The 23rd International Technical Conference on Circuits/Systems,
Computers and Communications (ITC-CSCC 2008)

# Lossless compression of color halftone images using color channel adaptive templates

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**Abstract**: A novel lossless compression scheme is presented for color halftone images dithered by a clustered dot ordered screen. In the encoder, the context template is designed according to the line pattern of each color channel image. Based on the designed template, then, each channel image is compressed by a context-based arithmetic encoder. Finally, both the compressed image data and the template information are transmitted to the decoder. In the decoder, the template shape information is reconstructed, and then, the halftone image is decoded losslessly. Based on the adaptiveness of the template to the input image, the proposed system yields better compression performance than the conventional JBIG, which saves $35\%$ of the JBIG bitstream.

*Keywords*— **Lossless halftone image compression, context-based arithmetic coding, template design, line pattern, and clustered dot ordered halftone image.**

## 1. Introduction

In the electronic document printing, a clustered dot ordered halftoning is widely used to convert a continuous tone image to a halftone image [1]. Though a typical halftone image has only two gray levels, however, it requires huge storage and wide bandwidth. For example, one page data ($600$ dpi and A4 size) takes about $4$ MBytes per color channel, and it is often prohibitive for compact processing in the pipeline. Therefore, efficient compression of the halftone image is critical.

To address the size issue of the halftone image, various compression techniques have been introduced [2], [3], [4], [5]. The JBIG is the standard codec for bilevel images, which is based on the context-based arithmetic coding [2]. In [3], to enhance the performance of the context-based arithmetic coder, a template design method was introduced. Though the template design is computationally high, the correlation-based template in [3] yields a promising compression performance. In [4], the block arithmetic coding scheme was proposed to replace the conventional JBIG standard. Recently, Xiao *et al.* presented a weighting method of multiple templates for efficient bilevel image compression [5].

On the clustered dot ordered halftone image, line patterns are easily obtained [1]. For reducing the Moiré artifact on the color halftone image, moreover, each color channel image shows the distinct line patterns [1]. As the same gray level pixels are located on these line patterns, it is shown that high correlation is revealed on these line patterns. By simply tracing the line pattern on each color channel image, therefore, we can detect pixels with high correlation and build template shapes adaptive to each color channel.

In this paper, we present a new lossless image compression scheme for the color halftone image. Inspired by the line pattern on each color channel image, the context template is adaptively designed for each channel image. Specifically, the template is outlined according to the direction of the line pattern on the input halftone image. Then, the input image is compressed by a context-based arithmetic coder in [2], which is transmitted to the decoder. Note that the template information is also sent to the decoder because it is variable to the input image pattern. In the decoder, the context is revealed by the transmitted template information, and thus, the halftone image is losslessly reconstructed. Therefore, an efficient compression scheme is provided for color halftone images, which outperforms the conventional JBIG standard [2].

## 2. Proposed algorithm

The block diagram of the proposed system is shown in Figure 1. In the encoder, the template is adaptively shaped according to the line pattern of the input halftone image. Then, the halftone image is losslessly compressed by a context-based arithmetic encoder in [2]. Note that the template shape is also compressed and sent to the decoder. In the decoder, the template is reconstructed, followed by the halftone image reconstruction.

### 2.1 Derivation of optimal context template

Assume that the halftone input image is the stochastic process $S = \{S_i | i = 1, 2, \cdots, n\}$, where $S_i$ is the $i$-th pixel and $n$ is the number of pixels on the image. By the stationary assumption of the image, the entropy rate $H(S)$ is simplified as

$$\begin{aligned} H(S) &= \lim_{n\to\infty} \frac{1}{n} H(S_1, S_2, \cdots, S_n) \\ &\simeq \lim_{n\to\infty} H(S_n | S_{n-1}, S_{n-2}, \cdots, S_1) \\ &= \lim_{n\to\infty} H(S_n | C_n), \end{aligned} \quad (1)$$

where $C_n$ is the context function and expressed as

$$C_n = C(S_{n-1}, S_{n-2}, \cdots, S_1).$$

As the Markov property holds on the image, $C_n$ becomes the concatenation of finite pixels. Generally, these pixels are laid on the fixed area on the image, called the context template. In the context-based arithmetic coding, thus, the goal of the

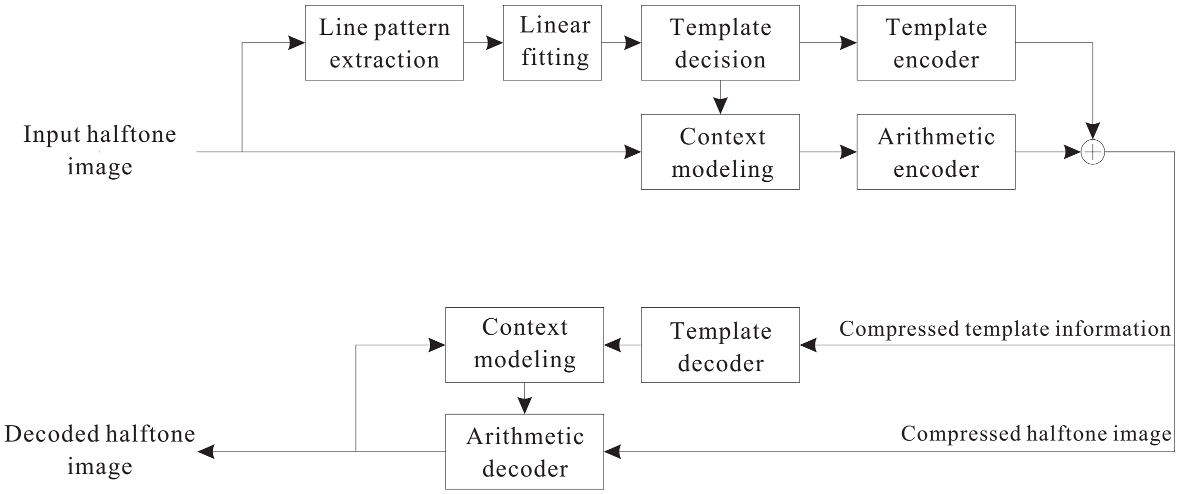



Figure 1. System block diagram of the proposed halftone image compression scheme.

context modeling is to find the template shape that minimizes (1).

One solution for (1) is to design a template according to the image statistics like the correlation-based template design [3]. Though it outperforms the conventional JBIG having fixed templates [2], the complexity for the template design becomes critical. In this paper, as an alternative, we investigate the line patterns on the clustered dot halftone images. Then, the template is simply obtained.

### 2.2 Line pattern extraction

In the clustered dot ordered halftone image [1], line pattens are easily revealed shown in Figure 2 (a) and (b). As the same colored pixels exist on the line pattern, these pixels have high correlations. It is shown in Figure 2 (c) and (d) that the highly correlated pixels are laid along the line pattern direction. Note that the correlation value for the halftone image is demonstrated in [3]. Therefore, in this work, it is our goal to extract the direction of the line pattern for the template design.

To derive the line pattern on the image, we first divide the image domain into $K \times K$ sub images ($K = 15$, in this work). On each sub image, then, we extract the line segment that crosses the sub image center. Finally, each pixel of the extracted line segment is accumulated on $K \times K$ bins called a cumulative matrix, where the accumulated bin position is the position of the pixel.

In Figure 3 (a), the cumulative matrix is illustrated, where brighter bins show more frequent occurrences of pixels on each bin position. As shown in Figure 3 (a), the cumulative matrix demonstrates the directional property of the line pattern. Therefore, the cumulative matrix is used in the least square fitting of the representative line in Section 2.3

### 2.3 Least square fitting of the representative line

The cumulative matrix is employed to describe the line characteristic of the image. Specifically, a line equation is obtained by the linear approximation of the cumulative matrix, which keeps the number of pixels at each bin location.

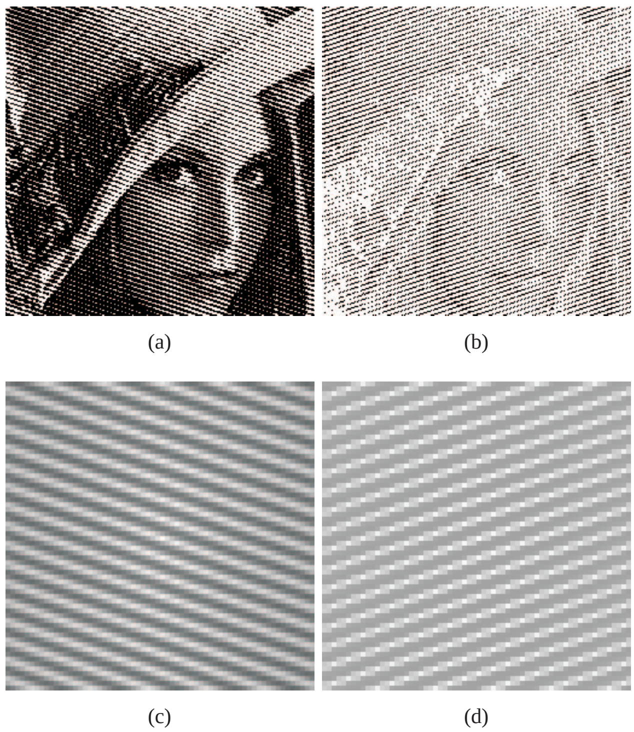
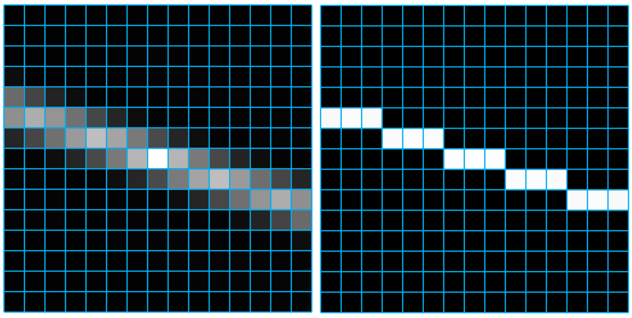



Figure 2. Example of color channel images and their correlation maps: (a) magenta channel image, (b) yellow channel image, (c) correlation map of (a), and (d) correlation map of (b), where bright pixels indicate high correlation and the correlation value is evaluated using [3].

When the $K \times K$ cumulative matrix is given, the best fitting line is obtained by solving the constrained minimization



(a) (b)

Figure 3. Least square fitting of the representative line to design the template: (a) visualization of the cumulative matrix and (b) representative line segment after the line fitting.

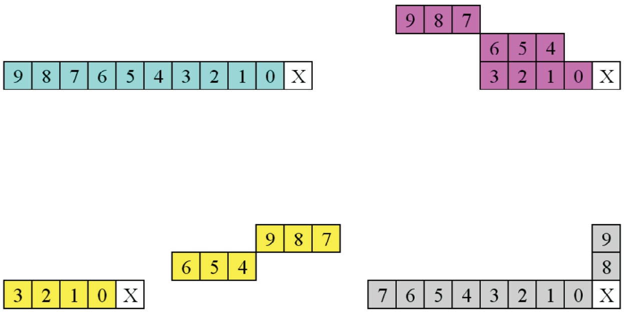



Figure 4. Designed templates, where cyan, magenta, yellow, and black channel templates are shown, respectively. Note that 'X' is the position of the current encoding pixel, and the series of numbers reveal the template pixel order.

as

$$(n_x, n_y) = \arg\min \sum_{i=1}^{K}\sum_{j=1}^{K} M(i,j)[n_x(i-c)+n_y(j-c)]^2, \quad (2)$$

subject to ${n_x}^2 + {n_y}^2 = 1$, where $M(i,j)$ is the occurrent of the pixels on the position $(i,j)$ in the cumulative matrix and $(c,c)$ is the center position of the $K \times K$ cumulative matrix ($c = 8$ when $K = 15$, in this work). Therefore, the line equation is describes as

$$n_x(x-c) + n_y(y-c) = 0. \quad (3)$$

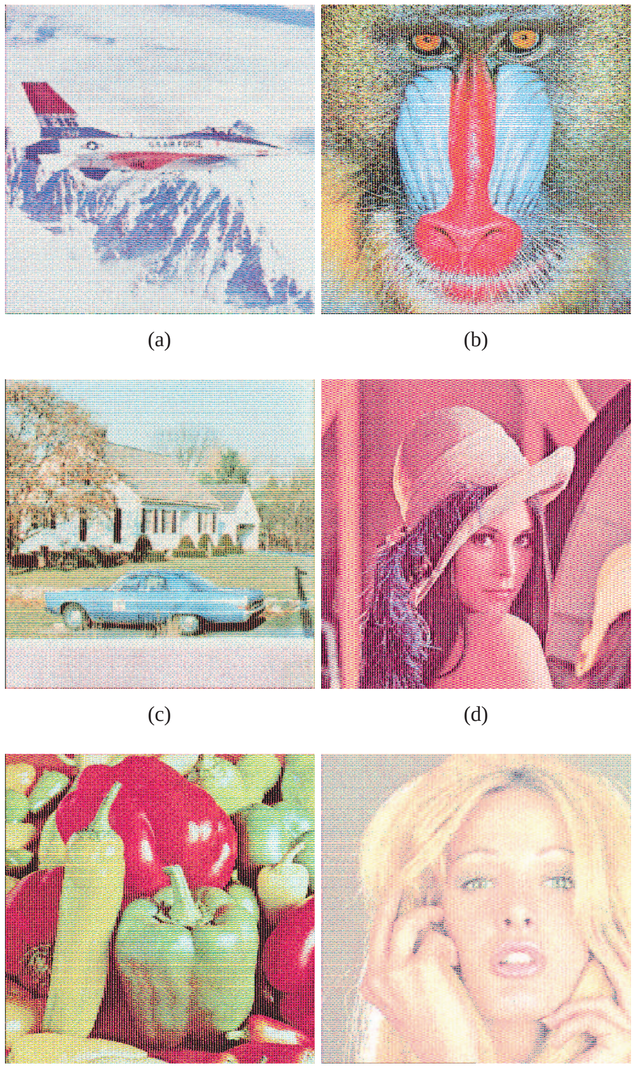
In Figure 3 (b), we illustrate the linear approximation of the cumulative matrix of Figure 3 (a), where the fitting line is depicted as a white dots. The line segment builds the basic shape of the template.

### 2.4 Template design constraints

After the line fitting of the cumulative matrix, we employ two constraints to regularize the complexity of the implemented codec. Thus, the final template is obtained by applying the following two constraints, respectively.

- Complexity constraints: In the basic mode of the JBIG, the number of the reference lines are three and ten pixel templates are used [2]. In this work, we employ the JBIG constraints to limit the complexity of the proposed template method.
- Neighborhood constraints: After applying the complexity constraints, some pixels out of ten pixels may be left. In this case, the pixels on the same line of the encoding pixel are further selected as the template pixels.

The example of the obtained templates are shown in Figure 4. Based on both the line fitting and two design constraints, the shape of the template is adaptively determined according to each color channel halftone image. These templates are used in the context modeling shown in Figure 1.



(a) (b) (c) (d) (e) (f)

Figure 5. Experimental color halftone images: (a) Airplane, (b) Baboon, (c) House, (d) Lena, (e) Peppers, and (f) Tiffany, where the size of each image is $512 \times 512$.

### 2.5 Compression of the template shape information

As the template shape is variable to the input halftone image, the template shape is also encoded, which is transmitted to the decoder shown in Figure 1. Though various method might be possible, we simply extract the differences of the

Table 1. Compression performance of the proposed halftone image compression system. 'JBIG' = compressed bits using [2]. 'Proposed' = compressed bits using the proposed templates. Note that the data size and the compressed bits are expressed in 'bytes.'

| Data | Original data size | JBIG (A) | Proposed (B) | Bit saving (1-B/A) |
|---|---|---|---|---|
| Airplane | 131,072 | 33,369 | 18,324 | 45.09% |
| Baboon | 131,072 | 50,605 | 39,737 | 21.48% |
| House | 131,072 | 38,998 | 25,582 | 34.40% |
| Lena | 131,072 | 40,260 | 24,789 | 38.43% |
| Peppers | 131,072 | 38,775 | 26,997 | 30.38% |
| Tiffany | 131,072 | 28,322 | 13,492 | 52.36% |

position between $p$-th template pixel and $(p+1)$-th pixel.

For example, to encode the magenta channel template in Figure 4, we only send the sequence of the position differences as

$$\{(-1,0),(-1,0),(-1,0),(-1,0),(2,-1),(-1,0),(-1,0),(-1,-1),(-1,0),(-1,0)\}.$$

Note that only one byte is sufficient to encode each digit. Therefore, the overall bit consumption for each template is $20$ $(= 10$ pixels $\times 2)$ Bytes.

## 3. Experimental result

The proposed halftone image codec is tested on various color halftone images shown in Figure 5. Note that each image has four color channels (i.e. cyan, magenta, yellow, and black channels), and each channel image is dithered by the clustered dot ordered halftone method [1]. The halftone image is losslessly compressed using the halftone image compression system shown in Figure 1. Note that the template shape is also compressed, which requires $20$ Bytes per template.

For comparison, the standard JBIG codec is utilized, which is available at [6]. The three line template is employed in the JBIG codec and the hierarchical mode is skipped in the experiment. In order to test the performance of the template, the arithmetic coder of the JBIG is also used in the proposed halftone image compression system shown in Figure 1.

Table 1 summarizes the overall performance of the proposed algorithm. As the shape of the template is variable to the line pattern of the input image, $35\%$ of overall bits are saved compared with the conventional JBIG codec. Note that, though extra bits are required for sending the template information, their bit contribution is negligible.

## 4. Conclusion

In this paper, an efficient lossless compression scheme was proposed for the color halftone image. According to the color channel image characteristics, the context template was adaptively determined. Specifically, the template shape was determined by the image line pattern which reveals the correlation between pixels. Each channel image was encoded using the distinct template, and the template shape information was also compactly expressed. As the designed context template was variable to the input image pattern, the proposed image compression system outperformed the conventional JBIG standard.

**References**


[1] K. Kang, *Digital color halftoning*, SPIE/IEEE Press, 1999.

[2] *Information technology - Coded representation of picture and audio information - Progressive bi-level image compression*, ITU-T Recommendation T.82, Mar. 1993.

[3] K. Denecker, S. Assche, P. Neve, and I. Lemahieu, "Context-based lossless halftone image compression," *Journal of Electronic Imaging*, vol. 8, no. 4, pp. 404–414, Oct. 1999.

[4] M. Reavy and C. Boncelet, "An algorithm for compression of bilevel images," *IEEE Trans. Image Processing*, vol. 10, no. 5, pp. 669–676, May 2001.

[5] S. Xiao and C. Boncelet, "On the use of context-weighting in lossless bilevel image compression," *IEEE Trans. Image Processing*, vol. 15, no. 11, pp. 3253–3260, Nov. 2006.

[6] *JBIG-KIT losssless image compression library*, http://www.cl.cam.ac.uk/ mgk25/jbigkit/.