Improved block truncation coding using modified error diffusion

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Block truncation coding (BTC) is an efficient compression technique, offering good image quality. Nonetheless, the blocking effect inherent in BTC causes severe perceptual artefact when compression ratio is increased. Conversely, error diffusion (EDF) enjoys the benefit of diffusing the quantised error into neighbouring pixels. Consequently, the average tones in any local areas of the error-diffused image are preserved unchanged. Presented is a hybrid approach which combines the proposed modified EDF with BTC. As documented in experimental results, image quality is much better than BTC, and the complexity is even lower than traditional BTC.

Introduction: Block truncation coding (BTC) was introduced by Delp and Mitchell in 1979 [1]. The basic concept is to divide the image into non-overlapped blocks, each pixel in a block is replaced by either high or low mean while preserving the first and second moments of the block. The main advantages of the method are good image quality and relatively lower complexity compared to modern compression techniques, e.g. JPEG or JPEG2000. However, the image quality obtained by traditional BTC degrades rapidly when the coding gain is increased. Several investigations have addressed the issue of further improving the image quality or coding gain of BTC [2–6]: some include using vector quantisation (VQ) to further compress the overhead information of BTC outputs [2]; applying a hybrid coding model by using the LUT-based VQ to fast encode the bit-map, and the DCT to encode the high-mean and low-mean sub-images [3]; adopting universal Hamming codes and a differential pulse code modulation (PCM) to the bit plane and the side information of BTC to reduce bit rate and preserving the low computational complexity [4]; and using moment and visual information content to determine the regions for further BTC processing or neglecting in order to reduce the computation overhead, which preserves moderated quality while maintaining the possibility of real-time processing [5]. However, these auxiliary tools for BTC are complicated, which sacrifices the low complexity nature of BTC.

Digital halftoning [6] is a technique for converting grey level images into two-tone binary images. These halftone images can resemble the original images when viewed from a distance by the lowpass nature of the human visual system. Halftoning is commonly used in printing books, newspapers and magazines because these printing processes can only generate two tones, black and white (with and without ink). There are several halftoning methods, including ordered dithering [6], error diffusion [7–9], and iteration-based halftoning [10]. Among these, error diffusion (EDF) offers good visual quality and reasonable computational complexity. Moreover, it maintains the local grey level after converting the pixel value into a two-tone result. Hence, the work reported in this Letter utilises the key feature of EDF to diffuse the error between the original multi-tone pixel and the corresponding block-truncated two-tone result into the neighbourhood pixels to eliminate the blocking effect inherently existing in BTC images.

Proposed hybrid scheme: The original image is first divided into $n \times n$ blocks. Suppose $m = n^2$, and $x_1, x_2, \ldots, x_m$ are values of the pixels in a block. The average, maximum, and minimum, values of the block are denoted $\bar{x}$, $x_{\max}$, $x_{\min}$, respectively, where

$$\bar{x} = \frac{1}{m}\sum_{i=1}^{m} x_i \tag{1}$$

Fig. 1 shows the flowchart of the proposed hybrid scheme. The variable $x_{i,j}$ denotes the current input pixel value, and $x'_{i,j}$ denotes the diffused error sum added up from the neighbouring processed pixels. The variable $o_{i,j}$ denotes the binary output in position (i,j), and the error kernel $h_{m,n}$ is used to diffuse the error caused by the difference, $e_{i,j}$, between the output binary value and the input grey level value. Three well-known error kernels are shown in Fig. 2, where the * denotes the position of the currently processed pixel. The variable $v_{i,j}$ denotes the modified value. The relationships among $b_{i,j}$, $v_{i,j}$ and $e_{i,j}$ are organised as

$$v_{i,j} = x_{i,j} + x'_{i,j}, \quad \text{where} \quad x'_{i,j} = \sum_{m=0}^{2}\sum_{n=-2}^{2} e_{i+m,j+n} \times h_{m,n} \tag{2}$$

$$e_{i,j} = v_{i,j} - o_{i,j}, \quad \text{where} \quad o_{i,j} = \begin{cases} x_{\min} & \text{if} \quad v_{i,j} < \bar{x} \\ x_{\max} & \text{if} \quad v_{i,j} \geq \bar{x} \end{cases} \tag{3}$$

Notably, the high mean and low mean employed in traditional BTC are replaced with the maximum and minimum values of the block. Consequently, the complexity can be greatly reduced by saving the effort in calculating standard deviation used in high and low means. Another advantage of the proposed hybrid scheme is that the quantised errors are compensated for by the neighbouring pixels, which improves image quality significantly.

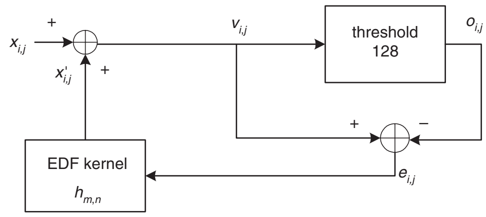

Fig. 1 *Proposed hybrid scheme*

	*	7/12
1/12	3/12	5/12

a

		*	7/48	5/48
3/48	5/48	7/48	5/48	3/48
1/48	3/48	5/48	3/48	1/48

b

		*	8/42	4/42
2/42	4/42	8/42	4/42	2/42
1/42	2/42	4/42	2/42	1/42

c

Fig. 2 *Error kernels* ($h_{m,n}$)
a Floyd [7]
b Jarvis [8]
c Stucki [9]

Results: In this Section we apply the proposed hybrid scheme to demonstrate the performance of the proposed algorithm. Eight tested images, Lena, Mandrill, Elaine, Boat, Airplane, Peppers, Milk, Lake, are employed in experiments. Suppose the image is of size $P \times Q$, the objective quality evaluation is defined as

$$\text{PSNR} = 10 \log_{10} \frac{P \times Q \times 255^2}{\sum_{i=1}^{P}\sum_{j=1}^{Q}[\sum_{m,n \in R} w_{m,n}(x_{i,j} - o_{i+m,j+n})]^2} \tag{4}$$

where $w_{m,n}$ denotes the Gaussian filter which is used to resemble the human lowpass visual system. The standard deviation and the size of the Gaussian filter are fixed at 1.3 and 7×7, respectively.

Fig. 3 shows quality comparisons between traditional BTC and the hybrid scheme with different error kernels. Although the traditional BTC has better quality with block size 8×8 than Jarvis and Stucki BTCs, the hybrid scheme outperforms in the other three block size configurations. Especially, the Floyd BTC is far better than traditional BTC. In general, a good compression scheme is suppose to have a stable quality performance under different compression ratios. The proposed method meets this condition. Fig. 4 shows some practical results with the Mandrill image, where Figs. 4*a*–*c* are the original image, the compressed result with traditional BTC, the compressed result with the proposed hybrid scheme, respectively. The block size = 16×16 and the Floyd error kernel is applied. It is clear that Floyd BTC has sharper and stereo rendition than traditional BTC, which can be easily observed in the beard part.

Finally, the complexity of the two approaches is analysed, where the numbers of addition/subtraction and multiplication/division are organised in Table 1. The Table shows results with block size $M \times N = 16$; other cases can be derived in the same manner. Apparently, the proposed hybrid scheme has much lower complexity than traditional BTC, the main reason is that the high/low means are replaced with the maximum and minimum values in a block.

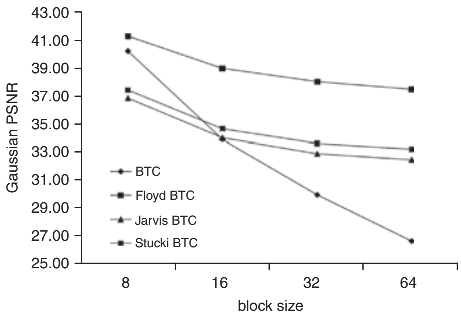

Fig. 3 *Quality comparisons between traditional BTC and three hybrid schemes, Floyd BTC, Jarvis BTC, Stucki BTC*

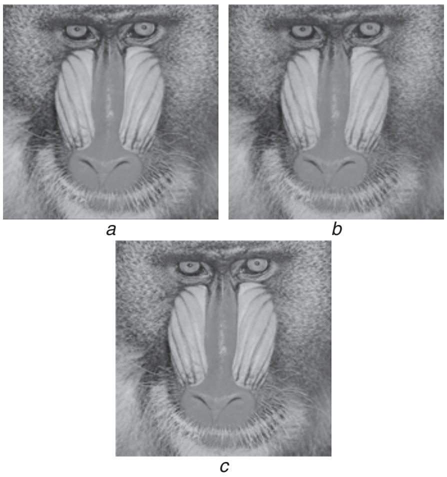

Fig. 4 *BTC results ($\sigma = 1.3$, bit rate = 1.0625 bits/pixel)*

a Original 512 × 512 Mandrill image
b Traditional BTC result with block size 16 × 16 (PSNR = 32.02 dB)
c Hybrid scheme result (PSNR = 37.4 dB)

Table 1: Complexity comparison (assume block size $M \times N = 16 \times 16$)

	Addition/subtraction	Multiplication/division
Traditional EDF	$2 \times (M \times N) + 3$	$M \times N + 11$
Proposed hybrid scheme	$M \times N + 3$	5

Conclusions: A hybrid method which combines traditional BTC with error diffusion is presented. Although many good approaches in the literature attempted to increase coding gain with some complicated auxiliary tools which proved to have good performance, this work dedicates itself to improve image quality under the same compression ratio without sacrificing the low complexity nature of BTC. As documented in the experimental results, the proposed Floyd BTC has far better image quality and much lower complexity than BTC.

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