

A Robust DWT–PVD Image Steganography for Secure Data Embedding

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DOI: <https://doi.org/10.51244/IJRSI.2026.1308000296>

Received: 31 August 2026; Accepted: 5 September 2026; Published: 23 September 2026

ABSTRACT

The purpose of image steganography, a common information-hiding method, is to embed hidden data into digital images while retaining their visual quality and preventing statistical detection. Although Discrete Wavelet Transform (DWT)-based methods improve imperceptibility by using the frequency-domain characteristics, they frequently have a limited payload capacity. Conventional Pixel Value Differencing (PVD) techniques offer high embedding capacity but may introduce noticeable distortion in smooth image regions. This study suggests a novel mshDWTPVD model that combines the benefits of the Pixel Value Differencing (PVD) method and the Haar Discrete Wavelet Transform (DWT) in order to get around these restrictions. The most suitable sub-band is selected for data embedding, followed by coefficient quantization using different quantization factors ($Q = 2, 4, 6$, and 8). The quantized coefficients are shifted to positive values, and secret message bits are embedded adaptively using the PVD technique based on pixel difference ranges. Finally, inverse quantization and inverse DWT are performed to reconstruct the stego image. Both the quantization factor and the embedding sub-band can be changed in order to evaluate the proposed model. The statistical parameters are among the objective quality metrics used to analyze performance. The proposed mshDWTPVD model achieves good visual quality, great embedding capacity and computing efficiency, according to experimental data. Additionally, the comparison analysis shows that choosing a suitable high-frequency sub-band and quantization factor substantially enhances imperceptibility while preserving strong embedding performance, making the proposed approach feasible for reliable and secure image steganography applications.

Keyword: DWT, Frequency Band, Haar Wavelet, Pixel Value Difference, Quantization Value

INTRODUCTION

With the development of digital technology, secure confidential communication has become major issue for everyone. In digital world, technologies such as cloud computing and Internet of Things (IoT), along with bank statements, medical reports, examination results, financial records, and government documents, are stored on online platforms and exchanged between one side and the other over public communication channels. Transferring secret data from one side to the other in a secure way faces many challenges [1]. Cryptography has one method used for secure information transmission, which encrypts data from its original form. During encryption, the message is protected confidentially, but increase the risk of cryptanalytic attacks. Cryptography, which hides the information, steganography is used to hide the existence of secret communication. In steganography, a cover medium is used to conceal the encrypted original data. Different types of cover media, such as text, images, audio and video can be used as a cover media to hide the secret message. With hide of secret data in cover image without disturbing its original forms [2].

In steganography, a cover medium which hides secret message. Different types of cover media, such as text, images, audio and video, can be used for secure information hiding and transmission. To overcome the

difficulties, image steganography play an important role to hiding method that conceals secret data within an cover image while preserving its visual quality [3].

Over the past years, researchers have been used to developing image steganography algorithms. Image steganography is classified by two types of domain one is spatial domain and other is frequency domain. Spatial methods having LSB, PVD and others. Based on spatial domain methods work on the differences between adjacent pixel value and give high embedding capacity. While other frequency domain based on DCT, DWT increased security by embedding data within cover image and provides superior imperceptibility and robustness by embedding secret information within frequency coefficients [4].

Existing image steganography techniques continue to face an inherent trade-off among embedding capacity, imperceptibility, robustness, and security. Several approaches optimize one or two evaluation parameters at the expense of others. With the goal to more effectively balancing these requirements, this study proposes a hybrid DWT-PVD-based image steganography technique [5]. This algorithm is specifically made to improve embedding capacity, imperceptibility, robustness, and computational efficiency while overcoming the limitations of standard spatial-domain and transform-domain steganography techniques [6].

The rest of the paper is structured in a well-formed manner. An analysis of recent advancements in image steganography is provided in Section 2, with a focus on spatial and frequency-domain, and hybrid data hiding methods. Research gaps and challenges are also defined. The proposed mshDWTPVD image steganography model, which includes Haar decomposition, secret data embedding and extraction techniques, is explained in Section 3. The experimental analysis, dataset implementation details and standard evaluation used to evaluate the proposed model are given in Section 4. The experimental results are evaluated in Section 5, with a comparison with most advanced steganography methods currently in use. Finally, Section 6 concludes the paper by summarizing the findings, highlighting the research contributions and suggesting directions for future research.

LITERATURE SURVEY

This section gives many existing research article to the proposed different techniques, with a focus on the Spatial and Domain techniques having LSB, PVD, DWT and DCT methods. This section include the different steganalyzer methods and deep learning process in image steganography. These different reviews fundamental works in LSB, PVD and DWT followed by different studies that combine PVD with DWT technique. It also illustrates recent advancements in image steganography including proposed new methods, adaptive methods, comparisons between different existing method and deep learning methods. The objective of this review is to highlight recent work by the researcher, identifying limitation and facing different challenges and establish research gap by the proposed method. The study [7] proposed a new data hiding technique, Optimal Pixel Adjustment Process, using LSB method. Using this new method reduces the MSE value and image quality is greatly increased with low computational complexity. Using pixel adjustment process on stego-image given by LSB method, image quality can be greatly increased with minimal computational analysis. Experimental results are obtained for both types of images: standard and randomly grayscale images with embedding 2 and 4 bits and illustrate that the stego image is similar to the cover image with the same quality. In [8], to improve the payload capacity, developments in deep learning-based CNN steganalysis were proposed. Experimental results show that Zhu-Net gives better result than other parameters across different payloads and steganographic schemes, while enabling input flexibility through SPP integration. The work presented by [9] introduced JPEG image filtering method based on DCT domain. This framework is used for accuracy of both types of images Grayscale as well as RGB images and offers a deep learning models. The obtained results illustrate that high visual quality, sharp edge detected and better information stored. A multidimensional image method introduced by [10] is used for JPEG images to remove the artefact and using high order MRF model to decreasing the effect of compression the image quality and preserving the same quality. This method also give the better result with low order models in terms of image quality and robustness across the compressed images. The Fully Convolution Networks introduced by [11], is extension of traditional CNNs method. In this method, replace fully connected layers with convolutional layers to generate output maps of arbitrary size. A chaos based steganographic method introduced by [12] is used a 2 D chaotic logistic map to

generate pseudo-random sequences for embedding locations. This method gives high imperceptibility and resistance to steganalysis and susceptible to geometric disturbance and image processing attacks. A hybrid image steganography technique is proposed by [13] which combines the different channels with GA method to select embedding location over the channels based on visual quality and payload capacity. The illustrated results shows that this method is used to gain maximum payload capacity, high imperceptibility and high security. The study [14] introduced a comprehensive review of the spatial, transform, CNN and GAN based image steganography. This study is to identify recent research work, advantage and challenges in digital image steganography. The finding tells that use of deep learning is increase rapidly, such as selecting domain, choosing dataset and robustness remain problems are there. The work [15] introduced a new technique named as AGFP which increase image quality with frequency domain embedding to greater imperceptibility, less robustness and less steganalysis resistance. Results gives that AGFP have balanced and secure steganographic technique, with the combination of both imperceptibility and robustness. The work [16] reviews optimization and evolutionary algorithms for image steganography. This paper firstly reviewed concepts and basic fundamentals of image steganography and then give suitable method in this field. The study [17] gives new method of RGB image steganography with focus on evolutionary algorithms, which are detected from an analytical approach. A new proposed method introduced by [18] based on High Net which is based on an invertible network frame for reversible colour image. This method optimizes information hiding and reversible process to recover the stego and cover image. This method gives fine image quality and robust extraction. Wu and Shih (2024) proposed a modified PVD-based image steganography approach using generalized quantization ranges for pixel difference values. The method improved embedding flexibility by designing adaptive range widths while maintaining resistance against statistical attacks.

To improve imperceptibility and robustness, transform-domain techniques based on Discrete Wavelet Transform (DWT) have gained significant attention. DWT technique first divides an image into four sub-bands LL, LH, HL and HH, which enables embedding more secret data in frequency coefficients with less distortion. Recent research has shown that secure data concealment can be obtained while maintaining image quality by embedding information in high-frequency wavelet coefficients. Wu et al. introduced new technique based on wavelet to increase embedding capacity while preserving image quality. This study emphasized how increasing embedding and selecting wavelet coefficients are key to maintaining image quality. Similarly, to achieve greater PSNR and SSIM values, recent DWT and PVD-based models have been developed to increase embedding capacity and better coefficient selection.

Since such techniques utilize both DWT and PVD methods have gained better results. Although PVD provides adaptive embedding based on local variations of pixels, DWT allows for frequency-domain localization and security. Optimal frequency-band selection, quantization parameter optimization, computational complexity and finding a balance between embedding capacity and image quality are some of the issues that still affect modern DWT-PVD techniques.

Therefore, the motivation of the present work is to develop an efficient DWT–PVD-based image steganography mshDWTPVD model by analyzing the effect of different quantization parameters (Q) and DWT frequency bands (LL, LH, HL and HH). The proposed approach aims to achieve an optimal trade-off between imperceptibility and embedding performance by evaluating the generated stego images using PSNR, MSE, SSIM and execution time.

Related Work

The continuous evolution of digital image steganography has led to many embedding techniques that aim to increase payload capacity while preserving image quality and security of the stego image. Among the various approaches proposed in the literature, transform-domain and spatial-domain techniques have gained significant attention due to their complementary advantages. The DWT is one of the most widely adopted transform-domain methods because it decomposes an image into multiple frequency sub-bands, enabling secret information to be embedded in perceptually less sensitive regions while maintaining high imperceptibility and robustness. PVD, in contrast, is one such commonly adaptive method in the spatial

domain that is highly effective in ensuring the optimal balance between payload and image quality through use of the intensity difference of the neighbouring pixels to estimate the embedding capacity.

The use of hybrid steganography approaches can prove to be very efficient in embedding, reducing any kind of distortion, and make the process more robust to steganalysis through the advantages of DWT in the frequency domain and adaptive embedding capacity of PVD. Figure 1 shows the types of domains in image steganography. This figure shows that there are mainly two types of domain and having techniques in this field.

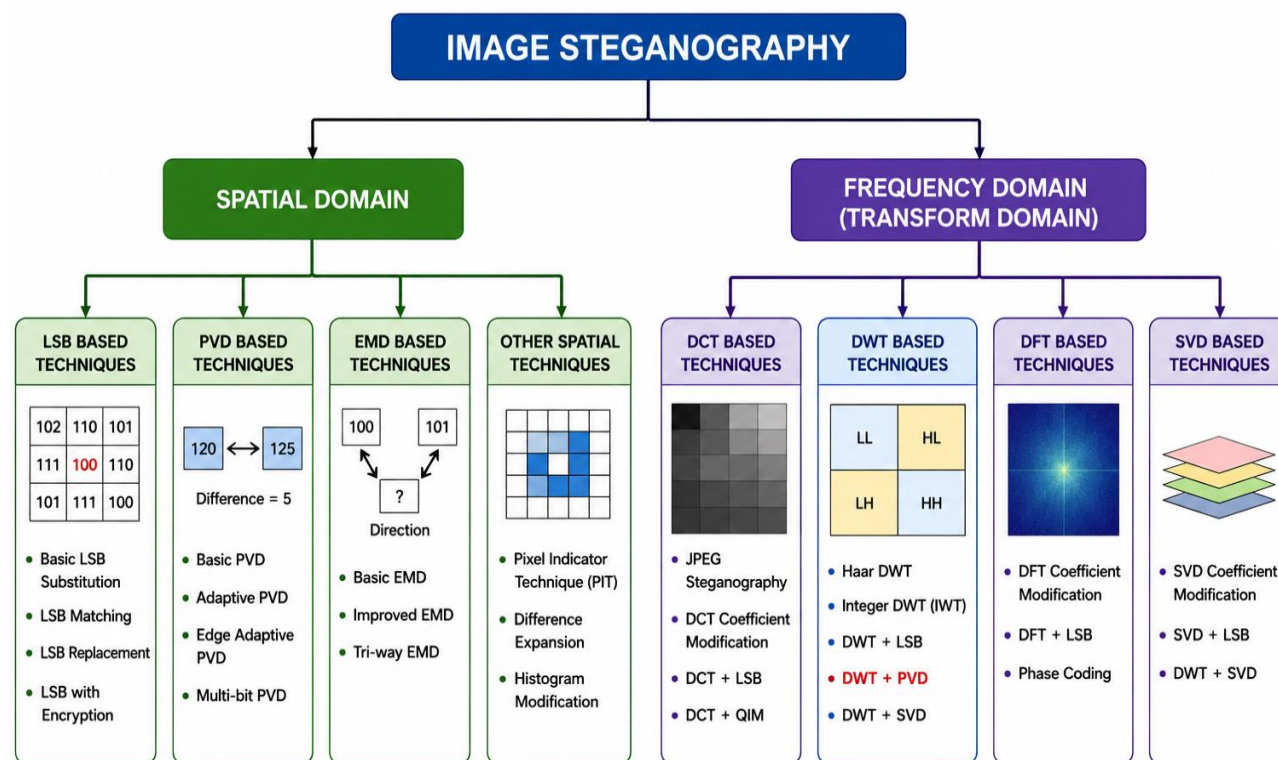


Figure 1. Classification of Domains in Image Steganography

Image Steganography Using the Discrete Wavelet Transform (DWT)

DWT provides high levels of invisibility, robustness and embedding efficiency. It decomposes a cover image into frequency sub-bands in comparison with a spatial-based approach that manipulates the pixel value of an image. One level 2-D DWT of an image results in four sub-bands LL, LH, HL and HH. The low-frequency component of the image is represented by the sub-band LL while LH, HL and HH contain high-frequency components.

However, traditional DWT-based steganographic techniques are still suffering from a number of challenges despite all the above improvements. The existing steganographic schemes have predefined embedding algorithms which cannot dynamically adapt themselves based on local characteristics of images, thus decreasing embedding capacity. In order to make the embedding more efficient but keep its imperceptible nature and security, recent studies have focused on using DWT together with adaptive spatial domain schemes such as Pixel Value Differencing (PVD). Such scheme can be considered as an area of secure image steganography due to its successful combination of the adaptability of PVD and frequency localization of DWT. Figure 2 shows the how DWT method work on RGB image.

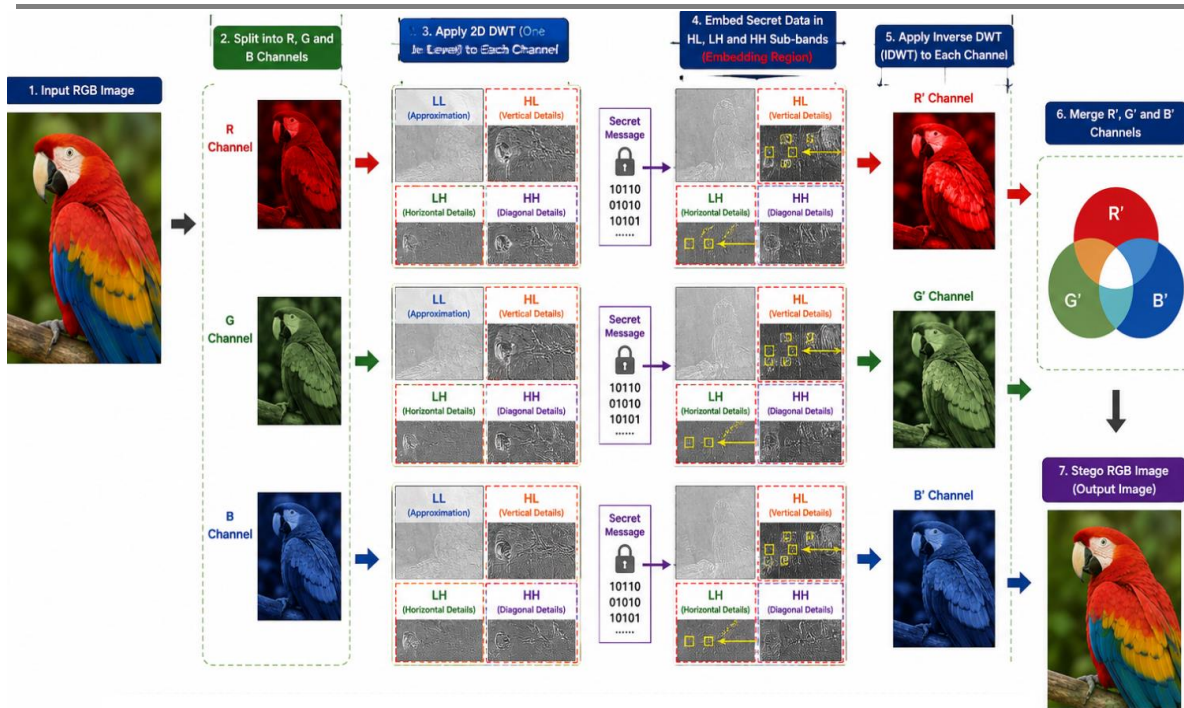


Figure 2. DWT Technique Flow Diagram.

Image Steganography Using Pixel Value Differencing (PVD)

One of the spatial domain image steganography algorithms for secure data hiding is the Pixel Value Differencing. This algorithm makes use of the difference in intensity of adjacent pixels to determine the embedding capacity adaptively, unlike the traditional Least Significant Bit (LSB) replacement approach. The basic concept of PVD was laid by Wu and Tsai. It works on the concept of manipulating the difference values between two adjacent pixels to hide secret data. The reason behind

the adoption of this approach is that changes are less noticeable in the edge portions of an image compared to the smooth portions due to human visual system characteristics. However, the smooth portions have a lower embedding capacity whereas the edge portions can accommodate a higher number of bits.

The differences between two adjacent pixels are determined and grouped according to the range table in the PVD technique. The number of secret bits that are used for embedding depends on the size of each group. The proposed scheme offers better trade-off between embedding capacity and visual imperceptibility compared to the traditional method. Using modified range tables, better pixel pair generation techniques and incorporating certain security measures, many researchers were able to enhance the PVD technique.

Though there have been many advances in recent times, the choice of embedding positions, compromises between payload and security, resistance to attacks and suitability for color images still pose unsolved problems in the existing techniques based on PVD. It is thus imperative to find an efficient technique for image steganography using RGB images through combination of transformation and smart edge selection along with PVD embedding.

Hybrid DWT–PVD Image Steganography Techniques

Researchers are investigating hybrid approaches that combine the benefits of spatial and transform-domain steganography techniques due to the drawbacks of traditional spatial-domain steganography techniques. Because it may strike a compromise between embedding capacity, imperceptibility and security, with both methods DWT and PVD has drawn a lot of interest among different hybrid techniques. The basic concept of DWT–PVD-based steganography is to combine the adaptive embedding mechanism of PVD with the frequency localization capacity of DWT.

The cover image is first converted into the wavelet domain using DWT in DWT–PVD-based methods. After decomposition, a pair having some selected frequency coefficients is made and then the difference of those coefficient values is calculated. The embedding capacity of secret bits depends upon the coefficient difference, just like in the case of classical PVD. The smaller the difference, the lower the chances of change, while the greater variance gives scope for embedding more bits.

Moreover, the use of DWT-PVD algorithms for color image steganography has been improved, as these algorithms deal with either separate RGB channels or a combination of them for the purpose of hiding information. Extra capacity for embedding has been gained because of the separate processing of R, G and B channels; nonetheless, it has been observed that there will be chromatic distortion in case of incorrect manipulation of color components.

The fusion of flexibility of PVD in spatial domain and resilience of transform-domain methods, hybrid DWT-PVD schemes provide a better result for image steganography with security. Achieving an optimal trade-off between these three factors is a challenge to be faced in the future. It is the motivation behind building advanced hybrid models for secure RGB image communication involving DWT decomposition and intelligent edge detection.

Proposed Model

The following mshDWTPVD model that depends on both DWT and PVD methods. Figure 3.1 shows the whole procedure of the proposed image steganography technique using mshDWTPVD. The process starts with choosing a cover image represented in the form of RGB, followed by decomposing this image into three components that are red, green and blue. Further apply the Haar DWT to all three images separately to form four sub-bands, including LL, LH, HL and HH. In these sub-bands, the HH is chosen for hiding data due to fact that it contains high-frequency components of the image.

After selecting the HH sub-band, quantization is performed to reduce the dynamic range of the wavelet coefficients, making the embedding process more stable and efficient. Since quantization may produce negative coefficient values, an offset is applied to shift all coefficients into the positive range before embedding. By converting the text into its ASCII representation and adding a message length to enable precise extraction, secret text message is converted into binary bits.

The secret data is concealed within the quantized HH coefficients by employing PVD technique through the proposed algorithm. As per the table of the range of PVD, the pixel pairs are generated and their differences are observed according to their embedding capacity. The required secret bits are embedded by varying the pixel pairs while maintaining the visual quality of the cover image.

The specified offset is eliminated when the embedding process is complete and reverse quantization is used to recover the coefficients. The final stego image with the hidden data is created by reconstructing the RGB image using the inverse Haar Discrete Wavelet Transform (IDWT). The same steps are conducted in reverse during extraction. The stego image is decomposed using Haar DWT, the HH sub-band is quantized and shifted, pixel pairs are analyzed using the same PVD range table and the embedded binary data are extracted and converted back into the original secret message. Finally, the proposed method is evaluated using objective image quality and embedding performance metrics such as PSNR, MSE, RMSE, SSIM, entropy, correlation, NCC, payload capacity, bits per pixel (BPP), embedding rate and execution time to verify the imperceptibility, robustness and embedding efficiency of the proposed steganography framework. Figure 3 shows the proposed mshDWTPVD image steganography model. In this model, we take RGB cover image then apply DWT process after then PVD apply to hide the secret message.

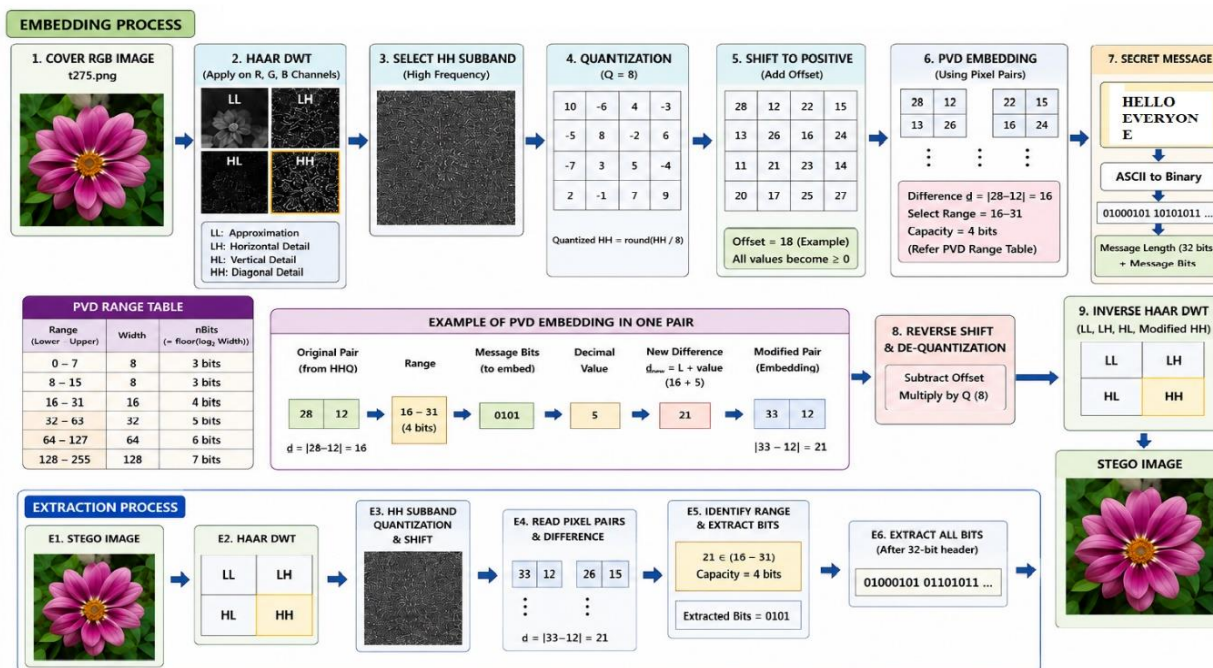


Figure 3. Flow Diagram of the Proposed mshDWTPVD Image Steganography Algorithm.

Experimental Evaluation

The proposed mshDWTPVD model was evaluated using various quantitative parameters to analyze the imperceptibility, distortion level, computational efficiency and effect of frequency band selection. The experiments are conducted on a set of standard test images, which are given below in table 1 and the effectiveness of the proposed approach is measured using PSNR, SSIM, MSE, execution time and different DWT frequency bands. Additionally, the quantization parameter (Q) was observed by this model. Figure 4 shows the cover image dataset, which is taken from BOSS data set and on MATLAB 2015 (R) having size 256×256 .

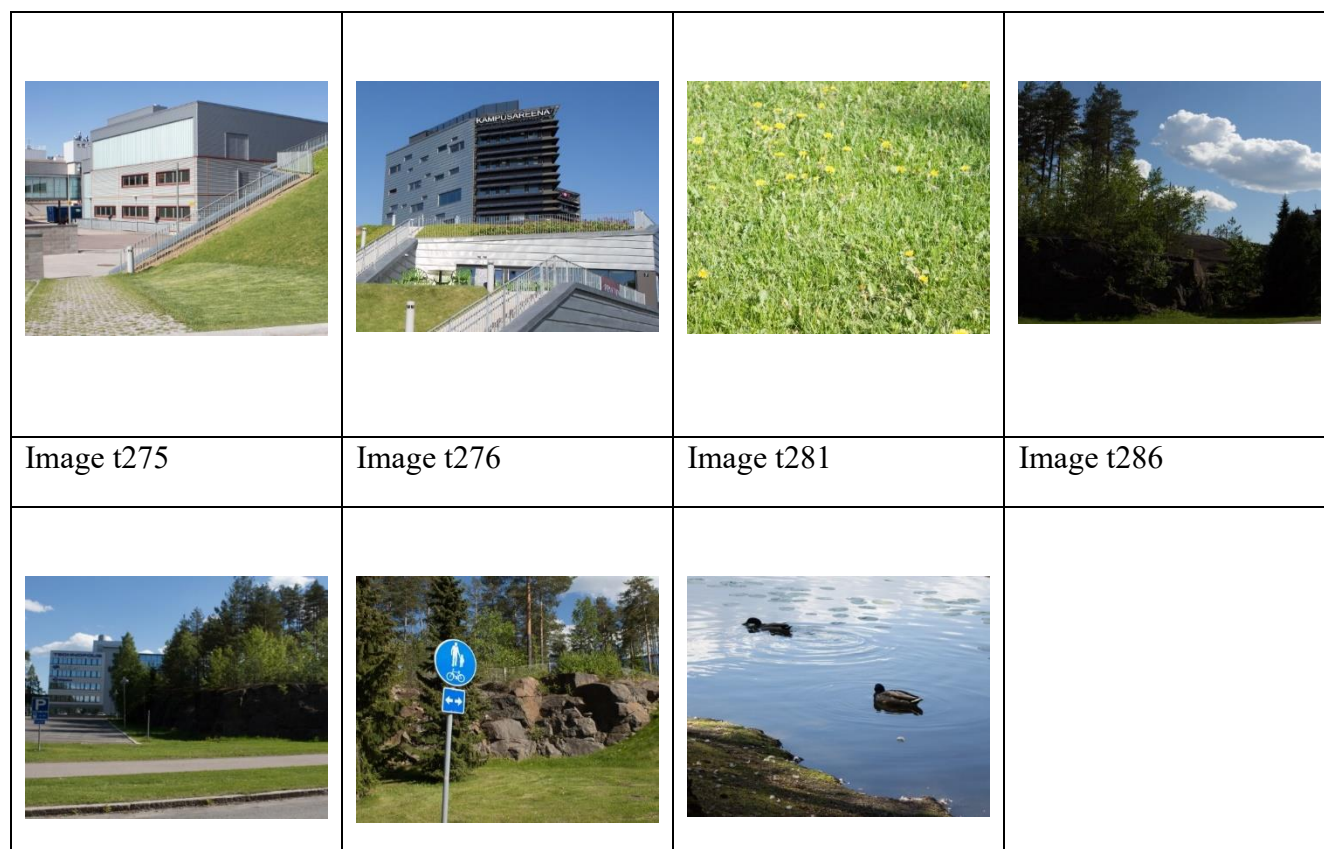


			
Image t287	Image t288	Image t298	Image t300

Figure 4. Cover Image Data Set

Quantization Parameter (Q)

The quantization parameter controls the strength of modification during the data embedding process. In the proposed mshDWT-PVD model, the value of (Q) determines the quantization interval used for modifying transform coefficients. A smaller value of (Q) results in smaller coefficient modifications and provides better image quality, whereas a larger value increases the embedding capability by allowing more significant modifications. Therefore, an appropriate selection of (Q) is required to achieve an optimal trade-off between embedding capacity and image imperceptibility.

Peak Signal-to-Noise Ratio

PSNR used for evaluating image quality of both cover and stego image. It measures the ratio between the maximum possible signal power and the distortion introduced after data embedding. A higher PSNR value indicates lower distortion and better preservation of image quality.

Mean Square Error

MSE is used to evaluate to average squared difference between the corresponding pixels of the cover and stego image. It represents the amount of distortion introduced during the embedding process. A lower MSE value indicates minimum modification and better image preservation.

Structural Similarity Index Measure

SSIM evaluates structural similarity between cover and stego images by considering contrast and structural information. Unlike PSNR and MSE, SSIM provides a perceptual measurement that corresponds more closely to human visual perception.

Execution Time

The proposed algorithm's computational complexity is represented by its execution time. It is described as the entire amount of time needed to complete the embedding process, which includes the development of the final stego image, DWT decomposition and PVD-based data embedding.

Evaluation with Various Q Values

Using cover images and adjusting the quantization value (Q) from 2 to 8, Table 1 shows the quantitative performance evaluation of the suggested DWT-PVD image steganography algorithm. Three commonly used objective metrics PSNR, MSE and SSIM are used to evaluate the stego image quality. Combined, these evaluations assess how imperceptible the embedding process was and how much distortion was added to the cover images.

Based on the experimentally obtained results, one can conclude that for different values of (Q), the proposed model offers high visual resolution of the embedded images. There are comparatively large pixel value

variations due to the embedding operation when increasing the quantization parameter (Q). This leads to the decrease in PSNR and increase in MSE values. Due to the increased value of (Q), more embedding information is included at slight degradation of reconstructed image quality. However, the PSNR value was slightly decreased.

Moreover, the values of the SSIM for all eight test images keep close to 1 throughout the process, showing that the contrast, local luminance and structural properties of images are preserved during the embedding of secret data. Stability in the values of SSIM proves the better perceptual quality of the proposed model. Higher values of quantization give increased embedding capacity while better visual quality, smaller values give better image quality with higher PSNR and lower MSE.

Overall, the proposed model gives better visual quality while ensuring safe data embedding, high PSNR, low MSE and SSIM values. These findings show the resilience and dependability of the suggested technique for safe and high-quality image steganography.

Image Name	Q Values	PSNR	MSE	SSIM
Image t275	Q=2	47.7741	1.0856	0.9981
	Q=4	41.7413	4.3546	0.9922
	Q=6	38.1574	9.9389	0.9825
	Q=8	35.4664	18.4688	0.9696
Image t276	Q=2	47.6786	1.1097	0.9983
	Q=4	41.5755	4.5240	0.9928
	Q=6	38.0249	10.2467	0.9845
	Q=8	35.4158	18.6854	0.9794
Image t281	Q=2	45.5970	1.7921	0.9994
	Q=4	41.8940	4.2041	0.9988
	Q=6	38.9528	8.2755	0.9976
	Q=8	36.5869	14.2688	0.9959
Image t286	Q=2	47.7673	1.0873	0.9951
	Q=4	41.7837	4.3123	0.9806
	Q=6	38.2756	9.6720	0.9600
	Q=8	35.7467	17.3143	0.9357
Image t287	Q=2	48.1932	0.9857	0.9963
	Q=4	41.7033	4.3929	0.9842
	Q=6	37.9854	10.3405	0.9659
	Q=8	35.3134	19.1309	0.9434
Image t288	Q=2	47.3820	1.1881	0.9984
	Q=4	42.2667	3.8584	0.9942
	Q=6	38.9048	8.3676	0.9874
	Q=8	36.2004	15.5971	0.9779
Image t298	Q=2	47.6786	1.1097	0.9983

Image t300	Q=4	41.5755	4.5240	0.9928
	Q=6	38.0249	10.2467	0.9845
	Q=8	35.4158	18.6854	0.9794
	Q=2	47.7463	1.0925	0.9967
Image t300	Q=4	41.5355	4.5659	0.9948
	Q=6	37.9230	10.4900	0.9882
	Q=8	35.3370	19.0276	0.9784
	Q=2	47.7463	1.0925	0.9967

Table 1. Analysis of the proposed DWT-PVD model's performance under different quantization (Q) values.

Image Name	Frequency Band	PSNR	Time	MSE	SSIM
Image t275	LL	41.0640	88.0223	5.0895	0.9925
	LH	41.8510	116.8029	4.2459	0.9925
	HL	41.5381	87.2040	4.5632	0.9924
	HH	41.7413	97.8260	4.3546	0.9922
Image t276	LL	40.6773	107.7403	5.5634	0.9933
	LH	41.6582	196.0175	4.4387	0.9930
	HL	41.1352	100.0407	5.0068	0.9930
	HH	41.5755	107.2596	4.5240	0.9928
Image t281	LL	40.6773	107.7403	1.3255	0.9933
	LH	41.4871	140.7394	4.6170	0.9986
	HL	39.3748	104.6376	7.5093	0.9979
	HH	41.8940	97.0493	14.2688	0.9959
Image t286	LL	41.2620	106.8943	4.8627	0.9808
	LH	41.8190	106.0712	4.6170	0.9986
	HL	41.7155	186.9493	4.3805	0.9812
	HH	41.7837	93.6588	4.3123	0.9806
Image t287	LL	41.5071	151.9144	4.5958	0.9856
	LH	41.8412	101.0179	4.2555	0.9847
	HL	41.8451	101.8065	4.2518	0.9852
	HH	41.7033	89.8861	4.3929	0.9842
Image t288	LL	40.0421	111.0676	6.4397	0.9933
	LH	42.1313	110.9513	3.9806	0.9941
	HL	41.3203	90.8941	4.7979	0.9938
	HH	42.2667	102.3371	3.8584	0.9942
Image t298	LL	41.4174	88.712	4.6917	0.9914

Image t300	LH	41.5404	102.0712	4.5607	0.9909
	HL	41.4640	86.0257	4.6416	0.9906
	HH	41.4472	97.5873	4.6596	0.9904
	LL	40.9641	90.8214	5.2079	0.9946
Image t275	LH	41.4869	103.1826	4.6173	0.9948
	HL	41.4811	111.2735	4.6235	0.9948
	HH	41.5355	94.7604	4.5659	0.9948
	LL	40.9641	90.8214	5.2079	0.9946

Table 2: Comparing the proposed model across several DWT frequency bands.

Performance Analysis of DWT Sub-band Selection for Proposed Model

The mshDWTPVD model is compared in Table 1 using sub-bands for secret data embedding. The obtained findings show that the computational analysis and imperceptibility of the proposed model are directly affected by taking frequency sub-bands. These results show that the LL sub-band gives lower results as compared to other sub-bands. The LL sub-band gives poor image quality, while the other sub-bands give better image quality.

According to the experimental findings, the LH and HH sub-bands perform better. Taking Image t275 and selecting LH band gives greatest PSNR value, while Image t288 has highest PSNR values for HH and LH bands. Similarly, LH and HH frequency bands give lower MSE values for each image and SSIM values of stego image are very close to cover image. On the other hand, the results using the execution time parameter are shown by mshDWTPVD model also. The execution time varies from one sub-band to another sub-band.

In general, the comparative analysis proved that the proposed model can be efficiently used for embedding in high-frequency sub-bands. LH and HH sub-bands demonstrate improved transparency, minimizing distortion and improving computing efficiency among all considered sub-bands. The effectiveness of the proposed technique for secure and transparent data hiding is confirmed by high values of PSNR, low values of MSE and higher SSIM values.

CONCLUSION

The mshDWTPVD model gives large embedding capacity and better image quality by using DWT and the adaptive PVD methods. The quantization factor (Q) and the embedding frequency sub-band were varied to conduct a comprehensive performance evaluation. By decreasing embedding distortion, the experimental analysis showed that raising the quantization factor enhances image quality, leading to lower MSE and higher PSNR and SSIM values. Additionally, because changes in the high-frequency area do not affect visual perception, embedding in the HH sub-band produced better imperceptibility. This model gives high PSNR, low MSE, better SSIM, high embedding capacity and less execution time. These results, compared to traditional methods that the suggested hybrid strategy offers a better trade-off between visual quality, payload capacity and computational complexity. As a result, the proposed model is better for digital image preservation, private information sharing and secure multimedia communication.

REFERENCES

1. Yadav, V., Hooda, M., Dhaka, N. (2025). A Novel Steganography Algorithm based on Interval Type-1 Fuzzy Logic System. *Statistics, Optimization Information Computing*, 14(3), 1512-1524
2. Hooda, M.(2026).An Intelligent Security Framework Integrating Fuzzy Logic–Driven Image Enhancement with CNN for Robust Steganography. *Systems and Soft Computing*, 200514.

3. Dhaka N, Hooda M, Gill S, Yadav V. A comparative study of Fuzzy Logic Type-1, Type-2 and Gradient-based method for Edge Detection in RGB Images. *Communications on Applied Nonlinear Analysis*, 2024, no. 7S, 170–176. ISSN 1074-133X.
4. Yadav V, Hooda M, Dhaka N, Gill S. Comparative Analysis of mshedgegrayft2 and Laplacian of Gaussian Method for Edge Detection in Grayscale Images, *Journal of Computational Analysis Applications*, 2024, no. 2, 501–507. ISSN 1572-9206.
5. Lata K, Rathee S, Hooda M, Yadav V, Dhaka N. A Survey of Chaos Based Cryptography and Steganography Techniques. *Tuijin Jishu / Journal of Propulsion Technology*, 2024, X, 1-10. ISSN: 1001-4055.
6. Dhaka N, Hooda M, Yadav V, Gill S. A novel RGB Image Steganography Algorithm using Type-1 Fuzzy Logic, *Indonesian J Elec Eng Comp Sci*, 2025, no. 1, 123-133. ISSN 2502-4760.
7. Chan CK, Cheng LM (2004) Hiding data in images by simple LSB substitution. *Pattern Recognition* 37(3):469–474
8. Zhu F, Wang J, Liu G (2019) An improved convolutional neural network for spatial image steganalysis in the scenario of reuse of the stego-key. *IEEE Trans Inf Forensics Security* 14(12):3026–3038.
9. Dong W, Li X, Zhang D, Shi G (2013) Compression artifacts reduction by a redundant wavelet transform. *IEEE Trans Image Process* 22(12): 4699–4711.
10. Long J, Shelhamer E, Darrell T (2015) Fully convolutional networks for semantic segmentation. In: *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*, pp 3431–3440.
11. Kadhim IT, Al-Shamasneh TAM, Ahmad MA (2018) An information hiding technique using chaos-based image steganography. *IEEE Access* 6: 38649–38659.
12. Zhou J, Zhang X, Wang Z (2020) Channel-aware image steganography via attention mechanism and genetic optimization. *IEEE Trans Inf Forensics Security* 15: 3235–3249.
13. Jing X, Xu W, Wu Z, Liu L, Hauptmann AG (2021) HiNet: deep hierarchical invertible network for steganography and steganalysis. *IEEE Trans Circuits System Video Technology*, 31(9): 3467–3480.
14. Zhong H, Zhao Y, Luo X, Sun S (2021) Attention-guided generative adversarial networks for image steganography. *IEEE Trans Inf Forensics Security* 16:3972–3987.
15. Cevik, T., Cevik, N., Pasaoglu, A., Sahin, F., Kiani, F., & Ag, M. S. (2026). AGFP: A Deep Attention-Guided Framework for DWT-Based Image Steganography. *IET Image Processing*, 20(1), e70288.
16. H. Li and S. Yu, “A Comprehensive Survey of Deep Learning- based Image Steganography and Steganalysis,” *IEEE Access* 8 (2020): 142169–142194.
17. L. Zhang, Y. Lu, T. Li, and G. Lu, “Joint Adaptive Robust Steganography Network,” *IEEE Transactions on Industrial Informatics* 20, no. 8 (August 2024): 10156–10166
18. Wu, D. C., & Shih, Z. N. (2024). Image steganography by pixel-value differencing using general quantization ranges. *Computer Modeling in Engineering & Sciences*, 141(1), 353–383.
19. Wu, T., Hu, X., Liu, C., Wang, Y., et al. (2024). An efficient steganography scheme based on wavelet transformation for side-information estimation. *Journal of King Saud University Computer and Information Sciences*, 36, 102109.