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Image Steganography in Wavelet Domain

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ABSTRACT

Steganography is the science of hiding secret data within any kind of medium such as image, video, audio and document. The two main category of image steganography are spatial-based embedding and transform-based embedding. In this paper an image steganography method in transform domain is proposed, which is based on discrete wavelet transform and a canny edge detection technique. The proposed method is an attempt to increase amount of embedded data into cover image and improve quality of stego image. The least significant bit substation is used as an embedding method.

KEYWORDS: Steganography, Canny, Stego image

1. INTRODUCTION

Steganography is literally meaning 'covered writing'. Steganography is the practice of hiding messages in such a way that no one knows the presence of messages except the sender and the recipient [1]. Steganography techniques are used to address digital copyrights management, protect information, and conceal secrets [2].

Hiding information consists of two main phases: An embedding phase and an extracting phase. All the previous proposed techniques can be classified into two major domains: spatial-based embedding and transform-based embedding. In spatial-based techniques, the main idea is to alter pixels' value of cover image to embed secret data in order to get stego-image. The simplest and the most common embedding method is the least significant bit substation (LSB) [3], as the least bit in pixel value is replaced by a bit from secret message. While in transform domain, the main idea is to embed the secret data in cover image coefficients. In order to get image's coefficients, the cover image is converted into frequency domain by one of transformation techniques such as discrete cosine transform (DCT), discrete wavelet transform (DWT), etc.

In this paper a method for data hiding in transform domain is proposed. It is based on DWT as it has its own excellent space frequency localization property [4] and Canny edge detection. The paper is organized as follow: In Section 2 the related work of steganography is briefly reviewed. The proposed method is described in Section 3. Experimental results are given in Section 4. Section 5 concludes the paper with directions for future work.

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2. RELATED WORK

In this section, previous steganography techniques are reviewed. Chi-Kwong Chan et al. [3] proposed a simple data hiding technique in spatial domain using LSB substitution. The optimal pixel adjustment process (OPAP) was then applied to improve quality of stego image with acceptable embedding capacity.

An embedding method based on human vision sensitivity to gray value variations is proposed in [5]. Cover image is divided into non-overlapping blocks of two pixels. The difference between the two pixels is calculated and a pixel-value differencing (PVD) method is used to distinguish between edged areas and smooth areas. The embedded bit length in edged areas is larger than the embedded length in smooth areas due to the human vision sensitivity. To increase the amount of bits embedded in smooth areas, the LSB scheme is used with fixed size in [6] and PVD is used in edged areas to determine the length of embedded bits.

A DWT method for image steganography is proposed in [7]. The image is decomposed using Haar wavelet transform and then, high frequency coefficients are modified using a pseudo-random number that is added to the coefficients when secret bit is equal to 0. This method preserved the visible quality of original cover image after extraction of embedded data.

Leng et al. [8] proposed a block based data hiding technique. The image was divided into 4×4 non-overlapping blocks. The length of embedded bits for each block was set based on which length of replaced LSBs will result in minimal distortion. This method increased embedding capacity with high image quality.

H.S. Reddy et al. [9] proposed a wavelet based non LSB steganography algorithm. The cover image was divided into 4×4 blocks and integer wavelet transform

IWT/DWT was then applied to the sub-bands. The secret bits were divided into sequence of pairs and manipulated with 2×2 sub-bands of IWT/DWT. This method achieved better results for peak signal to noise ratio (PSNR) in case of using IWT instead of using DWT.

S. Jayasudha [10] proposed a data hiding scheme using integer wavelet transform and optimal pixel adjustment algorithm (OPA). The image is divided into 8×8 non-overlapping blocks and the integer wavelet transform (IWT) is then applied to each block. According to hiding capacity function different numbers of bits are embedded in a randomly selected high frequency coefficient. This method reduced the error between original coefficients and the modified coefficients and increased hiding capacity.

L. Chang et al. [11] proposed a simple data hiding method based on Haar discreet wavelet transform (HDWT). The image was divided into 8×8 sub-blocks and each block was decomposed using HDWT. The LSB method was used in the embedding process of secret message stream and the length of embedded bits was determined by a data hiding capacity function.

3. PROPOSED SCHEMA

3.1 Preprocessing

After the embedding process and applying the inverse transformation, some pixels values become smaller than zero or larger than 255. To avoid that situation which is known by underflow/overflow case, an adjustment step is needed to overcome this situation. A histogram modification step [11] is applied to the cover image before starting the embedding process and it is given as:

$$\boldsymbol{p'(i,j)} = \begin{cases} \boldsymbol{p(i,j) + \frac{n}{2}}, & \boldsymbol{if p(i,j) \leq \frac{n}{2}} \\ \boldsymbol{p(i,j) - \frac{n}{2}}, & \boldsymbol{if p(i,j) \geq 255 - \frac{n}{2}} \end{cases} \quad (\mathbf{1})$$

where $p(i,j)$ and $p'(i,j)$ denote the pixel value before and after histogram adjustment, respectively and n is the adjustment factor which was set to 30.

After adjustment, DWT is applied on the cover image. The HL, LH and HH sub-band blocks of the transformed image are used to hide the secret bits while the LL sub-band block is used to store the information required for the embedding and extraction processes. The LL area represents the smooth image of the original image which contains the most information of the original image [12]. The canny edge detector is considered an optimal edge detector, as it minimizes the distance between the detected edges and actual edges and minimizes detecting false edges. So, canny edge detector is applied to the LL sub-band image to get the edge image.

3.2 Embedding process

The edge/non-edge information and the set partitioning in hierarchical trees (SPIHT) [13], which are illustrated in Figure 1, are used to find out the type of the descendent coefficients in the three sub-band blocks which are HL, LH and HH.

After applying the edge detector on the LL sub-band, suppose that the coefficient b is defined as an edge/non-edge, the four descendent coefficients (b1, b2, b3 and b4) in HL sub-band are then defined as edge/non-edge coefficients.

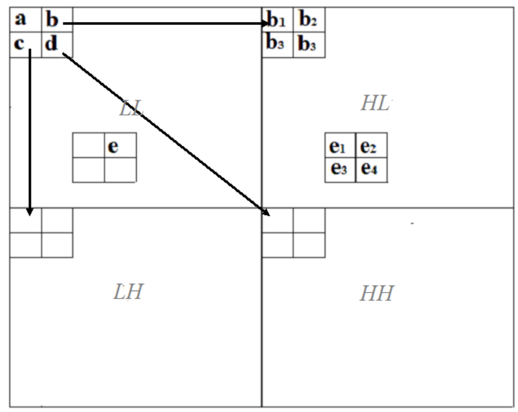

Figure.1. SPIHT Data Structure

LL sub-band is divided into 2×2 non-overlapping blocks. The top left coefficient in each 2×2 block remains unchanged, while in Leng et al., [8] it is used for storing the length of embedded bits in the edges, as it used different length of the embedded bits in the edges according to which length gave the minimum mean square error between cover and stego-image. The other three coefficients are used to store the type of the four descendent coefficients as if they are edge/non-edge coefficients as in Leng et al. [8]. If coefficient **b** is a non-edge coefficient then the LSB of coefficient **b** is replaced by '0'. If coefficient **b** is an edge coefficient then the LSB of coefficient **b** is replaced by '1'.

A 2×2 block is taken out from the LL sub-band and its corresponding coefficients in the other three sub-bands as an example illustrated in Figure 2. Let *x* be the number of non-edge embedded bits which is set to '1' and *y* is the number of edge embedded bits which is set to *x*+1.

In the 2×2 LL sub-band block, the top left coefficient $(213)_{10}$ remains the same and the other three coefficients are used to indicate the type of descendent coefficients in the other three sub-band blocks. The edge/non-edge information is stored in the LSB of each coefficient in the 2×2 block as follow:

$(213)_{10}$ has no change.

$(227)_{10} = (11100011)_2$ is defined as edge coefficient so, its LSB is replaced by '1' and become $(227)_{10} = (11100011)_2$.
$(234)_{10} = (11101010)_2$ is defined as non-edge coefficient so, its LSB is replaced by '0' and become $(234)_{10} = (11101010)_2$,
$(223)_{10} = (11011111)_2$ is defined as an edge coefficient so, its LSB is replaced by '1' and become $(223)_{10} = (1101111\underline{\mathbf{1}})_2$.

The coefficients in the 2×2 descendant block of the coefficient $(227)_{10}$ are considered as edge coefficients. Also the other 2×2 descendant blocks in the LH sub-band blocks are considered as non-edge coefficients and the 2×2 descendant blocks in the HH sub-band blocks are considered as edge coefficients.

Let the secret message is '**00111011001100111011**', the embedding process starts from the 2×2 descendant block in the HL sub-band block. Since the coefficients in that block are defined as edge coefficients, two bits of the secret message will be embedded in each coefficient.

The value of the first coefficient is $(-2)_{10}$ which is a negative value so the two's complement is computed which is equal to $(11111110)_2$. The first two bits to be embedded are '00', so the coefficient's two's complement is replaced by $(111111\underline{\mathbf{00}})_2$, then the two's complement is computed again to get the final coefficient value which is $(-4)_{10}$.

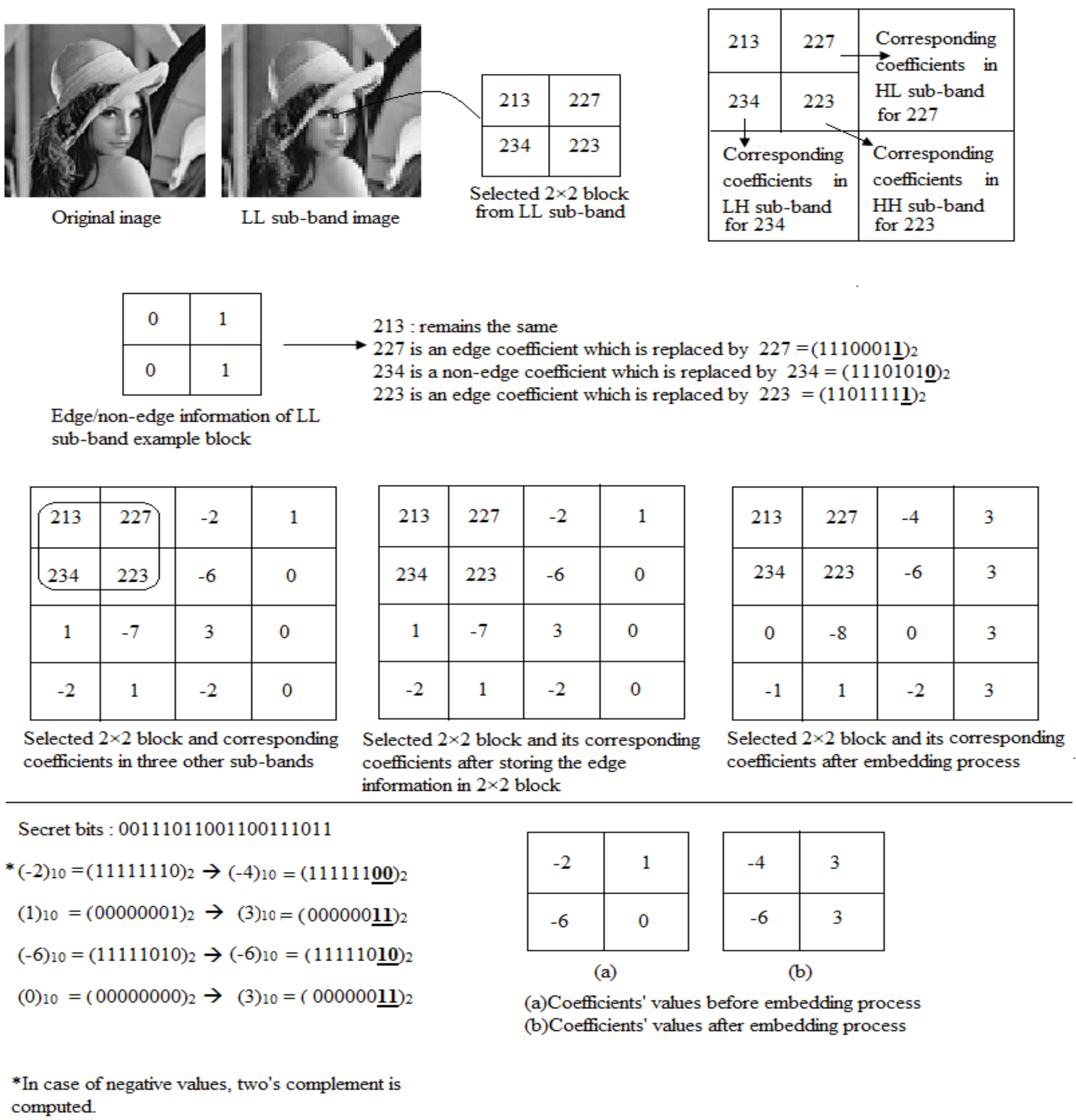

Figure.2. Embedding process example

The second coefficient is $(1)_{10} = (00000001)_2$ and the following two bits to be embedded are '11', so the coefficient is replaced by $(3)_2 = (000000\underline{\mathbf{11}})_2$.
The third coefficient is $(-6)_{10}$ and the following secret bits are '10', so the coefficient is replaced by $(-6)_{10}$. The fourth coefficient is $(0)_{10}$ and the following secret bits are '11', so the coefficient is replaced by $(3)_{10} = (000000\underline{\mathbf{11}})_2$. After the embedding process, OPAP [3] is applied to eliminate the difference between the original and stego image. The inverse DWT is performed to obtain the stego image.

Embedding algorithm

1. Histogram modification for cove image.
2. Perform DWT on cover image.
3. Apply Canny edge detector on LL sub-band image.
4. Divide LL sub-band block into 2×2 non-overlapping blocks, if coefficient is edge, then the LSB of coefficient is replaced by '1' else it is replaced by '0'.
5. Use the edge/non-edge information of LL sub-band to find out the type of the four coefficients in high frequency sub-bands of transformed image.
6. If the four coefficients of each high frequency sub-band are non-edge coefficients, *x* number of secret bits in LSBs of coefficients are stored, else *x*+1 number of bits are stored.
7. Apply OPAP on the image after embedding process.
8. Perform inverse of DWT to obtain the stego image.

3.3 Extracting process

DWT is applied on stego image, the LL sub-band is divided into 2×2 non-overlapping blocks and the extraction process begin by extracting the edge image from coefficients as follow: in the previous example the 2×2 block taken from the LL sub-band after embedding process has the following values (213, 227, 234, 223), the first coefficient is ignored and the process is started from the second coefficient which is $(227)_{10} = (1110001\underline{\mathbf{1}})_2$, according to the LSB which are assigned to '1' this coefficient and all of its descendent coefficients are edge coefficients.

The third coefficient is $(234)_{10} = (1110101\underline{\mathbf{0}})_2$, according to the LSB which is set to '0' this coefficient and all of its descendent coefficients are non-edge coefficients. The fourth coefficient is $(223)_{10} = (1101111\underline{\mathbf{1}})_2$, according to the LSB which is assigned to '1' this coefficient and all of its descendent coefficients are edge coefficients.

According to the proposed example: *x* = 1 which is transferred by the sender and *y* = *x*+1, one bit is extracted from the non-edge coefficients and two bits are extracted from the edge coefficients.

Starting with coefficients descendent from the top right coefficient $(227)_{10}$. According to the edge/non-edge information, two bit is extracted from the 2×2 descendent block. The first coefficient is $(-4)_{10}$ since the coefficient value is a negative the two's complement is computed which is equal to $(111111\underline{\mathbf{00}})_2$ and two bits are extracted from it. Two bits are extracted from the second coefficient $(3)_{10} = (000000\underline{\mathbf{11}})_2$. The third coefficient is $(-6)_{10}$ and two bits are extracted from its two's complement $(111110\underline{\mathbf{10}})_2$. Two bits are extracted from the fourth coefficient $(3)_{10} = (000000\underline{\mathbf{11}})_2$. The extracted bits are combined together to form the extracted bits with the following sequence '**00111011**' which are the same as the embedded bits of the illustrated example.

Extraction algorithm

1. Perform DWT on stego image.
2. Divide LL sub-band in transformed image into 2×2 non-overlapping blocks
3. Extract the edge/non-edge information from LSB of coefficients in LL sub-band blocks.
4. SPHIT data structure and edge/non-edge information extracted from LL sub-band are used to find out the type of coefficient in HL, LH, and HH sub-bands.
5. If coefficient is non-edge coefficient, *x* number of bits from LSBs of coefficients are extracted, else *x*+1 number of bits are extracted
6. Combine the extracted bits to get the embedded secret bits.

4. EXPERIMENTAL RESULTS

To evaluate the proposed method, experiments were performed on different gray level images of 128×128 pixels. Payload is used as measurement for image capacity. Also Peak signal to noise ratio (PSNR) was calculated as measurement for image quality after embedding process. PSNR formula is given by:

$$\boldsymbol{PSNR = 10.log_{10}(\frac{255^2}{MSE})} \qquad (2)$$

$$\boldsymbol{MSE = \sum_{i=1}^{H}\sum_{j=1}^{W}\left(p_{ij} - p'_{ij}\right)^2 / (H \times W)} \qquad (3)$$

where MSE is mean square error between the cover image p_{ij} and stego-image p'_{ij}, H and W are the height and the width of the cover image. Figure 3 shows the results of the proposed method for different values of *x*. It is observed from this figure that when the value of *x* is increased the payload value is also increased with acceptable image quality.

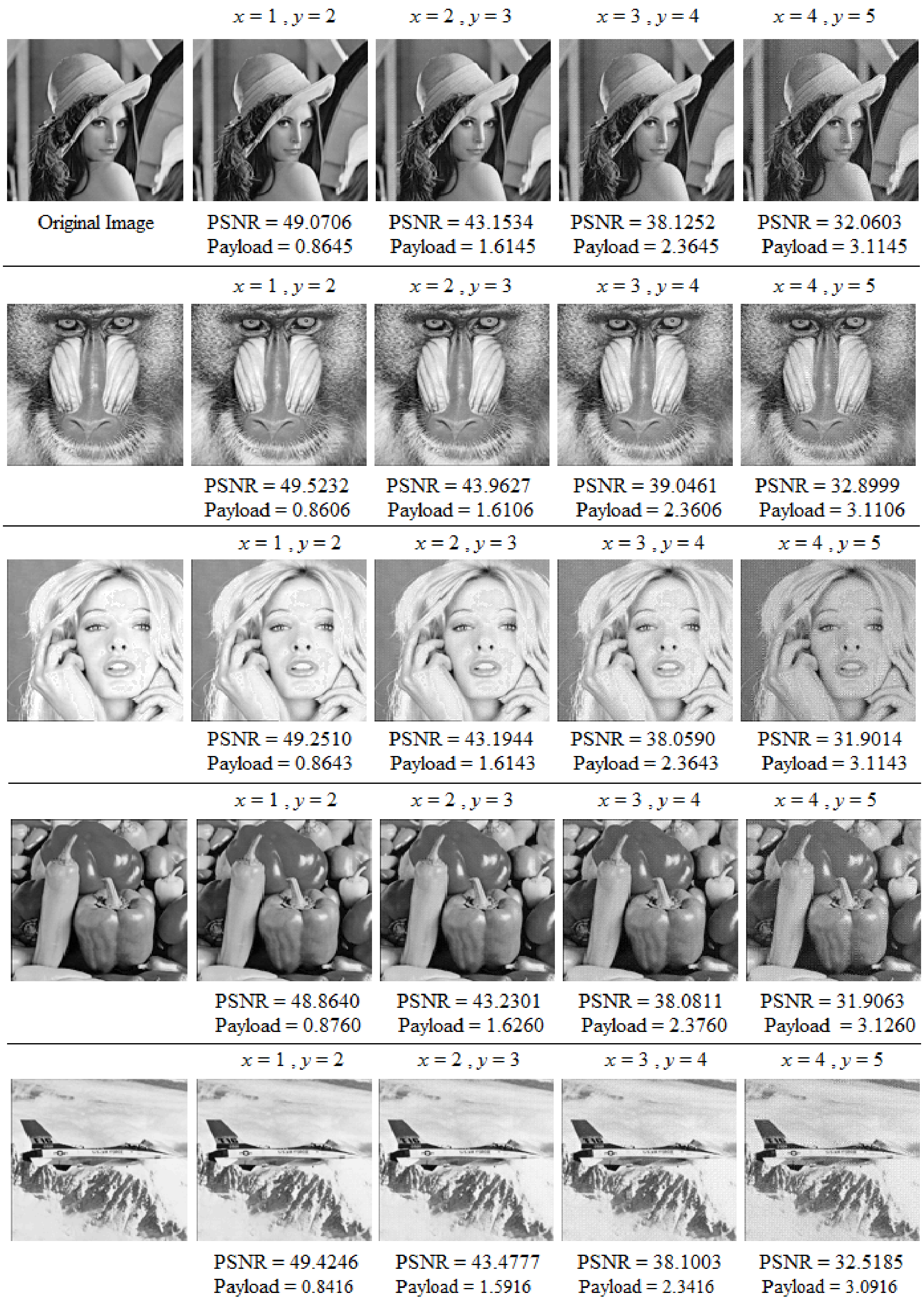

Figure.3. Experimental results for proposed method with different values for *x* = (1, 2, 3, and 4) for five 256-gray level images of 128×128 pixels.

A comparison between the proposed method and the spatial domain based embedding method presented by Leng et al. [8] is provided in Table 1. It is observed that the proposed method achieves higher stego image quality with acceptable embedding payloads than Leng et al. method. As it showed in the table, when (x = 1), PSNR value in the proposed method is increased by average value equal to '7' than Leng et al. method and when (x = 2) PSNR value is increased by average value '2'. When the value of x is increased, the embedding capacity is increased and the distortion in stego-image is also increased but is still better than Leng et al. method.

Table 1. Comparison between payload and PSNR for proposed method and Leng et al. scheme in spatial domain

Image	Metric	Leng et al. method			Proposed method		
		$x = 1$	$x = 2$	$x = 3$	$x = 1$	$x = 2$	$x = 3$
Lena	PSNR	42.18	41.03	38.18	49.0706	43.1534	38.1252
	Payload	0.91	1.66	2.41	0.8645	1.6145	2.3645
Baboon	PSNR	41.47	40.22	37.04	49.5232	43.9627	39.0461
	Payload	1.06	1.80	2.56	0.8606	1.6106	2.3606
Tiffany	PSNR	41.94	40.75	37.84	49.2510	43.1944	38.0590
	Payload	0.93	1.68	2.43	0.8643	1.6143	2.3643
Peppers	PSNR	41.99	40.88	38.16	48.8640	43.2301	38.0811
	Payload	0.90	1.65	2.4	0.8760	1.6260	2.3760
Jet	PSNR	42.10	41.02	38.16	49.4246	43.4777	38.1003
	Payload	0.90	1.65	2.4	0.8416	1.5916	2.3416

5. CONCLUSION

This paper proposed a data hiding method in the wavelet-based domain to increase image quality. The method is based on DWT and a canny edge detector. The embedding method used in this paper is LSB. The length of embedded bits is depending on edge/non-edge information. If the coefficient is defined as non-edge then x number of bits are embedded in LSB, otherwise x+1 of bits are embedded in LSB. Experimental results showed that the proposed method achieved a high image quality with an acceptable embedding capacity especially when x = 1. The next plan is to investigate more improvements to the proposed method in order to further improving image quality and increasing embedding capacity and also the work can be extended to support colored images.

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