Wavelet-Based ODBTC Image Reconstruction

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***Abstract*—This paper presents a new technique for improving the quality of Ordered Dither Block Truncation Coding (BTC) decoded image. The proposed method exploits the wavelet usability on decomposing the decoded image into low and high-frequency subbands. It employs the two-dimensional Discrete Wavelet Transform (DWT) and two-dimensional Stationary Wavelet Transform (SWT). This scheme considers the ODBTC decoded image as noisy image in which the occurrence of noise can be minimized by modifying the wavelet high frequency. As documented in experimental results, the proposed method yields a promising result in the ODBTC image reconstruction.**

***Index Terms*—Image Reconstruction; Image Quality Improvement; Odbtc; Wavelet.**

I. Introduction

The ODBTC is efficient and effective image compression scheme. It is formerly proposed for the grayscale image [1-2]. This method compresses an image into a new representation, i.e. two color extreme quantizers and bitmap image, for reducing the required bit while an input image is recorded in the storage device. In the image decoding stage, the bitmap image is simply replaced by the two color extreme quantizers. Thus, the encoding and decoding processes of ODBTC are very fast making it suitable for real-time application. Since of its effectiveness and usability, some researches extend the ODBTC into several applications such as grayscale image compression [1], Look-Up-Table-based grayscale image compression [2], image watermarking [3], color image compression [4-5], content-based image retrieval [4-5], and image classification [4-5]. As proved in the literature [1-5], ODBTC yields a promising result on several image processing and computer vision tasks.

In image compression task, the ODBTC often produces a little unpleasant decoded image quality. In most cases, the impulsive noise occurs in the decoded image. This noise is a result of ODBTC decoding process in which it simply replaces the ODBTC bitmap image with two extreme color quantizers. In order to improve the decoded image quality, the post-processing process is applied for the ODBTC decoded image. This process employs the wavelet transform to reduce the noise occurrence in the ODBTC decoded image. The post-processing of the ODBTC decoded image is detailed delivered in this paper.

II. Wavelet-Based Image Reconstruction

This section detailed presents the proposed method of ODBTC image reconstruction using the wavelet approach. The concept of ODBTC image compression is firstly delivered in this section, in which a new method for improving the ODBTC decoded image quality is subsequently explained. The main of goal the proposed method is to suppress the impulsive noise occurred in the ODBTC decoded image. This noise induces an unsatisfactory image quality. This noise is a result of the halftoning process of an input image.

A. ODBTC Image Compression

The ODBTC encodes an image in an effective and efficient way by introducing the halftoning illumination and utilizing two extreme quantizers. The ODBTC offers parallelism advantages, in which the encoding step can be concurrently processed over all several image blocks. The ODBTC employs the dither array [1-5] to generate the halftone image. Given a grayscale image I of size $M \times M$, the ODBTC firstly divides this image into several image blocks. Let i be an image block of size $m \times m$. The ODBTC compresses this image block into the following new representations:

$$i \to \{q_{min}, q_{max}, b\} \tag{1}$$

where q_{min} and q_{max} denote the min and max quantizers, respectively. The b is the bitmap (halftone) image of size $m \times m$. Under these new image representations, the number of required bit to store a given image can be reduced. Then, these new image representation are sent to the decoder module via transmission channel.

At the decoding process, the ODBTC simply generates the decoded image using the following strategy:

$$d(x,y) = \begin{cases} q_{min}, & \text{if } b(x,y) = 0 \\ q_{max}, & \text{if } b(x,y) = 1 \end{cases} \tag{2}$$

where $x, y = 1,2,\dots,m$ denote the pixel positions on each image block. The ODBTC decoding process is very efficient making it very suitable for real time application. For the color image compression and detailed explanation of ODBTC process, please refer to [4-5].

B. ODBTC Image Reconstruction

In order to improve the quality of ODBTC decoded image, an additional step, i.e. ODBTC image reconstruction, can be added in the decoding process. In this paper, the image reconstruction is performed using the wavelet approach since the wavelet transform can separate an input image into high and low-frequency subbands. The image noise remains into the high-frequency subbands in the wavelet transformed image. Thus, the low frequency of wavelet transformed image contains an image information from the lowpass filtered and downsampled version of an input image. This wavelet subband is almost similar as the noise-reduced image or noise-free image. The proposed method takes this wavelet subband to further improve the quality of ODBTC decoded image. Figure 1 shows the schematic diagram of the proposed method to reconstruct the grayscale image, whereas Figure 2 depicts the schematic diagram for the color image.

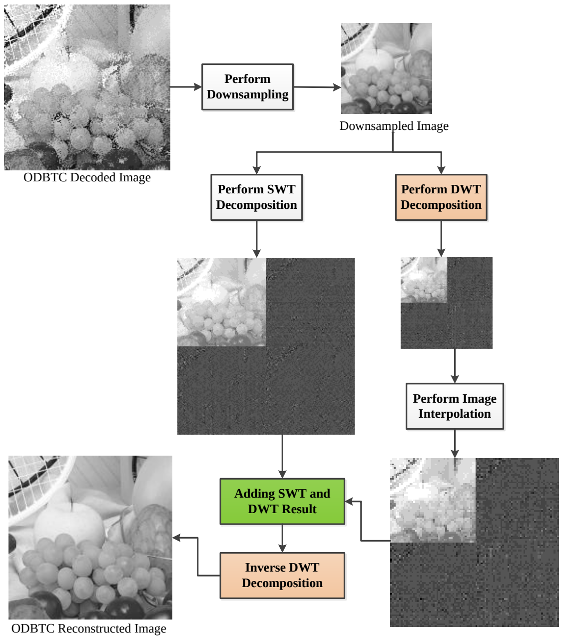


Figure 1: Schematic diagram of the proposed method for grayscale image

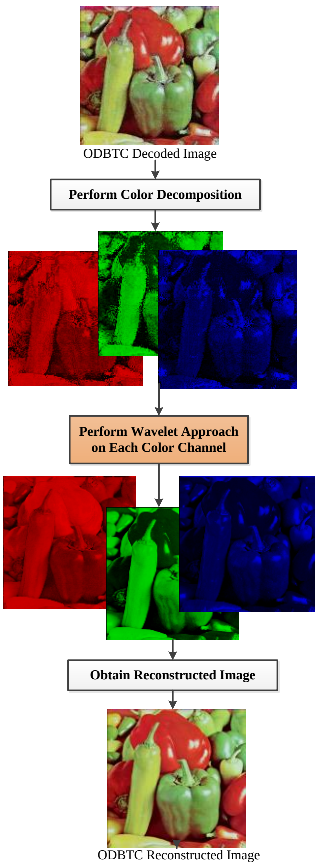


Figure 2: Schematic diagram of the proposed method for color image

Suppose A is downsampled version of ODBTC decoded image. This image is of size $N \times N$, where $N < M$ (in this paper, $N = \frac{M}{2}$). The two dimensional Discrete Wavelet Transform (DWT) decomposes the image A as follow:

$$\Im\{A\} \Rightarrow \{A_\theta | \theta = (LL, LH, HL, HH)\} \tag{3}$$

where θ denotes the DWT subbands, i.e. low and high frequency subband. The symbol $\Im\{\cdot\}$ represents the DWT operator. Herein, the transformed image A_θ is of size $\frac{N}{2} \times \frac{N}{2}$. The image interpolation process with upscale value 2 is further applied in A_θ to obtain the interpolated image of size $N \times N$.

At the same time, the two-dimensional Stationary Wavelet Transform (SWT) is also applied on image A as denoted follow:

$$\Im^*\{A\} \Rightarrow \{A_{\theta^*} | \theta^* = (LL, LH, HL, HH)\} \tag{4}$$

where θ^* and $\Im^*\{\cdot\}$ denote the SWT image subbands and SWT operator, respectively. Herein, the size of A_{θ^*} is $N \times N$. The interpolated DWT and SWT subband are then at the same size. In our proposed method, these two transformed images are combined together to obtain a better image representative, i.e. better reconstructed image. This operation can be performed by adding these two transformed images using the following formula:

$$\tilde{A}_\theta \Leftarrow \alpha_\theta A_\theta + (1 - \alpha_\theta) A_{\theta^*} \tag{5}$$

where α_θ denotes the weighting constant controling the contribution of DWT and SWT transformed image subbands for the final reconstructed image. This mathematical addition is applied over all image subbands $\theta, \theta^* = (LL, LH, HL, HH)$. The symbol $\tilde{A}_\theta$ is the modified transformed image subbands. At the end of ODBTC image reconstruction, the following process is conducted for all $\tilde{A}_\theta$ as:

$$B \Leftarrow \Im^{-1}\{\tilde{A}_\theta | \theta = (LL, LH, HL, HH)\} \tag{6}$$

where B denotes the ODBTC reconstructed image. The symbol $\Im^{-1}\{\cdot\}$ is the inverse DWT process. The ODBTC reconstructed image has the same size with the ODBTC decoded image. The image quality of B is better than the ODBTC decoded image using the wavelet approach. This claim is validated and supported by the experimental finding which is reported in the next section.

III. Experimental Results

This section reports some experimental results on the proposed wavelet-based ODBTC image reconstruction. The experiments were conducted under some testing images on grayscale and color space. Two ODBTC image block sizes are investigated in this experiment, i.e. 8×8 and 16×16. Firstly, an input image is compressed using the ODBTC method. The proposed method is then applied to the ODBTC decoded image to produce the reconstructed image. The proposed method employs the Daubechies 1 (db1) for DWT and SWT image decomposition.

A. *Experimental Setup*

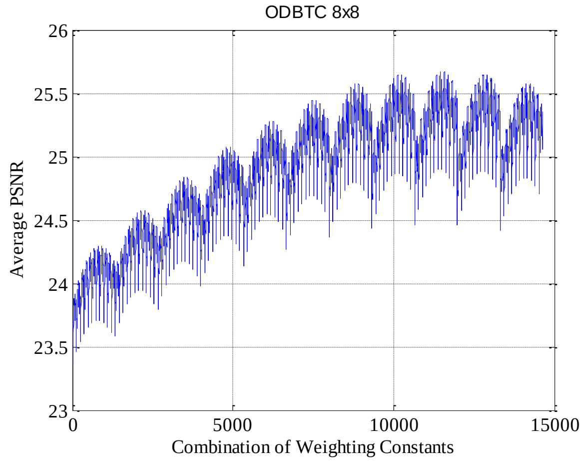
The performance of the proposed method is investigated under grayscale and color images. There are 20 grayscale images and 16 color images utilized for validating the proposed method performance as shown in Figure 3 and Figure 4, respectively. For the color image reconstructed, the reconstruction step is identical to the grayscale process. Each color channel of color image is processed using the proposed method as individual grayscale image. The performance of the proposed method is objectively measured in terms of Peak-Signal-to-Noise-Ratio (PSNR) and Color-Peak-Signal-to-Noise-Ratio (CPSNR) for the grayscale and color image, respectively. The CPSNR is the average of PSNR values over red, green, and blue channel of color image. Higher PSNR and CPSNR values indicate better quality of reconstructed image.

Figure 3: A set of testing images in grayscale

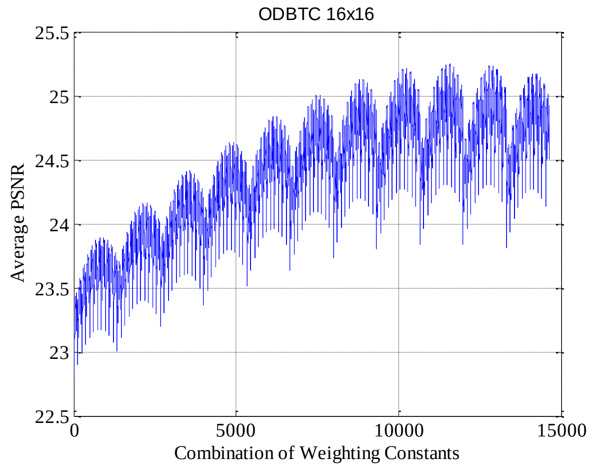
Figure 4: A set of testing images in color space

B. Effect of Different Weighting Constants

The proposed method employs two different transformed image subbands, i.e. DWT and SWT coefficient. The addition of these two different image subbands is controlled under the weighting constants α_θ over all $\theta = (LL, LH, HL, HH)$. This section investigates the effect of α_θ for the proposed image reconstruction. Different value of α_θ yields different reconstructed image quality. In this experiment, several combination of α_θ is tried and performed on the proposed method to obtain the best (the optimum) α_θ. Herein, the α_θ is set as $[0,1]$ with interval 0.1 between two successive values. Thus, it yields 11^4 combination for α_θ. The ODBTC image block size are simply chosen as 8×8 and 16×16. Figure 5 shows the average PSNR values over all grayscale testing images under different combination of α_θ values. As shown in this figure, the different α_θ values yield different performance on reconstructed image quality. The maximum PSNR values are 25.67 and 25.25 for ODBTC image block size 8×8 and 16×16, respectively. It is very interesting that these maximum values are the result of the proposed method under the weighting constants $\{\alpha_{LL} = 0.8, \alpha_{LH} = 0.7, \alpha_{HL} = 0.7, \alpha_{HH} = 0.6\}$. Thus, weighting constants are independent to the ODBTC image block sizes. The identical weighting constants can be utilized over various image block sizes.



(a)



(b)

Figure 5: Effect of weighting constants $\{\alpha_\theta | \theta = (LL, LH, HL, HH)\}$ on the proposed method over ODBTC image block sizes: (a) 4×4, (b) 8×8.

C. Visual Investigation of the Proposed Image Reconstruction

The visual investigation of the proposed method is reported in this subsection. The correctness of the proposed image reconstruction is observed visually between the ODBTC decoded image and reconstructed image. This experiment is conducted on the proposed method under grayscale and color images. The ODBTC image block size is set as 16×16. The proposed method employs $\{\alpha_{LL} = 0.8, \alpha_{LH} = 0.7, \alpha_{HL} = 0.7, \alpha_{HH} = 0.6\}$. Figure 6 shows the proposed method results on grayscale image. The PSNR values for Figures 6 (a) and (d) are 13.20 and 13.20, respectively. The PSNR values for the proposed method as given in Figures 6 (b) and (e) are 20.06 and 21.83, respectively. As proved from Fig. 6, the proposed method is able to improve the quality of ODBTC decoded image.

The similar phenomenon also occurs in the ODBTC color image reconstruction. Figure 7 (a) and (d) yield the PSNR values 17.39 and 14.58, respectively. Whereas the Figures 7 (b) and (e) give the PSNR values 25.91 and 22.37, respectively. The proposed method gives better image quality as indicated with higher PSNR value on image reconstruction compared to that of the ODBTC decoded image.

D. Performance Comparison on Grayscale and Color Images

This subsection summarizes the proposed method performances over the grayscale and color images. Herein, the ODBTC image block sizes are set as 8×8 and 16×16. The proposed method simply utilizes $\{\alpha_{LL} = 0.8, \alpha_{LH} = 0.7, \alpha_{HL} = 0.7, \alpha_{HH} = 0.6\}$. The performance of the proposed method is compared under the PSNR values between the ODBTC decoded image and ODBTC reconstructed image. Table 1 reports the performance comparison between the decoded and reconstructed image using the proposed method in terms of PSNR value for the grayscale images. Whereas, Table 2 gives the performance comparison for color images. As shown in these two tables, the proposed method yields better image quality indicated with higher average PSNR values. It clearly reveals that the quality of ODBTC decoded image can be improved using the wavelet-based image reconstruction.

Table 1
Image Quality Comparisons on Reconstructed ODBTC Grayscale Image

	ODBTC $\mathbf{8 \times 8}$		ODBTC $\mathbf{16 \times 16}$	
Image Number	Decoded Image	Reconstructed Image	Decoded Image	Reconstructed Image
1	15,21	20,29	13,20	20,06
2	20,44	27,64	16,52	26,97
3	18,66	23,26	15,89	22,99
4	18,53	24,85	15,14	24,48
5	21,12	26,65	17,48	26,31
...	...	...	...	...
19	22,61	30,31	19,02	29,72
20	22,72	31,49	18,91	30,69
Average	19,23	**25,67**	16,10	**25,25**

Table 2
Image Quality Comparisons on Reconstructed ODBTC Color Image

	ODBTC $\mathbf{8 \times 8}$		ODBTC $\mathbf{16 \times 16}$	
Image Number	Decoded Image	Reconstructed Image	Decoded Image	Reconstructed Image
1	19,73	26,43	16,27	24,70
2	21,17	26,77	17,98	25,92
3	22,67	28,00	18,78	27,24
4	19,97	24,76	16,27	22,82
5	20,26	25,53	16,74	24,02
...	...	...	...	...
15	19,12	25,17	15,30	22,46
16	17,64	22,96	14,64	21,92
Average	19,74	**25,11**	16,57	**23,56**

IV. CONCLUSIONS

A simple method for improving the quality of ODBTC decoded image has been presented in this experiment. This method looks the ODBTC decoded image as a noisy image in which additional post-processing should be conducted to further remove the noise occurrence. The experimental results validate the successfulness and efficiency of the proposed method in the ODBTC image reconstruction.

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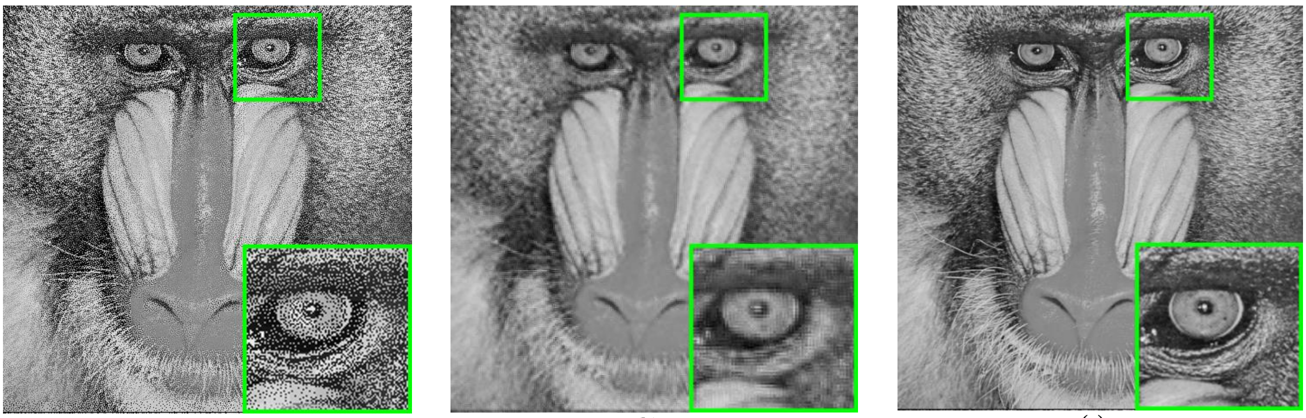

(a) (b) (c)

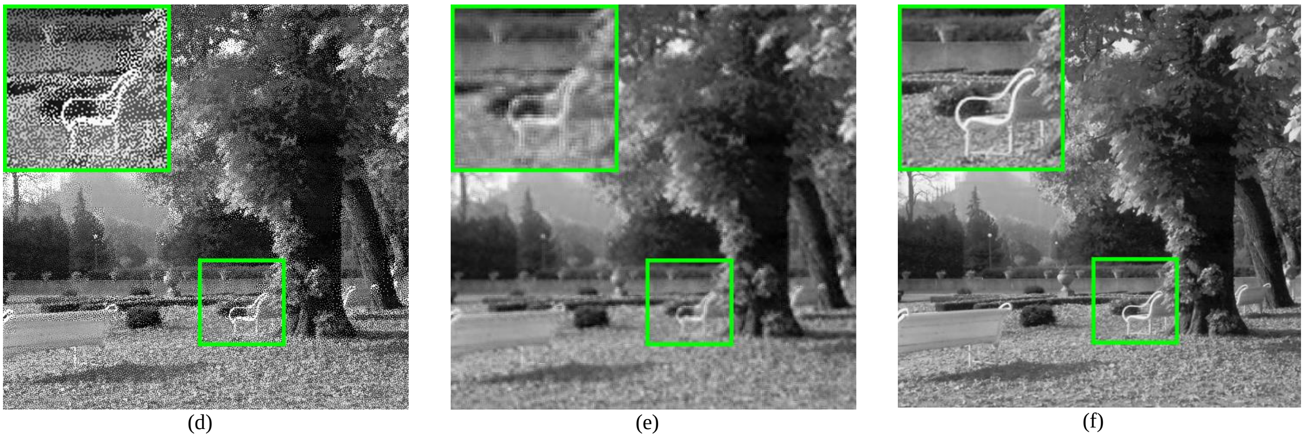

Figure 6: Reconstruction results on grayscale image: (a, d) ODBTC decoded images, (b-e) reconstructed images using the proposed image, and (c-f) original images

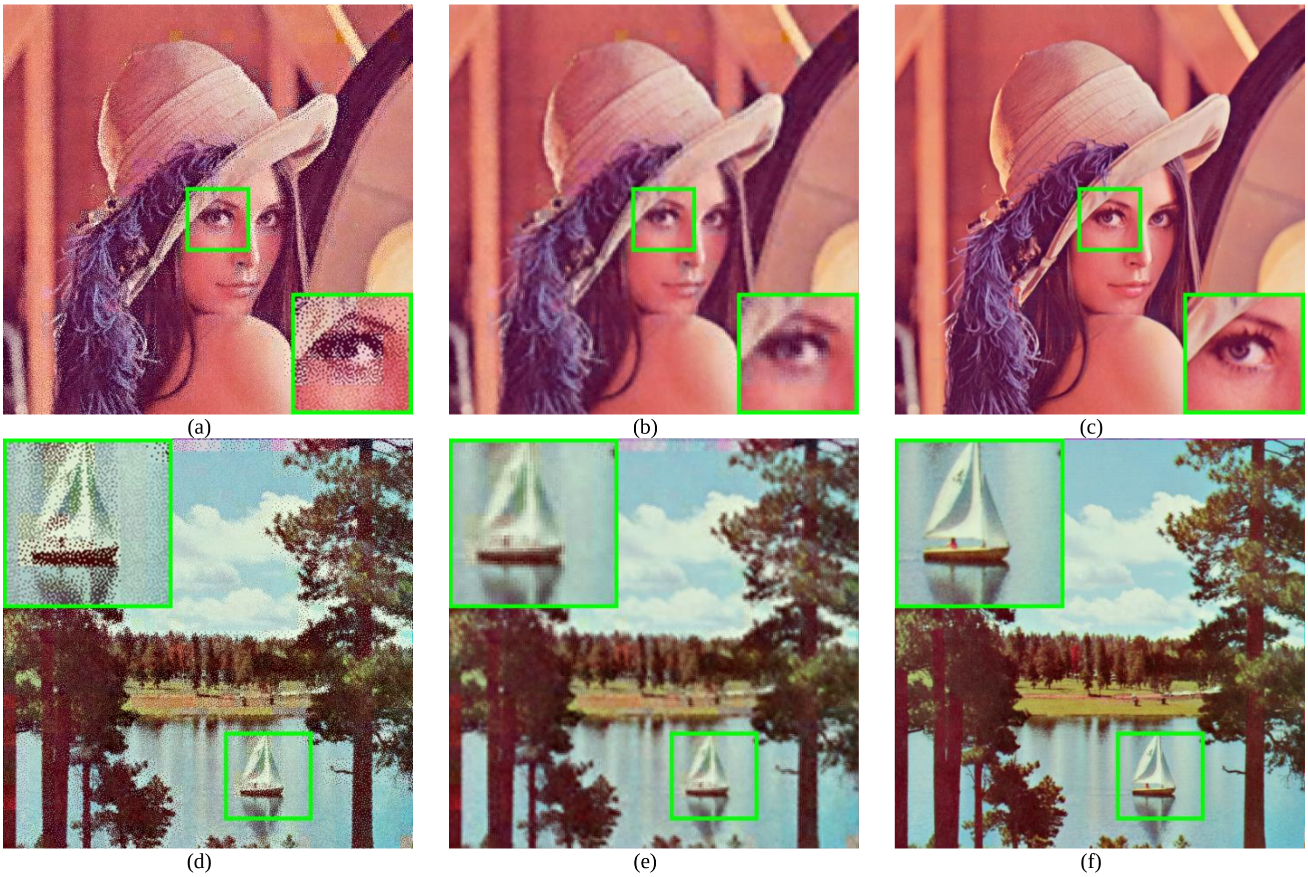

Figure 7: Reconstruction results on color image: (a, d) ODBTC decoded images, (b-e) reconstructed images using the proposed image, and (c-f) original images.