-Tree Complex Wavelet Transform (DTCWT):

The multi-resolution, complex wavelet transform known as DTCWT offers superior analysis in both the spatial and frequency domains [55] [56] [57]. Among the benefits of the DTCWT are reduced aliasing, directional selectivity, and shift-invariance. It is the perfect option for boosting the robustness and imperceptibility of hidden data in steganographic applications due to these qualities. The DTCWT approach is a refinement of the DWT technique which is capable of effectively implementing an analytical wavelet transform. The DTCWT complex coefficients are less redundant and robust oscillations and shift variance. These complex coefficients have real and imaginary components that may be represented by two DTCWT trees. The first tree represents the real component, while the second tree represents the imaginary component. The upper real part represents the low pass (h0) and high passes (h1) filter coefficients, whereas the lower imaginary part represents the low pass (g0) and high pass (g1) filter coefficients as shown in Figure 3. The DTCWT of a signal x is implemented using two critically-sampled DWTs in parallel on the same data [31] [32] [33].

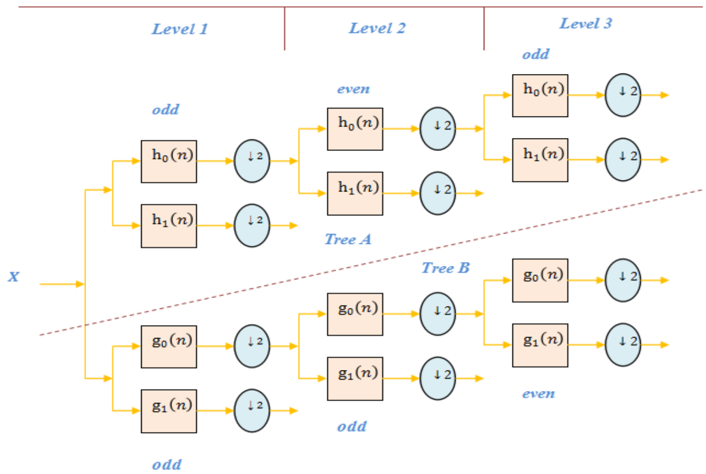


Figure 3: DTCWT FILTER BANK

3.3.1 Real 2-D Dual-tree Wavelet Transform

The real 2-D dual-tree DWT of an image x is implemented using two critically-sampled separable 2-D DWTs in parallel. Then for each pair of subbands we take the sum and difference. The six wavelets associated with the real 2D dual-tree DWT are illustrated in figure 4 as grayscale images. Each of the six wavelets is oriented in a distinct direction. Unlike the critically-sampled separable DWT, all of the wavelets are free of checker board artefact. Each subband of the 2-D dual-tree transform corresponds to a specific orientation. Figure 4 is the directional wavelets for reduced 2-D DWT.

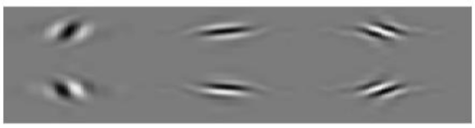


Figure 4: Directional wavelets for reduced 2-D DWT

3.3.2 Complex 2-D Dual-tree Wavelet Transform

The complex 2-D dual-tree DWT produces six different wavelets as well, however, there are two wavelets produced in each direction. One of the two wavelets can be regarded as the real component of a complex-valued 2D wavelet, while the other wavelet can be regarded as its imaginary component. The complex version of the transform has twice as many wavelets as the real version and is four times larger. A complicated 2-D dual-tree is implemented as four critically sampled separable 2-D DWTs working together. However, various filter sets are employed with the rows and columns. Sums and differences of sub-band images are used to produce oriented wavelets. Figure 5 illustrates the twelve wavelets of a real 2D dual-tree DWT in greyscale [34] [35] [36].

2D Dual-Tree Complex Wavelets

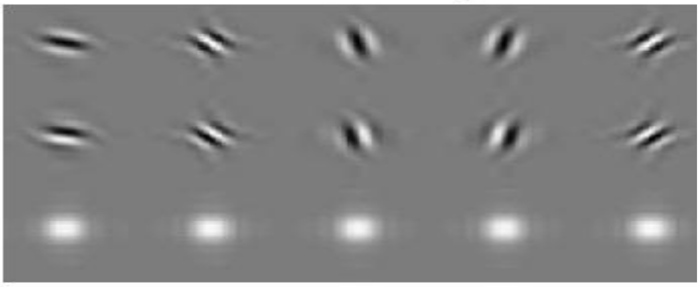


Figure 5: 2D Dual-Tree Complex Wavelet

The wavelets are orientated in the same six directions as the actual 2-D dual-tree DWT. Instead, there are two in each direction in this instance. The magnitude of the six complex wavelets is presented on the third row if the first (second) row's display of six wavelets is taken to represent the actual (imaginary) portion of a set of six complex wavelets. DTCWT produces complex coefficients by using dual-tree wavelet filters and gives real and imaginary parts, which consist of both low-frequency and high-frequency bands [37] [38] [39]. The high-frequency band is unnoticed and low low-frequency band is considered and decomposed into two portions for the next levels and the procedure is nonstop until the required levels. The magnitudes of both real and imaginary parts are intended using Equations 2, 3, and 4 respectively. Magnitudes are concatenated as specified in Equation 4 to obtain a single Vector. Where R_L, R_H & I_L, I_H are the real and imaginary tree coefficients.

$$M_L = \sqrt{[(R_L 6)^2 + (I_L 6)^2]} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$M_H = \sqrt{[(R_H 6)^2 + (I_H 6)^2]} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$M = [M_H : M_L] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

3.3.3 Two-Channel Perfect Reconstruction Filter Bank

Analysis filter bank af1 and af2 and synthesis filter bank sf1 and sf2 are shown in table 1. The synthesis filter bank combines the two sub band signals g (n) and h (n) to obtain a single output signal y (n). The synthesis filter bank first up-samples each of the two sub band signals [40] [41] [42]. The signals are then filtered using a low pass and a high pass filter. The low pass filter is denoted by sf1 (synthesis filter 1) and the high pass filter by sf2 (synthesis filter 2). The signals are then added together to obtain the signal y (n). If the four filters are designed so as to guarantee that the output signal y (n) equals the input signal x (n), then the filters are said to satisfy the perfect reconstruction condition [43][44][45]. One set of filters, is shown in the Table 1 below. These filters are approximately symmetric.

Table 1: Analysis and synthesis filters

af1	af2	sf1	sf2
0	-0.0112	0.0112	0
0	0.0112	0.0112	0
-0.0884	0.0884	0.0884	-0.0884
0.0884	0.0884	0.0884	-0.0884
0.6959	-0.6959	0.6959	0.6959
0.6959	0.6959	0.6959	-0.6959
0.0884	-0.0884	0.0884	0.0884
-0.0884	-0.0884	0.0884	0.0884
0.0112	0	0	0.0112
0.0112	0	0	-0.0112

3.4 Algorithm

The steps involved in proposed algorithm are depicted in Table 2.

Table 2 : Algorithm of Proposed Model

1. CI and SI are read and pre-processed.
2. The original image is converted to RGB planes if it is a color image.
3. Pixel Value Adjustment is performed on CI i.e., 255-15 is done, if pixel value is equals to 255.
4. **BPS**: BPS is applied on pre-processed CI and PI to get bit planes.
5. The average of MSB planes of CI is chosen for processing.
6. DTCWT is applied on the pre-processed PI after averaging of MSB planes.
7. Magnitude features are selected from DTCWT.
8. **Embedding:** The secret data is then embedded [46][47][48]. The MSB of each pixel in the payload image is extracted, and the payload image's MSB data is then embedded into the cover image.
9. Stego image is generated.

4. RESULT ANALYSIS

The steps involved in proposed algorithm are depicted as below. The result analysis [49][50][51] is described along with equations as below.

i) Mean Squared Error (MSE): MSE is represented in Equation 1.

$$\mathrm{MSE} = \left[\frac{1}{R * C}\right] \sum_{i=1}^{M} \sum_{j=1}^{N} (\mathrm{SI} - \mathrm{CI})^2 \ldots\ldots\ldots [1]$$

Here, R, and C is Row & Column.SI and CI are stego and cover image.

ii) Peak Signal-to-Noise Ratio (PSNR): PSNR in decibels (dB) is represented in Equation 2.

$$PSNR = 20\log\left[\frac{(255)}{\sqrt{MSE}}\right] \dots\dots\dots [2]$$

The result analysis is tabulated and is described as below in Table 3

Table3: Result Analysis

CI	PI	MSE	PSNR(dB)
Airplane	Asian Cat	0.0259	79.8733
Truck	Tank	0.0447	75.1226
cameraman	Barbara	0.0382	76.4812
Clock	Aerial	0.0402	76.0356
elephant	heron	0.0351	77.2247
female	couple	0.0249	80.1930
House	Boat	0.0302	78.5248
Lena	Baboon	0.0189	82.5919
Pepper	Airplane	0.0435	75.3573
Tree	jellybeans	0.0276	79.3117
Barbara	Butterfly	0.0168	83.6131
Airplane	Baboon	0.0150	84.6004

As shown in Table 3, the CI is Barbara and PI is Butterfly image. The PSNR and MSE are measured from the proposed methodology is 83.6131db and 0.0168 respectively.

The graph as shown in Figure 6 & 7 is the result analysis of Table 3 for various CI & PI; the PSNR & MSE is tabulated in Figure 6 and MSE in Figure 7 respectively.

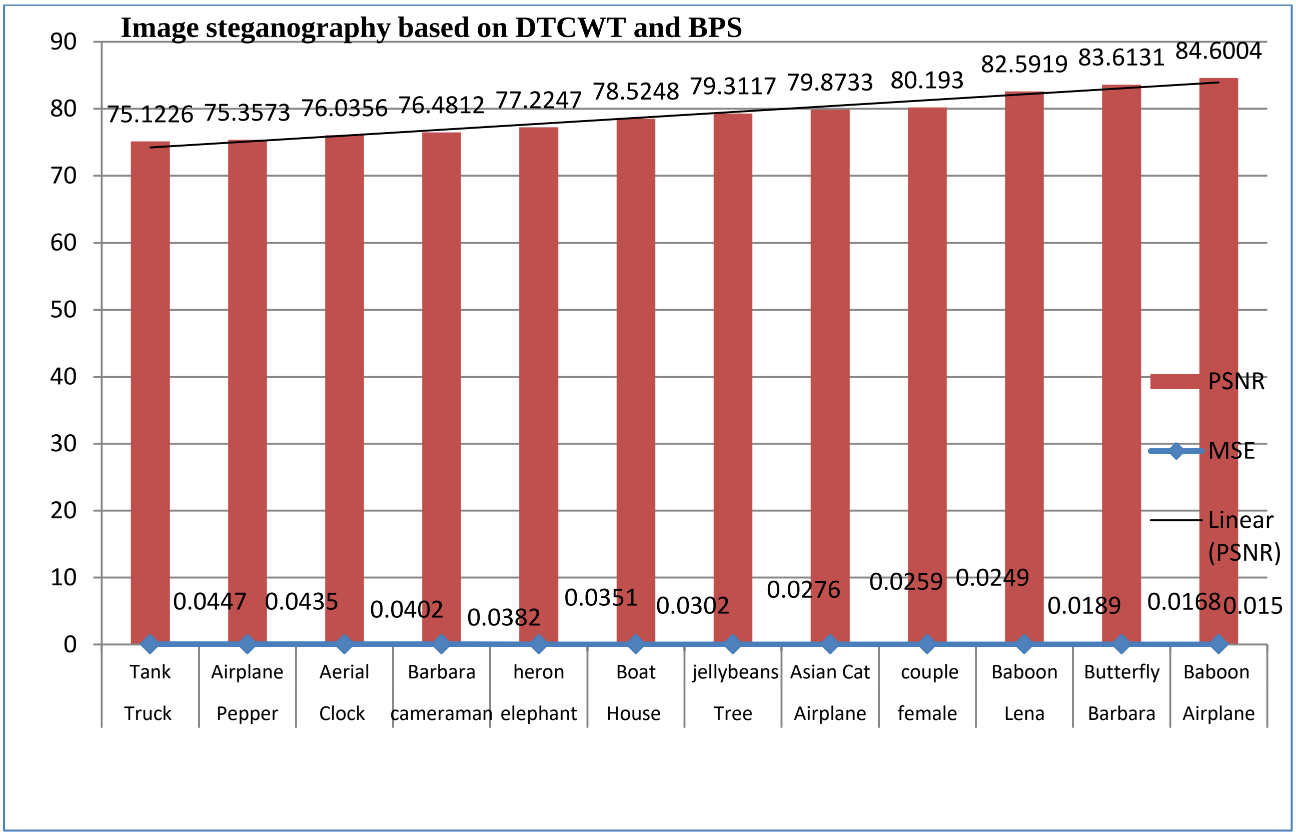


Figure 6: Result Analysis Graph from Table 3

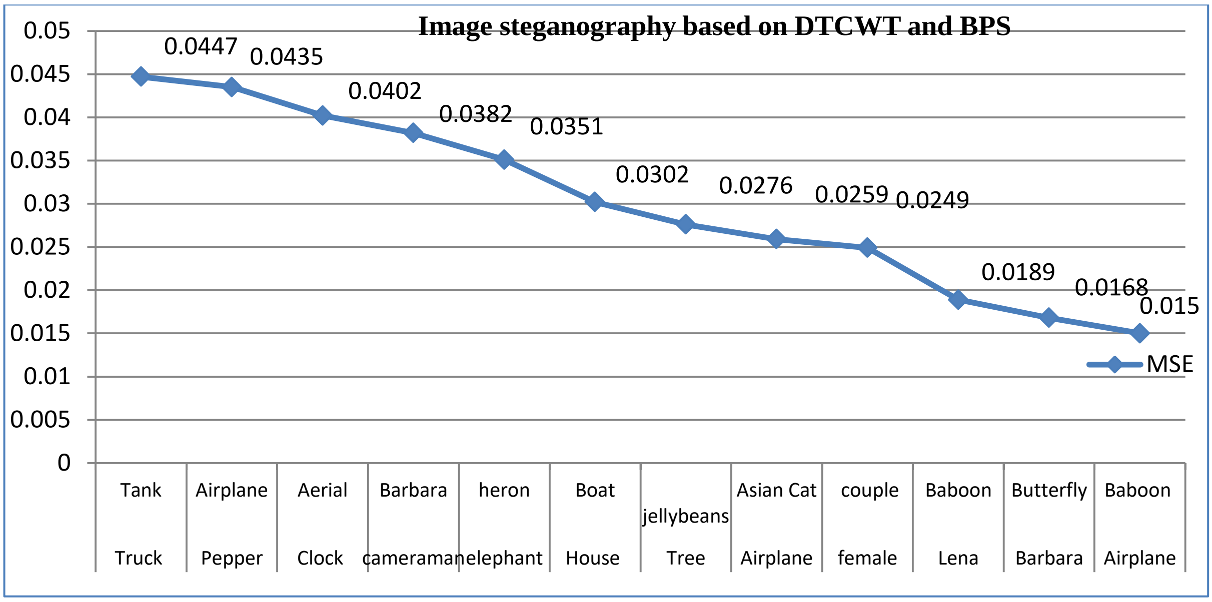


Figure 7: Result Analysis Graph from Table 3

Table 4 as shown below is the result comparison. The result as shown is MSE and PSNR. The achieved PSNR and MSE are 84.60db & 0.015 respectively.

Table 4: Result Comparison

Authors	PSNR
Ghoshal N. et al.[54]	33.20
H J Ko et al.[53]	44.0
Aya Jaradat et al.[52]	68.51
Proposed System	84.60

The result images are as shown below in Figure 7 and Figure 8: from left the cover image, payload image and stego image.

The histogram is the representation of number of pixels occurring total number of times in an image. Histogram of CI and SI of Figure 8 is shown in Figure 9 and Figure 10 respectively.

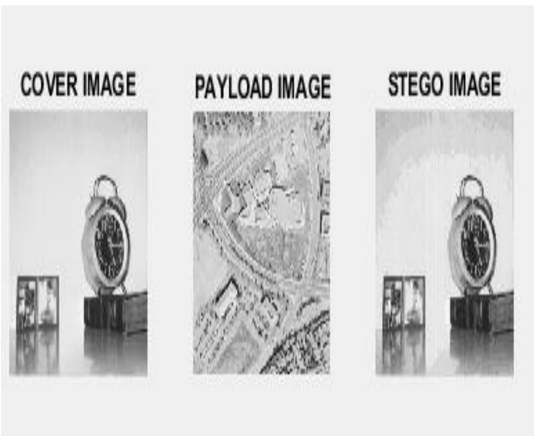


Figure 7 : Simulation Result

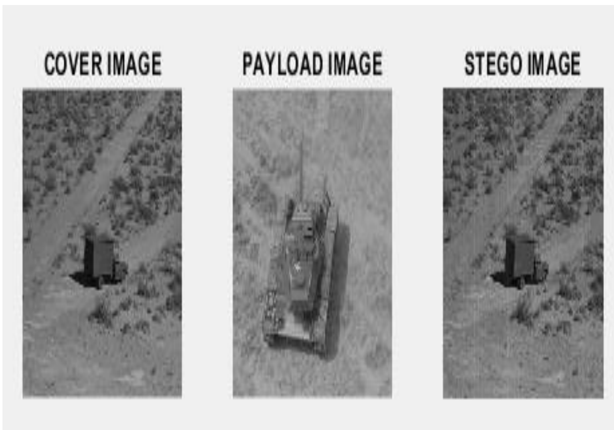


Figure 8: Simulation Result

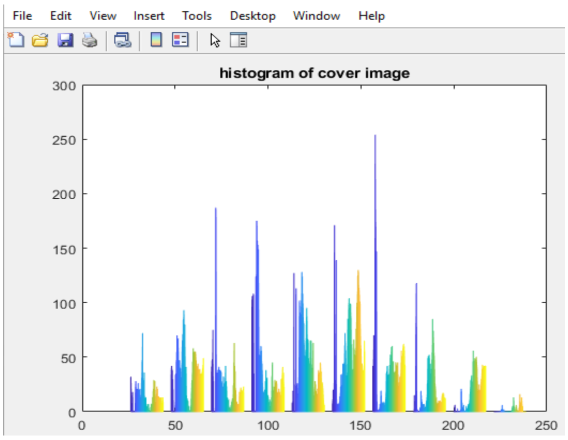


Figure 9 : Histogram of Cover image

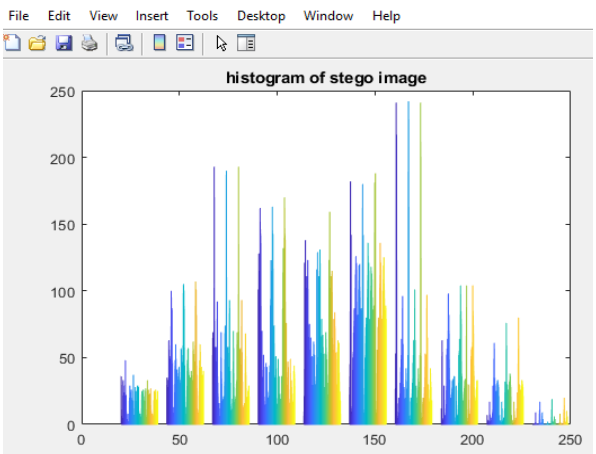


Figure 10: Histogram of Stego image

5. CONCLUSION:

The integration of Dual Tree Complex Wavelet Transformation (DTCWT) and Bit Plane Slicing (BPS) in image steganography presents a robust approach to enhancing security and concealing information within images. DTCWT as demonstrated in various studies proves effective in improving image security by steganography techniques. The method involves hiding encrypted bits in dual tree complex wavelet coefficient. Complementing this, Bit Plane Slicing (BPS) offers an additional layer of security by expressing images through the manipulation of pixel bit planes. The combination of DTCWT and BPS provides a multi-layered approach to image steganography, enhancing both the security and complexity of hidden information. Higher PSNR is achieved

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