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Short Communication

Halftoning-based Block Truncation Coding image restoration ☆

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ABSTRACT

This paper presents a new image restoration method for improving the quality of halftoning-Block Truncation Coding (BTC) decoded image in a patch-based manner. The halftoning-BTC decoded image suffers from the halftoning impulse noise which can be effectively reduced and suppressed using the Vector Quantization (VQ)-based and sparsity-based approaches. The VQ-based approach employs the visual codebook generated from the clean image, whereas the sparsity-based approach utilizes the double learned dictionaries in the noise reduction. The sparsity-based approach assumes that the halftoning-BTC decode image and clean image share the same sparsity coefficient. In the sparse coding stage, it uses the halftoning-BTC dictionary, while in the reconstruction stage, it exploits the clean image dictionary. As suggested by the experimental results, the proposed method outperforms in the halftoning-BTC image reconstructed when compared to that of the filtering approaches.

1. Introduction

Halftoning Block Truncation Coding (BTC) is an image compression method, which requires simple process for both the encoding and decoding stages. It compresses an image by dividing an input image into several image blocks, where each image block is subsequently represented by two quantization values and a bitmap image. The decoding process performs the reverse procedure by simply replacing the bitmap information with the high or low quantization values. Several improvements and enhancements of this image compression scheme are reported in literature [1,2,5] to further reduce the computational complexity, improve image quality, and achieve higher compression ratio.

The dithering-based BTC, namely Ordered Dither Block Truncation Coding (ODBTC) [1,2], and diffused-based BTC, called Error Diffusion Block Truncation Coding (EDBTC) [5] exploit the low-pass nature of the Human Visual System (HVS) for achieving an acceptable perceptual image quality. These methods replace the classical bitmap image with the halftone image. Given the high efficiency and low computational complexity of the ODBTC, some interesting applications are developed, including watermarking schemes [3] and content-based image retrieval [4]. The attractive properties of EDBTC then led to its deployment in several applications, including image watermarking [6], data hiding [7], and content-based image retrieval [8].

Despite their benefits and superior performances, ODBTC and EDBTC as well as their applications usually consider only the reconstructed image, but without image restoration for enhancement purpose.

To improve image quality, a restoration technique on the halftoning-based Block Truncation Coding (BTC) is proposed. Some halftoning-based BTC methods have been recently proposed: Guo et al. [9] employed the OD/ED BTC with the optimized classified filter set to remove the impulse noises. In this work, the image patch processing approaches are utilized: (1) The Vector Quantization (VQ)-based technique uses a set of clean images to obtain the representative visual codebook. (2) The sparsity-based technique uses a set of clean images and their corresponding halftoning-BTC decoded images to learn two representative dictionaries. These two techniques, which utilize codebook and dictionaries, lead to good image quality. Yet, the impulse noises are still differentiable. Thus, this study, we try to further improve image quality in terms of this issue.

The rest of this paper is organized as follows. The related work for image restoration of halftoning-BTC reconstructed image is briefly reviewed in Section 2. Section 3 elaborates on the image patch image restoration of halftoning-BTC decoded image. Experimental results are reported in Section 4. Finally, conclusions are drawn in Section 5.

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2. Related work

This section briefly reviews two halftoning-BTC methods, namely ODBTC [1] and EDBTC [5]. The related work on halftoning-BTC image restoration is also presented. Two filtering processes assuming that the halftoning-BTC decoded image is corrupted with additional noise are also presented, where the filtering approaches are conducted to suppress this noise for obtaining better image quality.

2.1. Halftoning-BTC

The halftoning-BTC methods, including ODBTC and EDBTC, convert a continuous tone image into another representation with lower bit requirement, which can be illustrated by the schematic diagram shown in Fig. 1. Let I be an image of size $M \times N$, which is then divided into non-overlapping blocks $i(x,y)$ each of size $m \times n$. Each image block is further represented by two extreme quantization values and the bitmap image as follows:

$$\mathcal{H}\{i(x,y)\} \Rightarrow \{q_{min}, q_{max}, bm(x,y)\}, \tag{1}$$

where q_{min} and q_{max} denote the two extreme quantization values, and $bm(x,y)$ represents the corresponding bitmap image. The quantization values can be simply obtained by searching the minimum and maximum pixel values within the image block defined as follows:

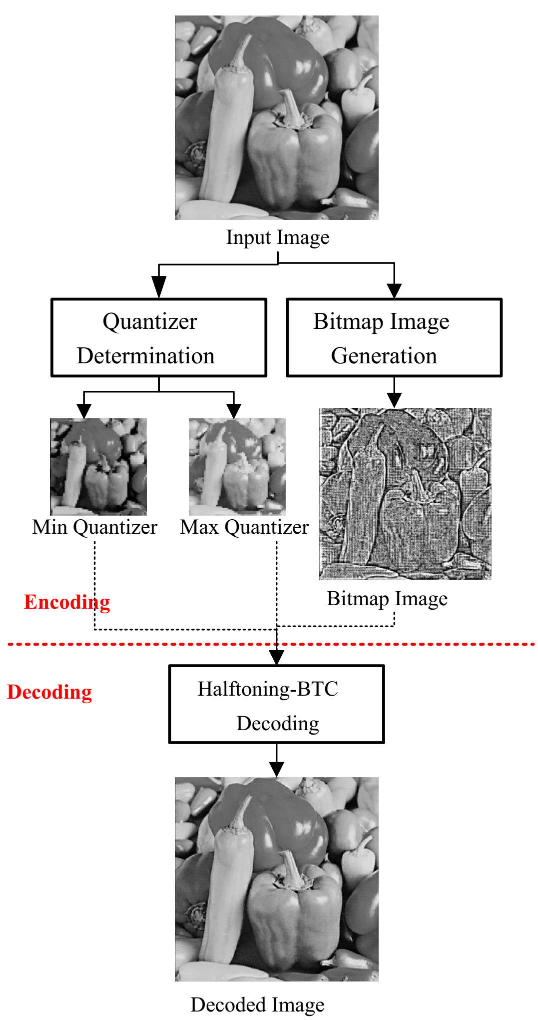

Fig. 1. Schematic diagram of halftoning-BTC image compression.

$$q_{min} = \min_{\forall x,y} \{i(x,y)\}, \tag{2}$$

$$q_{max} = \max_{x,y} \{i(x,y)\}, \tag{3}$$

for $x = 1, 2, \ldots, m$ and $y = 1, 2, \ldots, n$. Both ODBTC and EDBTC employ the same extreme quantization values, but the main difference between ODBTC and EDBTC is in the bitmap image generation process. Specifically, to generate the bitmap image, ODBTC utilizes a dither array that has the same size as the image block, while EDBTC exploits an error kernel.

Let $D(x,y)$ be a dither array of the same size as the image block, i.e., $m \times n$. The scaled version of this dither array $\{D^0, D^1, \ldots, D^{255}\}$ can be pre-calculated offline to reduce the computational time [2]. The ODBTC bitmap can be obtained by using the following thresholding method:

$$bm(x,y) = \begin{cases} 1, & \text{if } i(x,y) \geqslant q_{min} + D^d(x,y); \\ 0, & \text{otherwise}, \end{cases} \tag{4}$$

where $d = q_{max} - q_{min}$. On the other hand, the EDBTC bitmap image can be computed by incorporating the error kernel ϵ such as the Floyd–Steinberg kernel. The thresholding operation for EDBTC bitmap image is formally defined as

$$bm(x,y) = \begin{cases} 1, & \text{if } i(x,y) \geqslant \tilde{i}; \\ 0, & \text{otherwise}, \end{cases} \tag{5}$$

where $\tilde{i}$ denotes the mean value of all pixels in the image block. The error value obtained from this thresholding operation is further diffused into its neighboring pixels by means of the error kernel as follows:

$$i(x,y) \leftarrow i(x,y) + e(x,y) \times \epsilon, \tag{6}$$

where $e(x,y)$ is the error after the thresholding operation. Interested reader is referred to Refs. [1,2,5] for the detailed descriptions on ODBTC and EDBTC image compression techniques.

The two quantization values and the bitmap image are then transmitted to the decoder, which simply replaces the bitmap image of value 1 with the max, quantization value, and vice versa. The decoding process of ODBTC and EDBTC can be performed using the following step:

$$o(x,y) = \begin{cases} q_{max}, & \text{if } bm(x,y) = 1; \\ q_{min}, & \text{otherwise}. \end{cases} \tag{7}$$

The decoding process on halftoning-BTC is very simple, making it very suitable for real time application.

2.2. Lowpass filtering image restoration

The image reconstructed by halftoning-BTC often contains the halftoning impulse noise, making it less pleasant for human vision. To improve quality, image restoration can be performed on the halftoning-BTC decoded image. A naïve approach is to apply lowpass filtering [9]. Hereinafter, the Gaussian filter is exploited to suppress the halftoning noise as well as removing the blocking effect and false contour. Let $O(x,y)$ be the halftoning-BTC decoded image. The Gaussian lowpass filtering with μ and σ^2 is defined as

$$\widetilde{R}(x,y) = O(x,y) * f_{\mu,\sigma^2}(x,y), \tag{8}$$

for $x = 1, 2, \ldots, M$ and $y = 1, 2, \ldots, N$, where $\widetilde{R}(x,y)$ denotes the reconstructed image after applying the Gaussian lowpass filter.