IIETA International Information and Engineering Technology Association
Advancing the World of Information and Engineering

Ingénierie des Systèmes d'Information
Vol. 27, No. 2, April, 2022, pp. 313-319
Journal homepage: http://iieta.org/journals/isi

A Robust Color Image Watermarking Scheme Based on Discrete Wavelet Transform Domain and Discrete Slantlet Transform Technique

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https://doi.org/10.18280/isi.270215

Received: 4 December 2021
Accepted: 22 February 2022

Keywords:
information security, digital watermarking, copyright, discrete wavelet transform, discrete Slantlet transform

ABSTRACT

Watermarking is primarily used to prevent unauthorized copying of digital data by inserting a watermark as a symbol of ownership in the digital data. The purpose of this work is to increase the imperceptibility and robustness of watermarked image by utilizing the Discrete Wavelet Transform (DWT) domain and Discrete Slantlet Transform (DST) technique. In compared to existing methodologies, the strategies used in this work considerably increased the robustness, imperceptibility, and protection of the watermarked image against JPEG compression and other types of noise attacks. The proposed method's robustness was determined by comparing the image's Normalized Cross-Correlation (NCC) value before and after the watermarking operation. The proposed method increased the NCC value to greater than 0.7 and the Peak Signal-to-Noise Ratio (PSNR) value to greater than 59 decibels (dB). Additionally, the proposed approach does not require knowledge of the original image in order to extract the watermarks.

1. INTRODUCTION

Several privacy and security issues have recently emerged as a result of widespread Internet use and online data transfer; this is especially prevalent in the ownership of digital images and other digital resources published online. Numerous tools are freely available for the downloading and editing of digital images, and due to the associated security issues, digital watermarking has been considered an effective way of protecting the ownership and copyrights of such published digital images [1-3].

The process of digital watermarking involves the embedment of a unique identification signal called a watermark into digital content that can later be retrieved and used for authentication [4, 5]. The watermark can be embedded into any form of multimedia, such as images, text, or audio, to serve as the host. The embedded watermark is used as proof of ownership of the watermarked images whenever there seems to be illegal reuse of the images. Image watermarking is mainly used for three major purposes: authentication, copyright protection, and tamper recovery. Regarding copyright protection, the watermarking process is aimed at embedding the identification mark of the resource owner into the digital resource; the embedded information can be retrieved later as proof of ownership [6, 7].

Watermarking techniques could also be used to authenticate the contents of images; this involves the extraction and integration of some image features into the image such that a comparison of the digital images to the embedded data can be used to authenticate the contents during suspicion and to protect them from malicious modifications [8]. Watermarking is also used for tamper recovery; it involves the recovery of the original form of the image from the illegally altered image contents [9, 10]. Most studies on watermarking mainly focus on the authentication and tamper recovery aspects of watermarking [11, 12]. It is seen as a two-stage process where the image content is authenticated in the first stage, and if tampering is detected, the tampered regions are recovered in the second stage.

Watermarking systems come in different forms; one of the forms is robust watermarking, where the watermark is strongly embedded to withstand attacks. As a result, copyright protection is generally accomplished through the employment of powerful watermarking techniques [13]. The fragile systems for tamper detection and authentication are the second type of watermarking scheme [14]. These systems are used in times of unauthorised tampering of digital images for easy detection of the tampered regions and subsequent recovery of the damaged regions using the embedded recovery watermark.

Watermarking systems can be divided into two domains: spatial domain methods and transformation domain methods. For the transform domain methods, they rely on mathematical tools like Discrete Wavelet Transform (DWT) or Discrete Cosine Transform (DCT) for the conversion of the pixel values of the image into several correlated values; the process of embedding the watermark leaves a significant impact on the region of values within the digital image [14, 15]. The spatial domain method works at the image pixel level to watermark the signal; it's a method for the insertion of watermarked data into the chosen cover image in the spatial domain. The ultimate common method or algorithm for spatial domain watermarking is the Least Significant Bit modification (LSB). This technique changes the LSB of chosen pixels in the image [16, 17].

The goal of this paper is to protect digital data from illegal duplication by embedding a watermark in the digital data that serves as a token of ownership. Because intelligent attackers may attempt to remove the watermark from images just to use them without permission, this research aims to use DWT and DST to improve the imperceptibility and robustness of watermarked digital images against several forms of attacks.

The organization of this study is as follows: Section 2 explained the methodology of the proposed method. The results obtained from the use of the proposed scheme are discussed in section 3. Finally, the conclusion and future works is discussed in section 4.

2. PROPOSED METHOD

This section details the design of the suggested method and its evaluation in terms of imperceptibility and robustness of the watermarked color image. As illustrated in Figure 1, the proposed method consists of four primary stages: pre-processing, embedding, extraction, and evaluation. These stages are implemented in such a way that the human visual system (HVS) is considered, resulting in a higher-quality watermarked image.

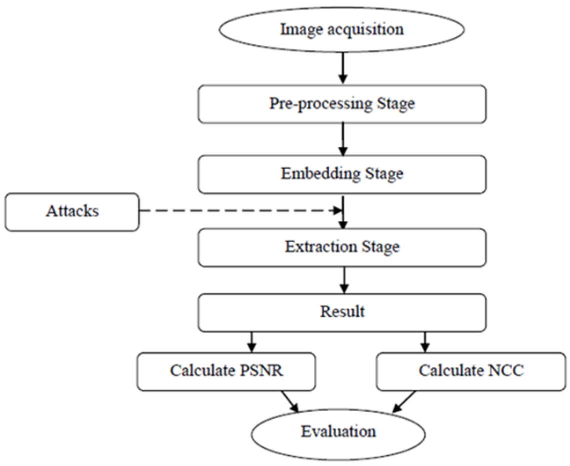

Figure 1. General stages of the proposed system

2.1 Pre-processing stage

This section explains the procedures for using the RGB (red, green, and blue) images as input data. The cover RGB image was used as an input while the output is a secret key with the best quadrant of the host image. This stage involves the partitioning of the image to demonstrate the pre-processing stage of the watermarking process (see Figure 2). This involves four main stages, which are first, reading the RGB host image; second, dividing the RGB image into three parts (Red, Green, and Blue); third, partitioning of the selected image channel into four parts; and fourth, selection of the sub-bands with low frequency for the embedment process. The following sub-section describes the process.

2.1.1 RGB image partitioning

This step is responsible for dividing the RGB cover image into three channels, which are the R, G, and B channels, to determine the best channel for embedding, as shown in Figure 3. The next process is to divide the selected channel into four quadrants so that the low-frequency sub-bands can be chosen. Figure 4 depicts the partitioning of the selected channel into four quadrants.

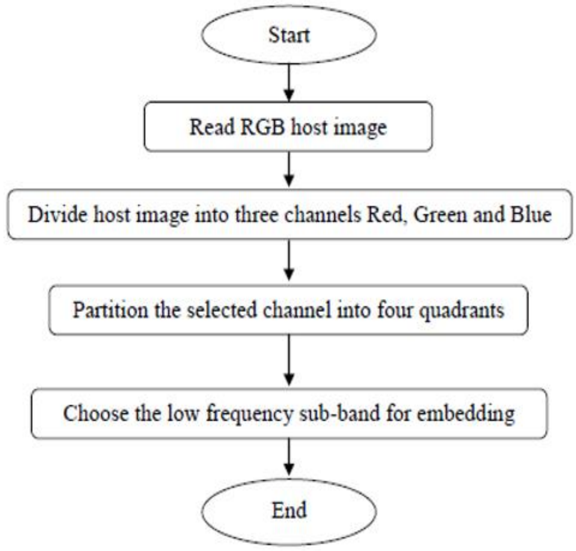

Figure 2. The pre-processing stage of the proposed study

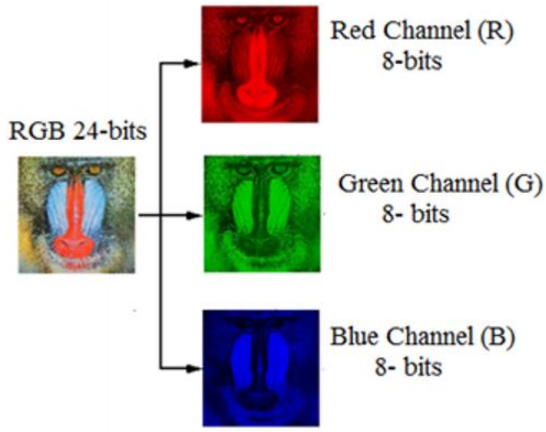

Figure 3. Dividing of RGB host image into R, G and B channels

Figure 4. Partitioning the selected channel into four quadrants

2.2 Embedding process

The embedding process consists of four stages: the commencement stage, the DST application stage, the frequency evaluation of the sub-bands stage, and finally, the application of Inverse Discrete Slantlet Transform (IDST) on the selected quadrant to create a watermarked image that combines all quadrants and channels as R, G, and B. Figure 5 illustrates the whole method for the suggested embedding technique. The following sub-sections illustrate the detailed scenario of the embedding process.

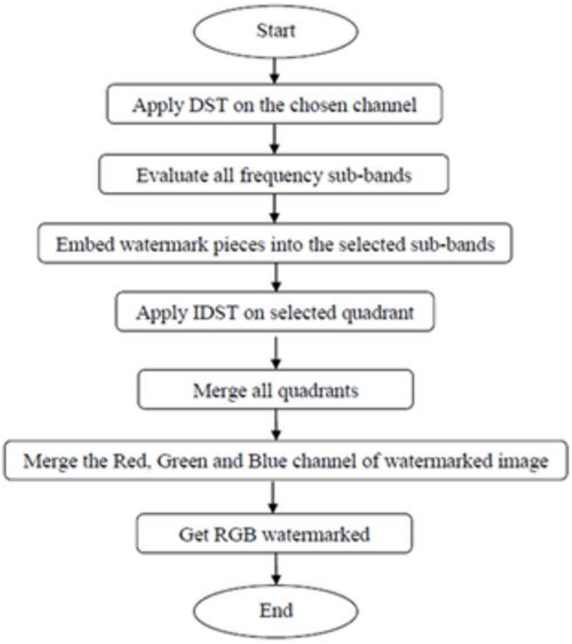

Figure 5. Procedures of the proposed embedding technique

2.2.1 DST application

The selected best quadrant is the output of the pre-processing stage, and it serves as the input during the embedding process. The proposed watermarking scheme hides a grayscale image (the BMW and UTM logos) as the watermark in the host image. Then, the best sub-band for the embedding is determined by applying a single level of 2-Dimensional lDST to the selected quadrant. For the DWT, it relies on the Slantlet filter bank (SFB), which is an orthogonal filter bank with shorter support filters compared to those of the iterated 2D filter bank tree [18]. Figure 6 shows Slantlet filter bank according to Barve et al. [18].

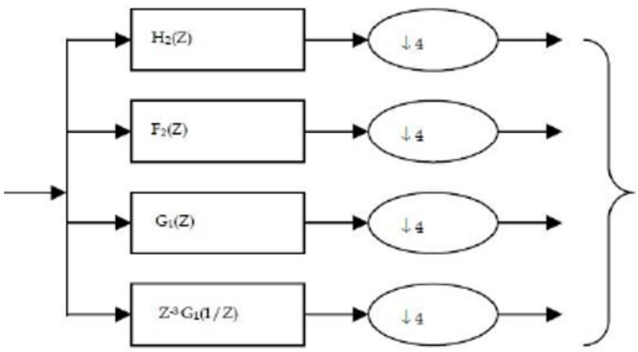

Figure 6. Slantlet filter bank [18]

The work of this filter bank is to retain the desirable attributes of the usual DWT filter bank. Figure 6 shows the SFB, which is generalised as follows: There are 21 channels in the l-scale filter bank, with the low-pass filter being called hl (n), while the one adjacent to it is called fl (n). Hence, both hl (n) and fl (n) are to be down sampled by 2l. The remaining 2l channels are filtered by gi (n) and its shifted time-reverse for i =1..., l-1, and each must be down sampled by 2i+1. Slantlet filter coefficients X (n). Each filter gi (n) in the SFB does not appear together with its time reverse. Despite hi (n) not appearing with its time reverse, it normally appears paired with the filter fi (n). Furthermore, it should be noted that the l-scale and (l + 1) scale filter banks have the filters gi (n) for i = 1... l-1, and their time-reversed versions in common. The SFB has the following features:

1) There is orthogonality of each filter bank; the analysis filter is time-reversed to obtain the filters in the synthesis filter bank.

2) For each filter bank, the scale-dilation factor is 2.

3) Multiresolution decomposition is achievable with each filter bank.

4) Improve time localization is achieved via frequency selectivity degradation.

5) The Slantlet filters are linear piecewise.

2.2.2 Evaluation of all frequency sub-bands

The spatial domain of the R channel of the cover image is transferred to the frequency domain (that is, LL, LH, HL, and HH) using the DST technique; then, 2-level DST is applied to each sub-band to achieve 16 sub-bands. This process is repeated on the G and B channels of the cover image to arrive at 16 sub-bands for each channel. The 16 sub-bands are evaluated for each channel to determine the best sub-bands for watermark embedment. The PSNR serves as the metric for the sub-bands' evaluation before the embedment process and after the extraction processes. The NCC will also be used as a metric to further evaluate the extraction process.

2.2.3 Embedment of the watermark

A watermark is normally partitioned into 4 pieces before the embedment process to ensure it is embedded more invisibly. To achieve this, each watermark quadrant pixel is first transformed to a bit stream and then into a sequence, Yi to Yn, with n being the bit stream length. So, if the watermark image has a bit value that is equal to 0's, replace the 1's. Else, retain the 1's if the bit value is equal to 1. This step aims to transform the watermark from its spatial domain into the frequency domain.

For the embedment, the watermarked image is achieved by modifying the DST coefficients. The embedment is done in the low-frequency sub-bands (LL) to achieve watermarked images with high robustness. This process is done using the formula:

$$W_i' = W_i + aY_i \tag{1}$$

where: W_i'= The watermarked image, W_i= the coefficients of the original partitioned image, Y_i= the bit of the watermarked image (-1's or 1's), α =the alpha which is the strength/power of the watermark. The actual points of watermark embedment are recorded as secret key 2; this key must be provided during the extraction process for efficient extraction and sequence arrangement.

2.2.4 IDST application

Following the embedment process, all the sub-band frequencies are assembled via the IDST application; this is aimed at the inversion of the frequency-based quadrant to the spatial-domain quadrant. All the sub-bands in the selected quadrant are reconstructed in this step using inverse DST stages. The output is the quadrant of the watermarked image after the IDST process. Figure 7 shows how to apply IDST to merge all the quadrants (LL, LH, HL, and HH) into columns and rows. The purpose of this step is that the frequency-based quadrant is inversed to the spatial domain to get the watermarked image; this process is called image reconstruction by using IDST.

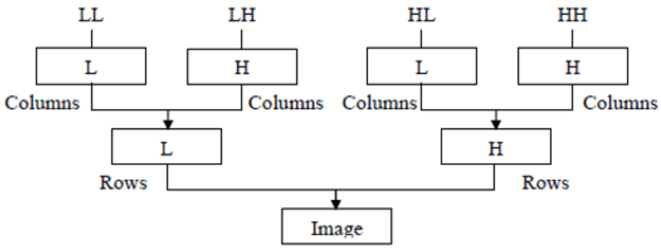

Figure 7. Image reconstruction using IDST technique

Figure 8. The process of merging of all quadrants

The watermarked image is then generated as a new B channel by combining the quadrant of the watermarked image with the other 3 quadrants. After embedding and merging all the quadrants, channel B remained the best channel in the color image. The new B channel is then merged with R and G to get the watermarked image. Figure 8 illustrates the merging of all quadrants.

After embedding and merging all quadrants, and based on the outcomes, we find out the that the best channel in colour of Baboon image is blue. The new blue channel is then merged with the red and the green ones to get watermarked images as depicts in Figure 9.

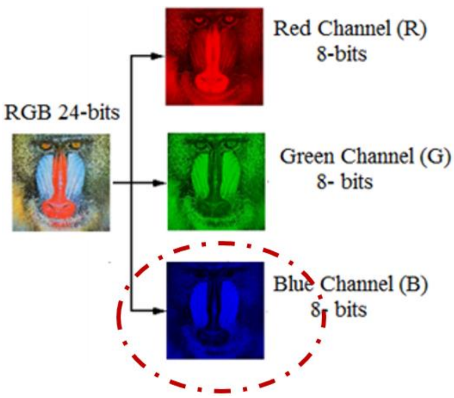

Figure 9. The watermarked image

2.3 Extracting stage

The extraction stage occurs after the suggested watermarking technique has been evaluated. The extraction method is depicted in Figure 10. The watermark extraction procedure is described in detail in Algorithm 1.

1) Divide the watermarked image into three channels: R, G, and B.

2) Divide the watermarked image's selected channel into four quadrants.

3) DST is applied to the quadrant specified in the received secret key 1.

4) Extract the low-frequency sub-bands (LL).

5) Utilize the relation to extract the watermark elements from the selected sub-band based on their actual locations:

$$Y_i = (W_i' - W_i)/\alpha \quad (2)$$

where: Y_i = Watermark that is extracted, W_i' = watermarked image coefficients, W_i = Partitioned original image coefficients, α = the watermark image's strength.

1) Inverse the watermark image from the frequency-based domain to the spatial-based domain to get the bit stream.

2) Merge all the watermark pieces in the proper sequence as revealed in the secret key.

3) Convert the image from the frequency-based domain to the spatial-based domain by applying IDST on the selected quadrant.

4) Combine all the image quadrants.

5) Get the host image by merging all the channels.

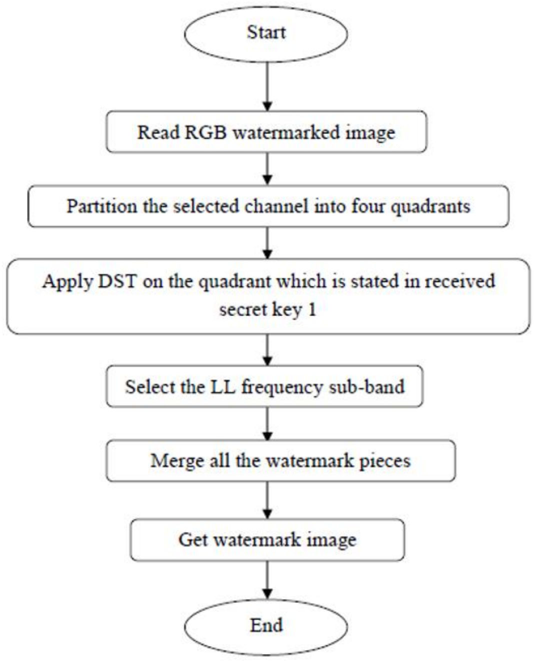

Figure 10. The extraction process of the proposed method

3. RESULT AND DISCUSSION

To implement the proposed system, the standard dataset SIPI images such as Lina, Baboon, Pepper, Tiffany, Airplane, and others were used as host images, while the grayscale BMW and UTM logos were used as the watermark images for embedding.

3.1 Attacks and evaluation

The level of robustness of the watermarked image was tested by subjecting the image to various kinds of attacks. The test results on the selected types of attacks (Poisson noise, salt and pepper) are detailed in the following subsections.

3.1.1 Poisson noise attack

A Poisson noise attack is a statistical noise in which the probability density function is the same as the normal distribution; it is also called the Poisson distribution. Figure 11 presents the results of Lina and Baboon dataset images evaluated by applying the Poisson noise attack; the figure shows the image before and after the attack. After applying Poisson noise, the image watermark showed through the extracted images, indicating no deterioration and the robustness of the extracted image against attacks.

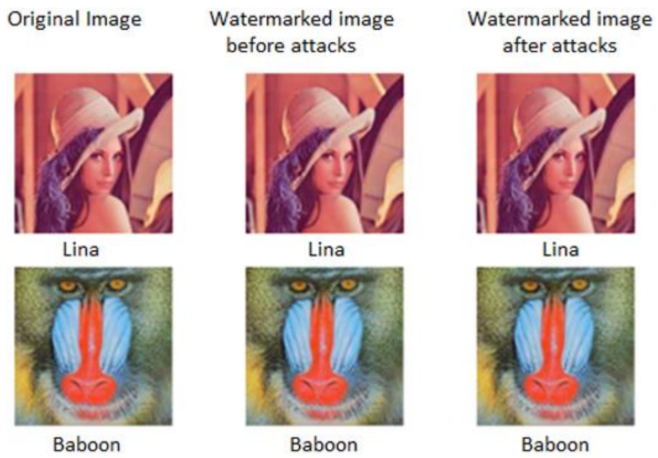

Figure 11. Applying Poisson noise attack on the Lina and Baboon images

3.1.2 Salt and pepper noise attack

The Salt and Pepper noise attack is a type of impulsive noise in which the random picture pixel value is set to either 0 or 255. When this noise is applied to an image, it results in black and white flecks in the image, as illustrated in Figure 12. (Images before and after applying salt and pepper attack). The results indicated that the picture watermark is resistant to attack and is recoverable following many attacks [19]. A robust watermark is expected to be resistant to harmful and non-harmful alterations without severely altering the image.

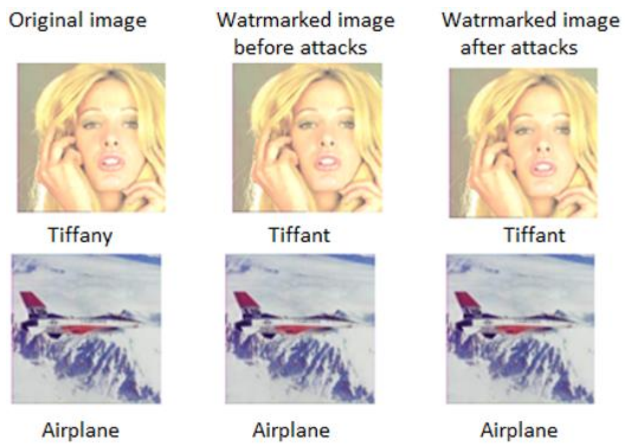

Figure 12. Application of salt and pepper attack on the Tiffany and Airplane images

The robustness of the retrieved watermark was assessed in the best quadrant in this investigation. The retrieved watermark was subjected to Gaussian, salt, and pepper attacks, with the NCC value calculated both before and after the attacks. The NCC values determined for each image are shown in Table 1; clearly, the most severe attacks were Poisson attacks, since their NCC value was 0.7. For the salt and pepper attack, the extracted watermark had the highest NCC value. These findings indicated that the applied attack (salt and pepper attack) distorted the retrieved watermark, as the extracted watermark was unrecognizable despite the high NCC value. The extracted watermarks for all the photos had NCC values near 1 following the attack; this demonstrated the suggested method's robustness in embedding the watermark in the cover image, as the extracted and original watermarks are highly similar. Additionally, the NCC value of the retrieved images grew in direct proportion to the alpha value.

3.2 Research implementations

This section describes the research implementations that have been made to the proposed scheme; Table 2 summarizes the PSNR values obtained for the selected images using the proposed embedding method. The blue channel of the cover image was converted from a single private to four frequency domains (LL, LH, HL, and HH) using the DST method, and each sub-band was then converted to 16 sub-bands using two-level DST. However, the 16 blue channel sub-domains were examined in order to choose the most suitable sub-domains for the watermark. PSNR was utilized to determine the quality ratio between the original host image signal and the watermarked image following DST application.

The experimental findings indicate the proposed approach's strength for the remainder of our data set. The results in Table 2 indicate that the best image is that of Lina in the LL quarter, with a value of 58.97dB, whereas the best image is that of the Baboon in the LL quarter, with a value of 44.58 dB. The best value for the Pepper image on the LL quarter was 36.95 dB. Similarly, in the LL quadrant, the best values for Gold hill and sailboat images were 47.97 dB and 48.92 dB, respectively. Similarly, in the LL quadrant, the best Tiffany and Airplane image values were 54.32 dB and 44.58 dB, respectively. Finally, the Lighthouse and Barbara images had the best values in the LH quadrant, with 56.31 dB and 50.66 dB, respectively.

The results indicated that the optimal value for embedding in the LL quarter had a PSNR more than 30 dB, which is highly encouraging. As a result, the proposed approach demonstrates excellent imperceptibility.

Figure 13 illustrates the plot of PSNR versus colour channel quadrant for all the dataset images. Each image has its colour level and PSNR value divided into quarters (LH1, LH2...), ranging from high to low ratio. As shown below, the highest PSNR value was 59.97 dB in the LL4 Lina image while the lowest PSNR value was 31.51dB in the LH2 Pepper image.

The outputs of the proposed system have been developed and compared with existing studies to test the system. Furthermore, we have selected the most relevant references and compared our results with them. Fortunately, the results of the proposed system significantly outperformed the results of previous studies, and this means the success of the proposed system. In this paper, we have tested the robustness of the proposed system using the most important evaluation metrics which are peak signal to noise ratio (PSNR) and standard cross-correlation (NCC). The main reason for choosing these two metrics is related to the main key issues of digital watermarking (robustness, payload capacity, security, and imperceptibility), and robust watermarking, whereby a watermark is robustly built in to withstand different types of attacks.

Table 3 shows the results of the comparison made with previous studies as shown by the proposed study. It also shows the improvement in the results of the proposed system compared to the previous research results.

Table 1. The NCC results for selected images

#	Image	NCC after Poisson attack	NCC after Salt & Pepper attack
1	Lina	0.7300	0.9760
2	Baboon	0.6560	0.9805
3	Pepper	0.6723	0.9724
4	Gold hill	0.6830	0.9925
5	Airplane	0.624	0.943
6	Tiffany	0.662	0.981
7	Barbara	0.623	0.965
8	Lighthouse	0.635	0.953
9	Sailboat	0.5960	0.964

Table 2. The obtained PSNR of the selected images

	Lena	Baboon	Pepper	Goldhell	Sailboat	Tiffany	Airplane	Lighthouse	Barbara
LH1	52.62	36.28	32.99	37.90	38.62	52.08	44.11	45.67	43.63
LH2	50.55	40.81	31.99	39.87	37.22	44.92	46.70	56.31	50.66
LH3	51.98	37.28	33.14	42.54	41.18	52.56	51.04	47.16	46.66
LH4	50.38	41.59	32.50	42.15	39.33	50.32	48.27	39.07	49.14
HL1	45.60	37.18	32.28	39.73	38.88	42.49	43.51	37.62	44.98
HL2	47.58	37.13	32.73	42.11	38.60	48.32	48.62	42.47	48.40
HL3	47.65	41.80	31.51	42.58	40.10	49.39	46.79	37.40	43.86
HL4	51.65	41.87	32.51	45.16	42.81	49.65	48.68	41.95	45.45
LL1	53.38	37.57	36.59	46.98	42.60	52.36	52.36	53.21	49.40
LL2	49.08	41.62	35.34	43.52	41.28	51.20	50.61	42.98	50.37
LL3	54.18	41.62	36.74	47.93	48.92	54.32	53.59	47.27	47.38
LL4	58.97	44.58	35.60	47.10	42.48	51.10	50.43	42.02	47.77

Table 3. Benchmarking of the proposed method with the existing methods

Image	Proposed study		Kong and Peng [8]		Zhou et al. [9]	
	PSNR	NCC	PSNR	NCC	PSNR	NCC
Lina	59.97	0.9660	50.73	0.9242	58.79	0.9271
Baboon	45.88	0.9705	45.46	0.9018	44.58	0.9621
Lighthouse	57.41	0.9430	49.82	0.8902	56.31	0.9018
Tiffany	55.61	0.9810	32.79	0.7933	54.32	0.9771
Airplane	54.69	0.9430	45.27	0.8375	53.59	0.9982

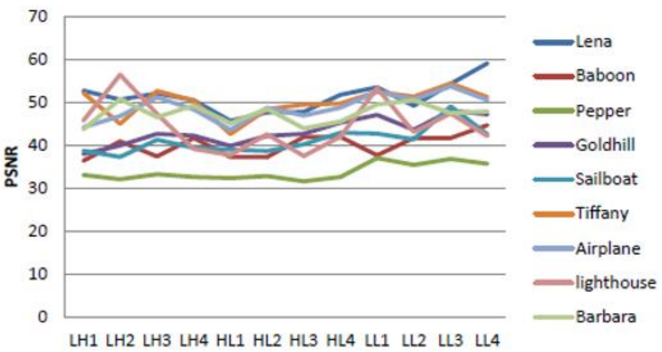

Figure 13. The plot of PSNR vs. Color channel quadrant

4. CONCLUSION AND FUTURE WORKS

The purpose of this paper is to suggest a method for embedding a BMW and UTM logos image into a color image in order to address the three key issues of unlawful intellectual property rights, data integrity, and unauthorized duplication and dissemination of digital data. By employing the DST embedding procedure, the proposed watermarking system performed admirably. The robustness and imperceptibility of the system were determined by testing the watermarked image against two typical attacks: Poisson noise, and salt and pepper. In addition, the security of the watermarked image has been checked for resilience against various attacks. Consider the following factors when reviewing the proposed work:

1) Evaluation of the relationship between the cover image and the watermark in certain cases, such as in situations where both the watermark and the cover image are horizontal.

2) Determination of the best possible watermark image frequency between the low and high frequencies such that the watermark can be embedded on both low & high-frequency images. The imperceptibility of the watermark image can also be improved by ensuring a careful distribution of the pixels of the image and the watermark using efficient algorithms.

3) Conducting experiments with various image formats, such as BMP (bitmap), JPEG (Joint Photographic Experts Group), and TIFF (Tagged Image File Format) to achieve better results.

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